# WATER QUALITY CHARACTERIZATION OF HIGHWAY STORMWATER RUNOFF FROM AN ULTRA URBAN AREA

by

Kelly Renee Flint

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Master of Science
2004

Advisory Committee:

Dr. Allen P. Davis, Advisor
Dr. Eric A. Seagren
Dr. Alba Torrents

# ABSTRACT

Title of Thesis: WATER QUALITY CHARACTERIZATION OF HIGHWAY STORMWATER RUNOFF FROM AN ULTRA-URBAN AREA

Kelly Renee Flint, Master of Science, 2004

Thesis directed by: Dr. Allen P. Davis
Department of Civil and Environmental Engineering

Water quality of highway stormwater runoff from an ultra-urban area was characterized by qualitatively and quantitatively defining flushing and determining the event mean concentration (EMC) and annual pollutant loadings for TSS, total phosphorus (TP), $NO_3^-$, $NO_2^-$, TKN, Cd, Cu, Pb and Zn. Characterization aids in evaluation of the performance of a retrofit bioretention facility. Furthermore, this research contributes to the limited data available on recent characterization of runoff from urban areas. Mean EMC's in mg/L were 0.04, 0.11, 0.22, 1.18, 420, 3.4, 0.96, and 0.56 for Cd, Cu, Pb, Zn, TSS, TKN, $NO_{3+2}^-$, and TP. Median values for the mass flushed in the first 25% of runoff were greater than the mass flushed in a 25% portion beyond the first, except for TSS and Cd. The mass in later 25% portions were greater than in the first 25% in 17% of the events for all pollutants.

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# Chapter 1

# INTRODUCTION

The Chesapeake Bay watershed is the largest of 130 estuaries in the United States, with area that extends into six states, Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia (Chesapeakebay, 2003). Fifteen million people are supported by the Chesapeake Bay watershed, directly or indirectly contributing to its deterioration by introduction of non-point source runoff, stormwater runoff, and toxicity to the 100,000 streams and rivers that empty into the Chesapeake Bay (Chesapeakebay, 2003). The most populated subwatershed within the Chesapeake Bay watershed is the Anacostia watershed (Anacostia, 1999), which extends approximately 8 miles from Bladensburg, Maryland to the District of Columbia (NRDC, 2002). Understanding the factors that contribute to the deterioration of the Anacostia watershed will allow for management strategies to be implemented that restore the quality of the Anacostia River.

Urbanization and cultivation of the watershed surrounding the Anacostia River contributed and continue to contribute to the deterioration of the river's water quality. Together urbanization and agricultural development have claimed almost 50% of the forested area in the Anacostia watershed (EPA, 2003), resulting in the direct erosion of sediments into the Anacostia River. In addition, stormwater collection systems introduce sediments into the Anacostia River as an indirect result of forest removal and land cultivation. Deposition of sediments in the Anacostia River directly degrades the water quality by damaging biological structures, burying aquatic organisms, and interfering with the respiration and digestion of aquatic organisms (Sartor and Boyd, 1972). Furthermore, sediments indirectly affect the water quality by inhibiting the light transmission that is necessary for photosynthesis through the river's depth.

In addition to contributing to the deterioration of the Anacostia River's water quality by deforestation, urbanization also impacts the water quality by increasing the amount of impervious area such as residential and commercial rooftops, roadways, sidewalks and parking lots. In order to prevent flooding of impervious surfaces during rainfall events, stormwater collection systems are created in urban areas to transport the rainfall runoff from the impervious surfaces to the nearest water body. As the rainfall runoff flows over the impervious surfaces to the collection systems, the runoff collects and transports sediments and other pollutants that have deposited on the surfaces. Nutrients (phosphorus and nitrogen), heavy metals, polycyclic aromatic hydrocarbons (PAHs), and oil and grease are pollutants found in stormwater runoff that degrade receiving water quality in a variety of ways. High nutrient concentrations cause high turbidity, odor, and low concentrations or fluctuations of dissolved oxygen by promoting excessive growth of aquatic plants, which creates adverse conditions in receiving water bodies. Also, heavy metals, oil and grease, and PAHs contribute to the toxicity of receiving water bodies to an extent that can be detrimental to aquatic organisms (Makepeace et al., 1995).

In order to address the deterioration of the Anacostia River, the District of Columbia, the State of Maryland, Montgomery County, MD and Prince George's County, MD signed the Anacostia Watershed Restoration Agreement in 1987, in which one of the six goals is to substantially reduce pollutant loads to the watershed to measurably improve water quality conditions (EPA, 2003). Removal of pollutants from stormwater runoff has received particular attention, because stormwater runoff contributes 75 to 90% of the pollution in the Anacostia River (NRDC, 2002). As a result of the more recent emphasis on pollutant removal from stormwater runoff, conventional stormwater best management practices (BMP's) were evaluated and found to be ineffective in their ability to remove pollutants (Barbosa and Hvitved-Jacobsen, 2001) and reduce hydrographic peaks (Wu et al., 1996). In addition to the variable effectiveness of BMP's, their design limitations and high construction and maintenance costs led to the use of low impact development (LID) practices as an innovative approach to stormwater management. LID practices are designed to employ the physical, chemical, and biological processes that are found in the natural environment, while striving to maintain the pre-development hydrology of a site.

Currently, the Prince George's County Department of Environmental Resources employs bioretention as a technique in managing sheet-flow runoff from small impervious or pervious drainage areas (Winogradoff, 2001). Bioretention facilities mimic interception, infiltration, evapotranspiration, assimilation, adsorption and degradation processes that are found in the natural environment through utilization of a plant, mulch and soil layer to control the quality and quantity of stormwater runoff. Although bioretention facilities have been implemented in Prince George's County and other areas, limited studies have been completed to evaluate their performance (Davis et al., 2001; Davis et al., 2003). Therefore, characterization of stormwater runoff quality at locations with retrofit bioretention facilities is needed to evaluate current bioretention design.

Current bioretention design is based on the first flush theory that the majority of the event pollutant load is contained in the initial portion of the event volume. Although qualitative analysis of flushing throughout storm events has been extensively completed (Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone et al., 1998; Barrett et al., 1998; Lee and Bang, 2000;), only limited studies have been completed to quantitatively analyze first flush (Deletic and Maksimovic, 1998). Moreover, studies quantifying flushing in the later portions of the runoff volume beyond the first portion are non-existent. Despite the limited quantitative data available to support the first flush theory, bioretention facilities are sized to completely capture only the initial portion of the runoff volume. Therefore, it is hypothesized that quantitative evaluation of flushing throughout the duration of a storm event will confirm that a significant amount of a storm event's pollutant load can be contained in portions of the runoff volume other than the first.

The findings of recent research lend support for this hypothesis. For instance, the transport of sediments has been found to be dependent on runoff flowrate, indicating that solids concentrations will be higher at times during a storm event that correspond to higher flowrates (Sansalone et al., 1998). Furthermore, certain pollutants such as Pb are predominantly associated with the particulate fraction of stormwater runoff (Morrison et al., 1984; Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger,1997). Consequently, it is further hypothesized that particulates and particulate-bound stormwater runoff constituents will exhibit a greater tendency to flush a significant portion of their mass loading in later portions of the runoff volume, in contrast to dissolved pollutant constituents which almost always qualitatively demonstrate first flush (Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger,1997).

In order to meet the goals of this project, which entails evaluating the effectiveness of a bioretention facility to remove pollutant loads from stormwater runoff, and to evaluate the hypothesis of this research, stormwater runoff from an urban highway in Mt. Rainier, Maryland will be characterized before and after installation of a retrofit bioretention facility. The research for this thesis focused on characterization of the stormwater runoff quality before installation of the facility. Future research will complete this project. Characterization of the stormwater runoff from Mt. Rainier, MD before bioretention installation included:

- Determination of event mean concentrations (EMC's) for total suspended solids (TSS), nitrate ($NO_3^-$), nitrite ($NO_2^-$), total Kjedhal nitrogen (TKN), total phosphorus (TP), Pb, Cu, Cd, Zn, and chloride ($Cl^-$).
- Determination of annual pollutant loadings in kg/ha/yr for TSS, $NO_3^-$, $NO_2^-$, TKN, TP, Pb, Cu, Cd, Zn, and $Cl^-$.
- Qualitative and quantitative analysis of flushing throughout each storm event.
- Comparison of the stormwater runoff quality at the Mt. Rainier, MD site to the stormwater runoff quality that researchers have measured at other sites.

Four additional chapters describe characterization of the stormwater runoff from the Mt. Rainier, MD site. Chapter 2 presents background pertaining to highway stormwater runoff quality and best management practices. Chapter 3 describes the methodology that was used to collect and analyze the stormwater runoff samples and to evaluate EMC, annual pollutant loadings, and flushing. The results and discussion of EMC, annual pollutant loadings, and flushing evaluation are presented in Chapter 4. Finally, the fifth and final chapter summarizes the pertinent findings of this research and recommendations for further research.

## Chapter 2

## BACKGROUND

### 2.1 Pollutants

### 2.1.1 Suspended Solids

Total suspended solids (TSS) are operationally defined by the Standard Method as the particulate matter retained by a glass fiber filter with 0.45 μm pore size (APHA *et al.*,1995). In actuality, some suspended solids have diameters smaller than 0.45 μm. As a result particulates with diameters less than 0.45 μm are not captured and measured as part of total suspended solids. As total solids are defined as suspended solids plus dissolved solids, the standard method implies that only dissolved solids, which theoretically are those species for which a chemical potential can be defined, remain in the filtrate. More specifically, dissolved solids are operationally defined as the sum of dissolved solids and suspended solids with diameters less than 0.45 μm.

Particulates deposit on impervious surfaces through a variety of pathways, such as dustfall, bulk precipitation, wear of automobile parts, and road corrosion. Pollutant loadings originating from dustfall were reported to be higher in urban areas than in rural areas (Gupta et al., 1981). Bulk precipitation was found to contribute 10-30% of TSS (Wu et al., 1998) and up to 48% of the TSS (Harrison and Wilson, 1985) to stormwater runoff. A wide range of concentrations, between 1 and 36,200 mg/L, have been found for TSS in urban stormwater runoff (Makepeace et al., 1995). Particulate characterization is of primary importance for two reasons: (1) particulates degrade water quality by contributing to the turbidity and toxicity of the water and (2) particulates affect the drainage of infiltration treatment methods.

Determination of the particle size distribution of TSS aids in the characterization of suspended solids. Information on size distribution can be used to determine long-term effectiveness of infiltration treatments and particulate content. One half of the total organics in sediments was associated with particles that have diameters between 100-600 µm (Ellis and Harrop, 1984). Understanding organic association with the various particle size fractions is important in determining pollutant behavior, because nitrogen and phosphorus have been found associated with organics (Sartor and Boyd, 1972).

Two studies determined the particle size distribution in stormwater runoff. Ellis and Harrop (1984) found highway sediment in stormwater runoff from metropolitan London to have median diameters between 600 –1000 µm (Figure 2.1). In contrast, Sansalone et al. (1998) determined that particles in highway runoff from Cincinnati, Ohio with diameters between 2-8 µm had the largest particle count (Figure 2.2). The difference between these two results may be due to the difference in the methods used for sample collection and sample analysis. Ellis and Harrop (1984) installed sieves at the site below the inlet grate to fractionate the different particle sizes with the final sieve designed to capture particles greater than 63 µm. Sansalone et al. (1998) samples were collected from the collection trough by an automatic sampler. Laboratory testing has shown that settleable particles are not collected during automatic water sampling (Legret and Pagotto, 1999). Analysis showed that 80% of the settleable particles in highway runoff from a metropolitan area in France had diameters greater than 200 µm (Pagotto et al., 2000). Automatic collection of samples in Sansalone et al. (1998) study may have missed collection of a fraction of the settleable solids. Settleable solids were accounted for in Ellis and Harrop's (1984) study, because solids collection occurred by sieving the

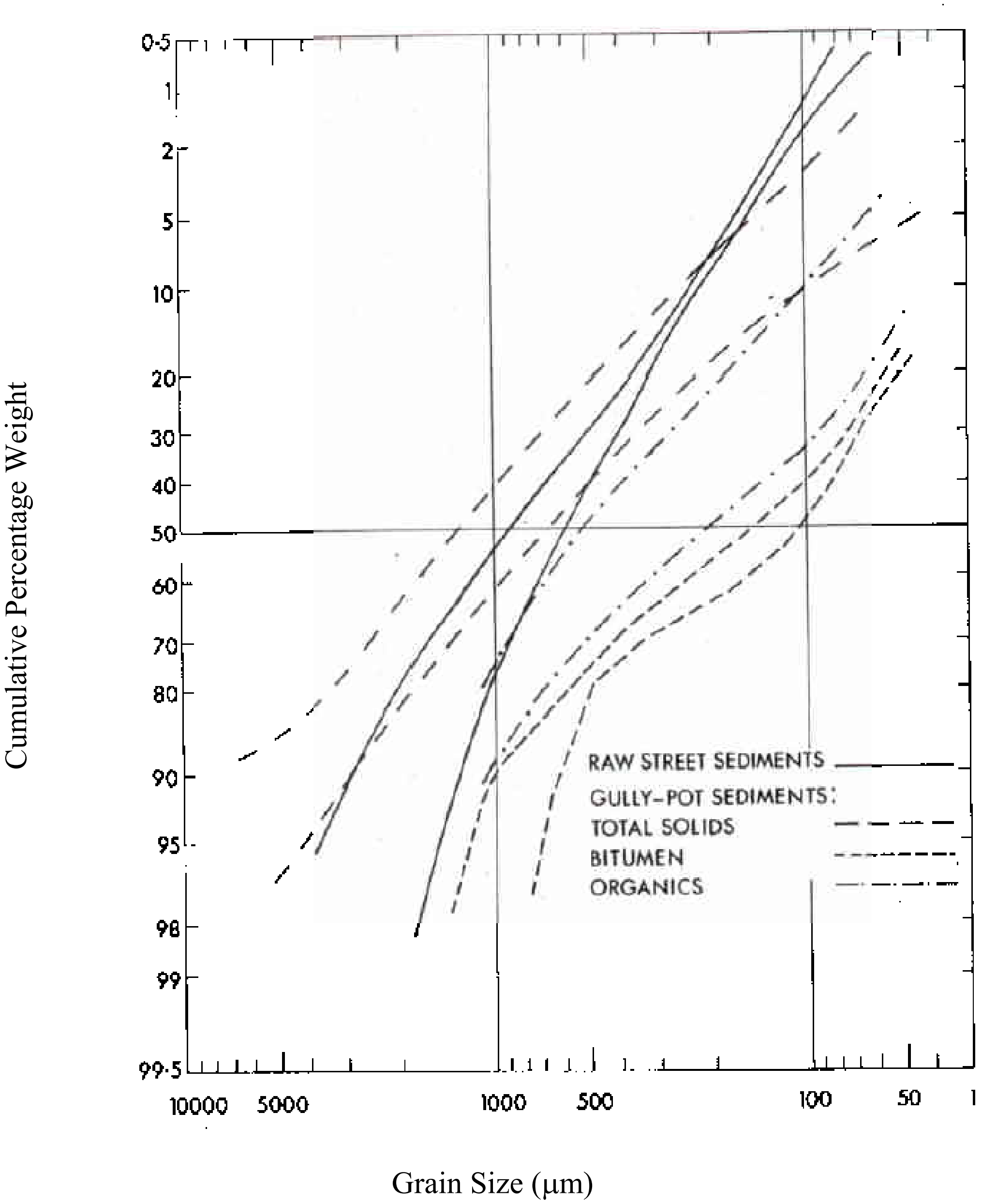


Figure 2.1. Particle size distribution of sediments in stormwater runoff from metropolitan London (Ellis and Harrop, 1984)

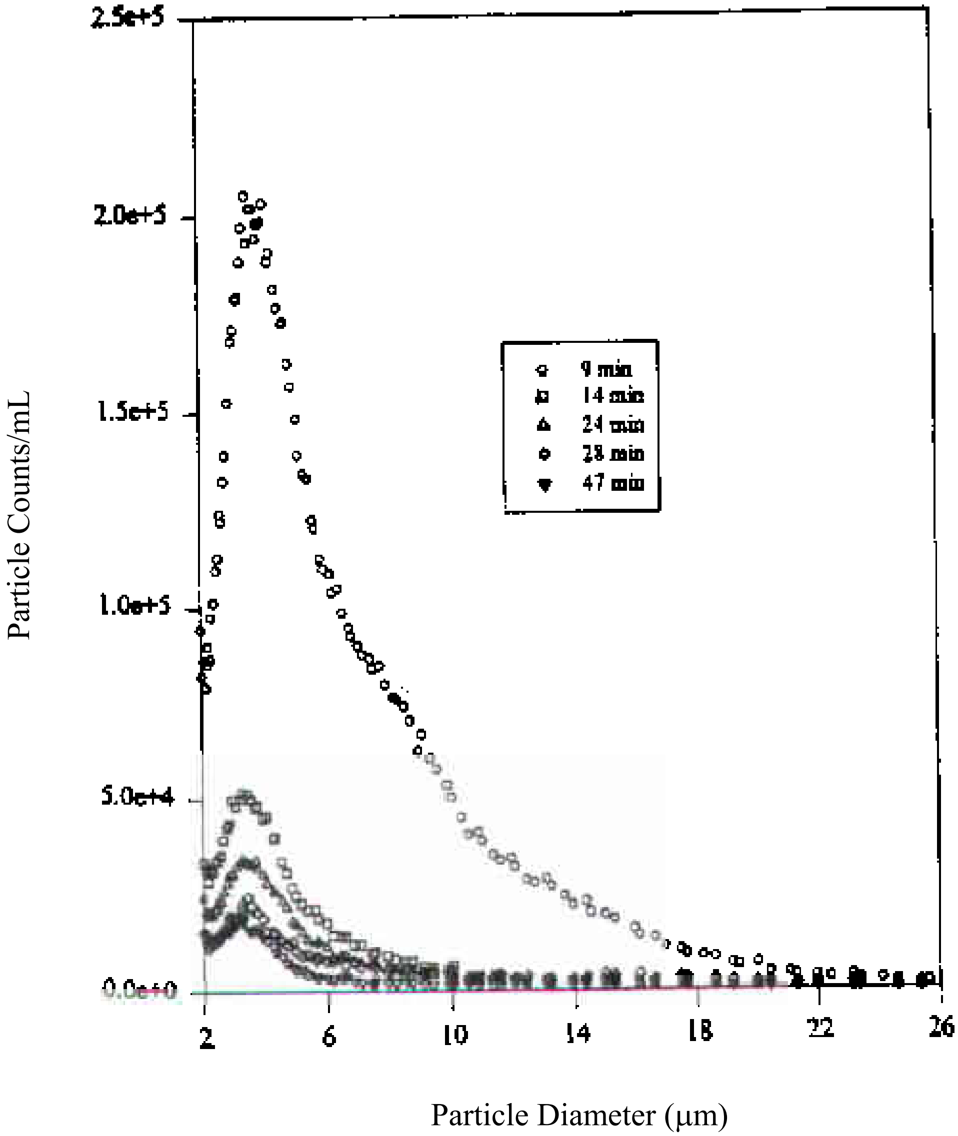


Figure 2.2. Variation of particle counts and diameters from highway runoff samples collected in Cincinnati, Ohio (Sansalone et al., 1998)

stormwater runoff as the runoff fell downward into the gullypot. Also both studies treated analysis of the smaller particle fractions differently. Sansalone et al. (1998) used instrumentation to count the number of particles for each particle diameter size between 2 and 26 μm, whereas Ellis and Harrop (1984) did not analyze particles smaller than 63 μm. Either collection method for particle size distribution should give similar results for organic content, because the majority of organics are associated with the fine particle fraction that is suspended in the collected runoff samples (Ellis and Harrop, 1984). In contrast, calculation of the lifetime filtering capacity of infiltration systems would be dependent on the method used to collect samples for particle size distribution. The sample collection method that was used by Sansalone et al. (1998) may underestimate the mean particle diameter, whereas Ellis and Harrop's (1984) particulate analysis may overestimate the mean particle diameter.

In addition to characterization of particle size distribution, information about traffic counts and storm characteristics (runoff volume, antecedent dry days, rainfall intensity, and rainfall duration) can be utilized to estimate the behavior of TSS in stormwater runoff. During storms with high volume runoff, the number of previous dry days has a greater impact than vehicle count and the converse is true for low volume runoff (Sansalone et al., 1998). For instance in a storm event in which only one dry day precedes the event, a higher traffic count on that dry day will produce a greater amount of available particulates than a lower traffic count. In contrast, the average daily traffic (ADT) count will be approached as the number of antecedent dry days increases at which point the number of antecedent dry days is more important than the daily traffic count.

The effects of storm duration and intensity depend on whether TSS loadings are determined for each storm event or multiple storm events. Particle transport depended on the amount of mass accumulated on the highway surface for long duration, high intensity events, but was limited by the rainfall volume for short duration, low intensity storms (Sansalone et al., 1998). Ellis and Harrop (1984) collected particulates over 2 to 4 week intervals for multiple storm events, finding that rainfall volume and duration had a greater impact on TSS loadings than storm intensity (Figure 2.3). As a result, rainfall volume and duration are more important than rainfall intensity and the antecedent dry period in predicting TSS loadings to infiltration treatment methods for an extended time period covering multiple storms. In addition, seasonal variations in loadings to stormwater were apparent when analyzing trends for a long time period. Peak TSS removal rates were 60 g/d in the summer but only half that in the early spring (Ellis and Harrop, 1984). Ellis and Harrop (1984) did not define their method for determining the removal rates.

### 2.1.2 Metals

Heavy metals impact the water quality of receiving waters, due to their potential toxicity. Cd, Cu and Pb have received focus in research because these metals are acutely toxic at concentrations as low as 0.0036 mg/L to rainbow trout, 0.017 mg/L to D. magna, and 1.17 to 1.47 mg/L with aquatic organism unspecified (Makepeace et al., 1995). In addition, the presence of Pb-Zn and Pb-Cu metal combinations cause synergistic toxic effects. The abundance of Zn in the environment increases the chance of reaching toxic Zn levels and so contributes to research focusing on Zn. A variety of sources contribute to the presence of metals in the environment. Wear of tires and brake pads is a source of

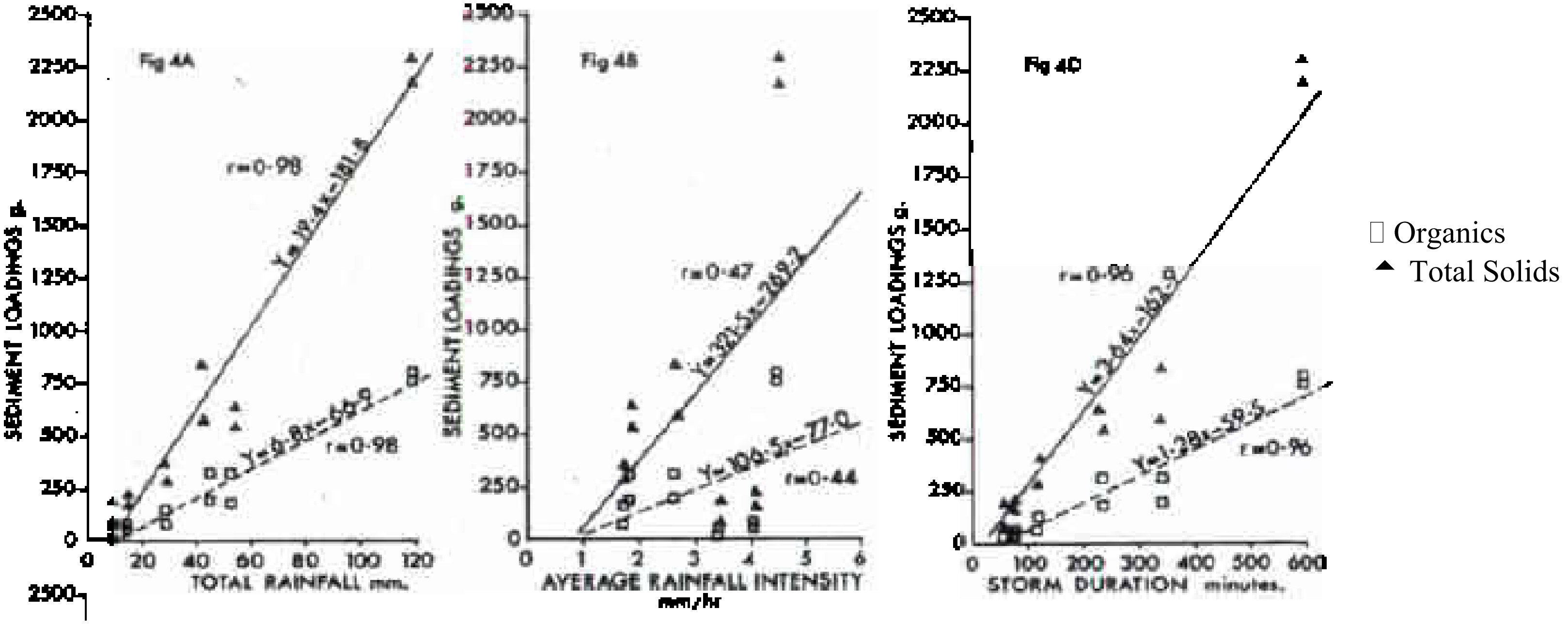


Figure 2.3. Correlation of sediment in stormwater runoff from metropolitan London with (a) rainfall volume, (b) rainfall intensity, and (c) storm duration (Ellis and Harrop, 1984)

all four metals (Makepeace et al., 1995): Cd, Cu, Pb and Zn. Other sources of Cd are combustion, combustion of lubricating oils, metal finishing industrial emissions, agriculture use of sludge, fertilizers, pesticides and corrosion of galvanized metals (Makepeace et al., 1995). Additional sources of Cu 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). Prior to 1973, gas emissions and gasoline additives such as tetra ethyl lead were a large source of Pb. As of 1973, the EPA implemented the first standards to reduce the amount of Pb in gasoline to 0.1 g/gal of gasoline by 1986, resulting in a reduction of lead emissions from 200,000 ton/yr in 1973 to 2,000 ton/yr in 1995 (EPA, 1996). Combustion of lubricating oils and corrosion of buildings and metal objects are also sources of Zn (Makepeace et al., 1995). Scavenging of metal emissions by precipitation contributed between 13-18% of Cd and Pb, 10-22% of Cu, and 10-33% of Zn to stormwater runoff for three different highway sections in Pleidelsheim, Obereisesheim, and Ulm-West, FRG (Stotz, 1987). Sources of metals reestablished contaminants in periods as small as 5 hours (Harrison and Wilson, 1985). Cd, Cu, Pb, and Zn concentrations have been determined in the range of 0.05 to 13,730 μg/L, 0.06 to 1410 μg/L, 0.57 to 26,000 μg/L, and 0.7 to 22,000 μg/L, respectively (Makepeace et al., 1995).

The behavior of metals in stormwater runoff depends on physicochemical speciation. Pb was associated predominantly with the particulate matter in stormwater runoff (Morrison et al., 1984; Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997;). As a result of the predominant association of Pb with the particulate fraction, Pb concentration profiles largely followed the profiles of suspended solids (Morrison et al., 1984; Hoffman et al., 1985; Hewitt and Rashed, 1992) and resulted in a high correlation between suspended solids and Pb (Hewitt and Rashed, 1985). Accordingly, particulate-bound Pb was affected by rainfall characteristics in the same manner as the particulates.

Inconsistent findings for partitioning of Cd, Cu and Zn resulted among various studies. Morrison et al. (1984) and Harrison and Wilson (1985) found similar concentrations of Cd, Cu and Zn in both the dissolved and particulate phases. In contrast, Sansalone and Buchberger (1997) determined Cd, Cu and Zn to be predominantly in the dissolved phase. Yet, a third study found greater than 70% of the Cu associated with the particulate phase (Hewitt and Rashed, 1992).

Many parameters affected the speciation of metals, including pH, flow, suspended solids concentration, dissolved organic carbon concentration, and dissolved chloride concentration (Morrison et al., 1984). The highest dissolved metal fractions corresponded to storms with low pH and high average pavement residence time (APRT) (Sansalone and Buchberger, 1997). APRT is the time between each rainfall intensity peak and the time of its corresponding flowrate peak. For the most part, mobilization of metals followed mobilization of organic matter (Amrhein et al., 1992), suggesting that particulate-bound metals are associated with the organic fraction of particulates. Bioavailable forms of metals occur at low pH. As a result, it may be assumed that bioavailable forms of metal would be low in buffered systems, which have a high capacity to maintain the system pH. However, Warren and Zimmerman (1994) found that the presence of NaCl increased partitioning of metals in the dissolved phase in systems with high buffering capacities or relatively stable pH. Therefore, conditions that increase partitioning of metals into the dissolved phase should be considered even in systems with high buffering capacity or stable pH.

Finally, some trends have been established between metal concentration and antecedent dry period. The antecedent dry period did not affect the phase distribution of metals (Morrison et al., 1984). In contrast, the length of the antecedent dry period correlated with the amount of Pb and dissolved Cu removed during a storm event at the 5% significance level (Hewitt and Rashed, 1992). Hoffman et al. (1984) found that one storm event preceded by intermittent rainfall did not exhibit peaks in metal concentrations. The limited number of storm events analyzed in the study, however, does not give a good basis for conclusions. In addition, Hoffman et al. (1984) did not monitor the intensity of the intermittent rainfall, which affects particulate-bound metal removal.

### 2.1.3 Nutrients

Phosphorus and nitrogen are two key nutrients needed for the growth of aquatic plants. If these nutrients are present in excessive amounts, high levels of aquatic plants will grow, creating adverse conditions in the environment, such as turbidity, odor, and low concentrations or fluctuations of dissolved oxygen. Nitrogen occurs as organic nitrogen, $NO_3^-$, $NH_4^+$ and $NO_2^-$. Nitrate and $NH_4^+$ are the forms used by aquatic plants. Organic nitrogen and nitrite are also included, because these forms can be converted to the available forms. Phosphorus occurs organically bound as orthophosphate or in the dissolved form as phosphate. 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). Sources of nitrogen are fertilizers, industrial cleaning operations, feed lots, animal excrement, and combustion of fuels (Makepeace et al., 1995). Tree leaves, fertilizers, industrial wastes (food, chemical, building material), detergents and lubricants are sources of phosphorus (Makepeace et al., 1995).

Generalizations derived from research studies concerning nutrient levels in stormwater runoff depend on the use of the watershed area. Sartor and Boyd (1972) found that TKN concentrations were the greatest in stormwater runoff from residential watersheds, $NO_3^-$ concentrations were greatest from commercial watersheds, and TP concentrations were greatest from industrial watersheds. In contrast, Lee and Bang (2000) found that TP concentrations were greater in stormwater runoff from residential watersheds and $NO_3^-$ and TKN concentrations were greater in stormwater from industrial watersheds. The conflicted findings may simply result from the complex and site-specific nature of pollutants in stormwater. More specifically, Wu et al. (1998) found that nitrogen levels were higher in stormwater runoff from a bridge deck than from impervious roadways. The greater degree and frequency of highway management of bridge decks, such as deicing applications, in comparison to impervious roadways enhances nitrogen levels of bridge decks.

Researchers also determined the contribution of nutrients to highway stormwater runoff by bulk precipitation and snowmelt. Eleven percent of $NO_3^-$, 98% of $NH_4^+$ and 88% of TKN was contributed by bulk precipitation (Wu et al., 1998). Stotz (1987) found that 40-54% of TP and greater than 50% of $NH_4^+$ was present in the bulk precipitation. Oberts et al. (2000) found $NO_3^-$ levels much higher in snowmelt at all sites than rainfall runoff, TKN levels higher in snowmelt than in rainfall runoff at most sites, and TP snowmelt concentrations similar to rainfall runoff concentrations. In addition, the degree to which the soluble pollutants are accumulated and available during melting depends on the number of times that the snowpack thaws and refreezes (Oberts et al. 2000).

Sartor and Boyd (1972) characterized nutrient association with the different particle size fractions of dry samples collected from the street surface of different cities. The majority of phosphates combined with particles smaller than 104 μm (Figure 2.4). Nitrate is also associated with smaller particles, but the trend was less pronounced (Figure 2.5). Finally, TKN distributed fairly evenly across the entire size spectrum (Figure 2.6). Flushing of nutrients depends on their association with the different particle size fractions. Nitrate and TP may flush more readily, due to their predominant association with smaller particles. Low rainfall intensities dislodge smaller particles more easily than large particles. In contrast, TKN bound with larger particles as well as smaller particles, which may cause more variability in the flushing of TKN. Lee and Bang (2000) found that $NO_3^-$ did not exhibit first flush immediately for four out of five storms and TP exhibited first flush initially for all five storms. Unfortunately, a comparison between flushing and contaminant levels with rainfall intensity was absent from Lee and Bang's (2000) results.

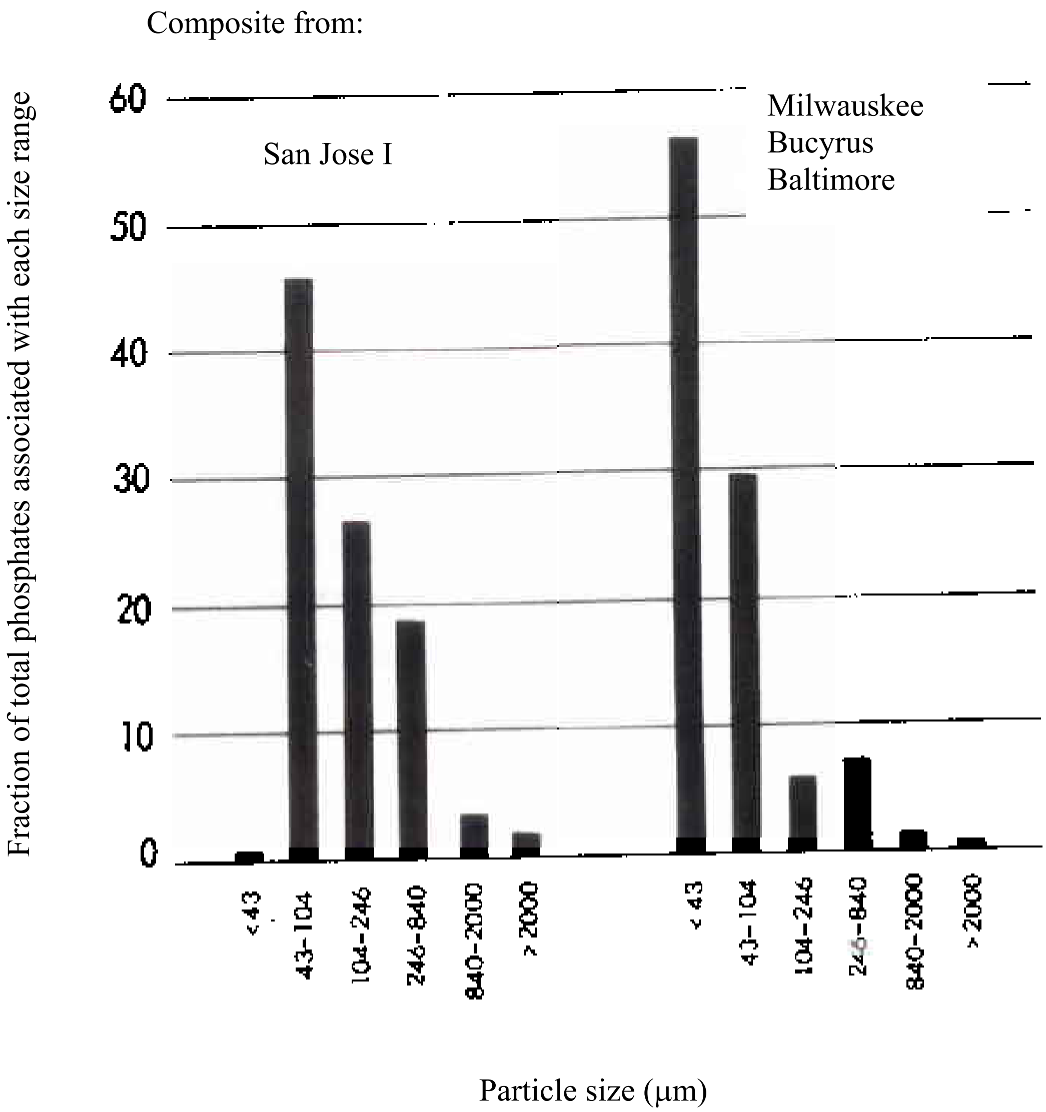


Figure 2.4. Variation of total phosphate with particle size (Sartor and Boyd, 1972)

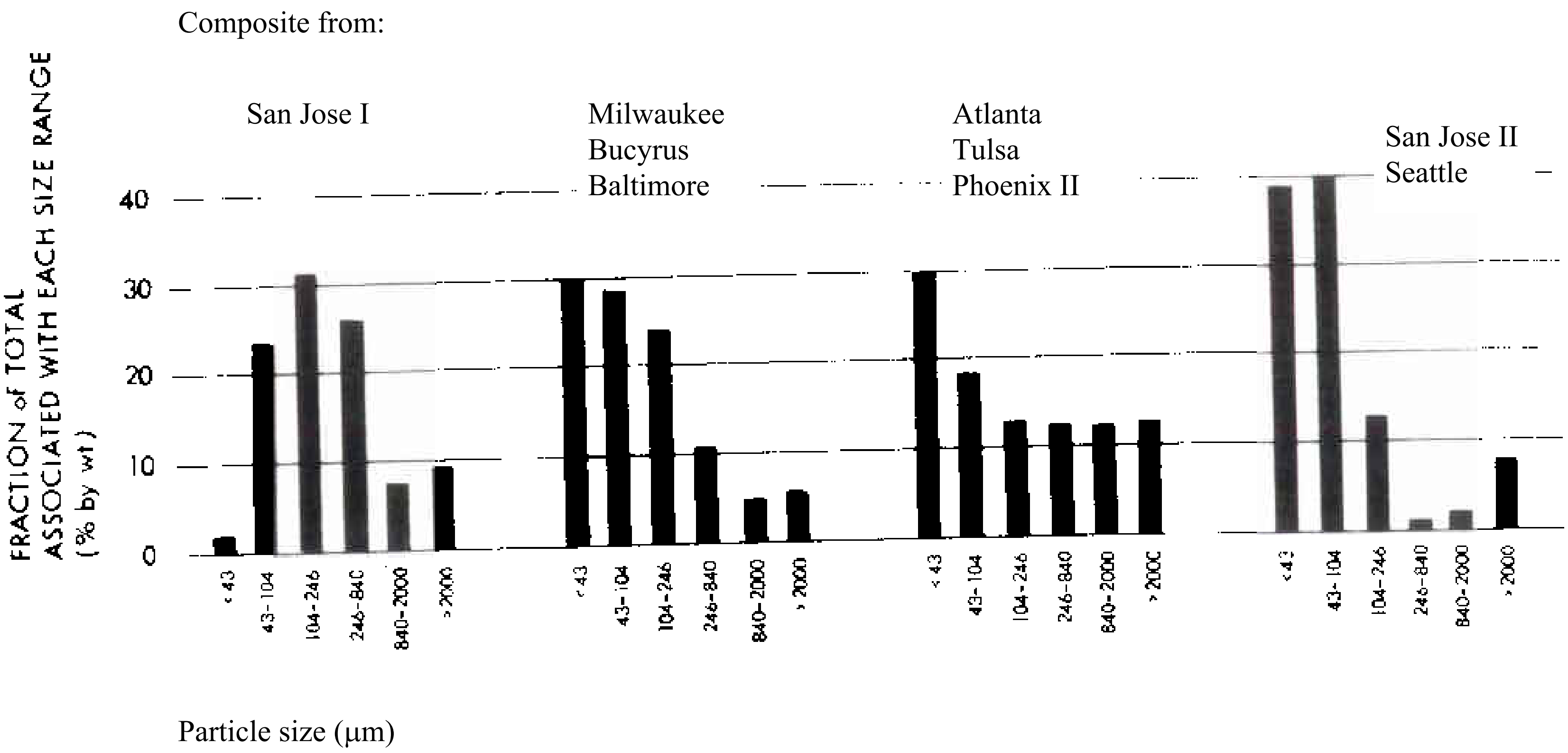


Figure 2.5. Variation of nitrates with particle size (Sartor and Boyd, 1972)

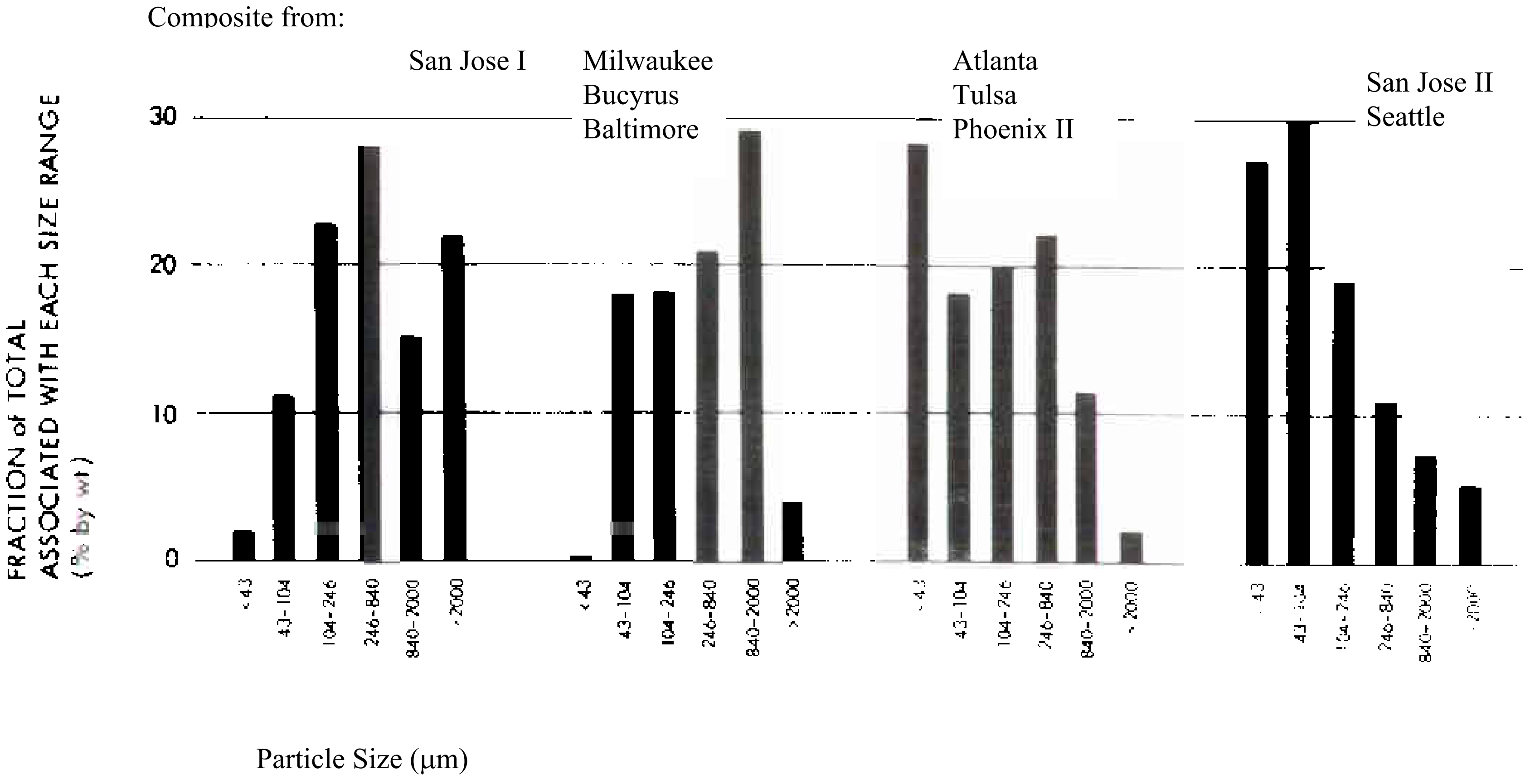


Figure 2.6. Variation of Kjeldahl nitrogen with particle size (Sartor and Boyd, 1972)

### 2.1.4 Chloride

Another constituent of concern in stormwater runoff is chloride. An estimated $10^7$ ton of salt are applied to USA roadways annually (Fritzsche, 1992). 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 $Mg^{2+}$ or $Cl^-$ concentration measurements can be used as an indicator for $Cl^-$ levels in stormwater runoff. Concentrations as high as 6500 mg/L and 25,000 mg/L have been measured for $Na^+$ and $Cl^-$, respectively (Table 2.1).

Table 2.1. Peak concentrations in mg/L of dissolved constituents in snowmelt resulting from deicing salts

| Reference | Site | $Cl^-$ | $Na^+$ | $Ca^{2+}$ | $Mg^{2+}$ |
|---|---|---|---|---|---|
| Buttle & Labadia (1999) | Highway 15, Toronto, Canada | 9916 | 6506 | | |
| Demers & Sage (1990)[a] | Rich Lake, NY | 17.05<br>7.21<br>3.73 | | | |
| Sansalone & Glenn (2002) | Cincinnati, Ohio | 10000 | | | |
| Warren & Zimmerman (1994) | Toronto, Canada | 1907 | 1059 | 143 | |
| Makepeace et al. (1995) | Compilation of literature | 0.3-25000 | 0.08-660 | 0.04-2114 | 0.02-304 |

[a] Mean concentrations for three different sites in Rich Lake, NY

Excessive amounts of chloride caused reductions in soil permeability to air and soil (Jones et al., 1992). In addition, chloride increased the preportioning of metals into the dissolved phase, which in turn increases the mobility and partitioning of trace metals (Warren and Zimmerman, 1994). Although chloride levels are elevated in stormwater runoff as a result of deicing applications, the effects are longlasting. For example, chloride levels remained elevated in the downstream portion of streams that crossed highway Route 28N in Essex county, New York, six months after application of deicing salt to the highway had ceased (Demers and Sage, 1990). Elevated chloride levels are also a problem in snowmelt. Elevated levels of salt output in snowmelt occurs continuously from snow cover throughout the melting period and is not restricted to the main release of meltwater (Buttle and Labadia, 1999).

## 2.2 Event Mean Concentration

The event mean concentration is a flow-weighted concentration of a water quality component during a single storm event. A number of studies characterized highway runoff using EMC's. A portion of the studies characterized highway runoff from rural areas (Stotz, 1987; Stotz and Krauth, 1994; Wu et al., 1998; Legret and Pagotto, 1999;), while the remaining studies focused on highway runoff from urban areas (Sansalone and Buchberger, 1997; Deletic and Maksimovic, 1998; Barrett et al., 1998). More specifically, Deletic and Maksimovic (1998) characterized two different urban sites: a carpark and a residential/some commercial area. Barrett et al. (1998) characterized highway runoff from three different types of sites: a rural/residential area, a commercial/residential area and a commercial/high density residential area. The EMC's were presented in a variety of ways: as the flow-weighted average concentration of storm events, the range of the EMC's found for all storm events, the median EMC value for all storm events, and the mean EMC value for all storm events. Table 2.2 presents a summary of the EMC data and site characteristics for the seven studies. Another difference in the presented data regards metal EMC's. Legret and Pagotto (1999) and Sansalone and Buchberger (1997) analyzed total metals, whereas Stotz and Krauth

Table2.2. EMC data for studies concerning highway stormwater runoff

| Reference | Site | Area (m$^2$) | ADT[f] | Land Use | TSS[d] | Cd[e] | Cu[e] | Pb[e] | Zn[e] | $NO_3$-N[d] | $NO_2$-N[d] | TKN[d] | TP[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deletic & Maksimovic (1998)[a] | Miljak., Sweden | 211 | 435 | Resid/ Commer. | 96-673 | | | | | | | | |
| | Lund, | 270 | 15-20 | Carpark | 5-417 | | | | | | | | |
| Stotz & Krauth (1994)[b] | Weins., FRG | 550 | 34675 | | 64 | 0.9 | 49 | 13 | 441 | 0.85 | 0.14 | | |
| | | | | | 49 | 2.5 | 88 | 7 | 737 | 3.11 | 0.29 | | |
| Legret & Pagotto (1999)[b] | Nantes, France | 3200 | 12000 | Bypass, Rural | 77 | 1 | 45 | 58 | 356 | | | 2.3 | |
| Wu et al. (1998)[b] | HB, NC | 1497 | 25000 | Rural/Res. | 283 | | 24.2 | 21 | | 2.25 | | 1.42 | 0.43 |
| | NC49, NC | 2307 | 21500 | Rural/Res. | 93 | | 11.5 | 14 | | 0.22 | | 1.18 | 0.52 |
| | I85, NC | 4452 | 5500 | Rural/Res. | 30 | | 4.6 | 6.5 | | 0.14 | | 1.00 | 0.47 |
| Barrett et al. (1998)[c] | W35, TX | 5341 | 58150 | Comm./Res | 129 | | 37 | 53 | 222 | 1.07 | | | 0.33 |
| | CH, TX | 526 | 8780 | Rural/Res. | 91 | | 7 | 15 | 44 | 0.71 | | | 0.11 |
| | WC, TX | 104600 | 47240 | Comm./Res | 19 | | 12 | 3 | 24 | 0.37 | | | 0.10 |
| Stotz (1987) | A81, FRG | 13000 | 41000 | Rural | 137 | 5.9 | 97 | 20 | 360 | | | | 0.25 |
| | A6, FRG | 25200 | 47000 | Rural | 181 | 5.9 | 117 | 2 | 620 | | | | 0.35 |
| | A8, FRG | 250000 | 52100 | Rural | 252 | 2.8 | 58 | 24 | 320 | | | | 0.31 |
| Sansalone & Buchberger (1997) | Millcreek, Ohio | 300 | 150000 | Urban | | 5-11 | 43-325 | 37-97 | 459-15244 | | | | |

[a] EMC range [b] Mean of EMC [c] Median EMC [d] Units in mg/L [e] Units in µg/L [f] Units in vehicles/day

(1994) and Wu et al. (1998) analyzed the supernatant of samples. Barrett et al. (1998) and Stotz (1987) do not directly state which fraction of metals were analyzed.

Trends were established between EMC's for highway runoff and deicing salt application, ADT, land use, antecedent dry days and first flush of TSS. Chloride, $NO_3^-$, $NO_2^-$, Cd, Cu, and Zn concentrations were higher in winter than in the summer (Stotz and Krauth, 1994). Zinc and Cu, as well as Pb, concentrations were also found to be higher in the winter season by Legret and Pagotto (1999). In addition, $NO_3^-$, TP, and Pb EMC's were higher in snowmelt runoff than rainfall runoff (Brezonik and Stadelman, 2002). Higher heavy metal EMC's occurred in winter as a result of the application of deicing salts to roadway surfaces (Stotz and Krauth, 1994). Therefore, the occurrence of higher pollutant EMC's is likely during the winter months in areas of deicing salt application.

In three of the studies in which more than one site was characterized, all three studies found that the sites with lower ADT corresponded with lower EMC's (Deletic and Maksimovic, 1998; Wu et al., 1998; and Barrett et al., 1998). In addition, EMC's were generally greater in residential areas than in industrial areas (Lee and Bang, 2000). Two of the seven studies also considered correlations between explanatory variables and EMC's. The greatest correlation between two variables is indicated by a correlation coefficient with an absolute magnitude equal to 1. Brezonik and Stadelman (2002) determined that correlations between explanatory variables and EMC's were weak, although rainfall duration and antecedent dry days correlated with EMC's more strongly than any other variables (Table 2.3). In contrast, Deletic and Maksimovic (1998) found weak negative correlation and weak positive correlation between TSS EMC and antecedent dry period at the Lund and Miljakovac sites.

Table 2.3. Pearson correlation coefficients between EMC's in stormwater and storm variables (Brezonik and Stadelman, 2002)

| Pollutant[a] | Precipitation | Duration | Intensity | Antecedent Dry Days |
|---|---|---|---|---|
| TSS | --- | -0.256 | 0.279 | 0.122 |
| VSS | --- | -0.387 | 0.423 | 0.204 |
| TP | | -0.198 | --- | 0.354 |
| DP | -0.348 | -0.375 | 0.233 | 0.326 |
| SRP | --- | --- | --- | 0.193 |
| COD | -0.366 | -0.401 | 0.238 | 0.543 |
| TKN | -0.180 | -0.381 | 0.317 | 0.360 |
| NN | -0.265 | -0.237 | --- | 0.338 |
| TN | -0.183 | -0.243 | --- | 0.371 |
| Pb | --- | --- | --- | 0.514 |

[a] Volatile suspended solids (VSS), dissolved phosphorus (DP), soluble reactive phosphorus (SRP), chemical oxygen demand (COD), nitrite nitrogen (NN), total nitrogen (TN)

## 2.3 First Flush

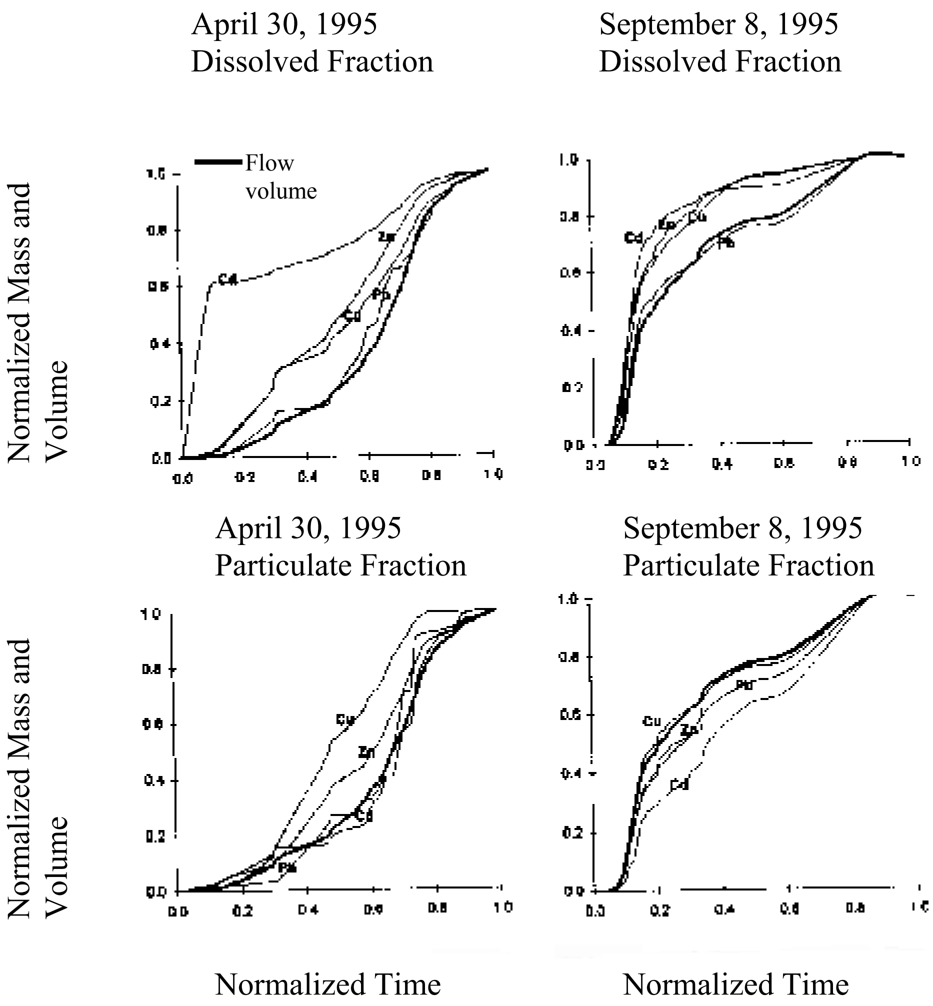
Flushing occurs when the pollutants wash from the pavement in a greater amount than the rainfall. More specifically, first flush occurs when the greatest proportion of the pollutants wash from the drainage area during the initial part of the storm. Therefore a working definition of first flush is needed for BMP design as well as to quantitatively characterize contaminant flushing. At least three different criteria have been used to define first flush:

(1) $m'(t) \geq v'(t)$ (Helsel et al., 1979)
(2) $m'(t) \geq 0.80$ and $v'(t) \leq 0.20$ (Urbonas and Stahre, 1993)
(3) $m'(t) \geq 0.50$ and $v'(t) \leq 0.25$ (Wanielista and Yousef, 1993)

In all three criteria, $m'(t)$ and $v'(t)$ represent the dimensionless normalized mass and flow volume or $m(t)/M$ and $v(t)/V$, where $m(t)$ and $v(t)$ represent the mass loading and runoff volume for a discrete time interval during the storm event and M and V equal the total mass loading and runoff volume for the entire storm event. In the first criterion, 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 contrast, the second and third criteria are more restrictive. In the second criterion, 80% of the total mass flushed during the storm duration must be flushed by the first 20% of the total event volume. The third criterion requires that 50% of the total mass must be flushed by the initial 25% of the total storm volume. Comparison of the three criteria illustrates that the first criterion is qualitative, while the second and third criteria are quantitative. As a result, use of the first criteria can indicate the incidence of flushing at any point during the storm, but not the magnitude of the flushing. Therefore, the second or third criteria should be used for a quantitative understanding of first flush.

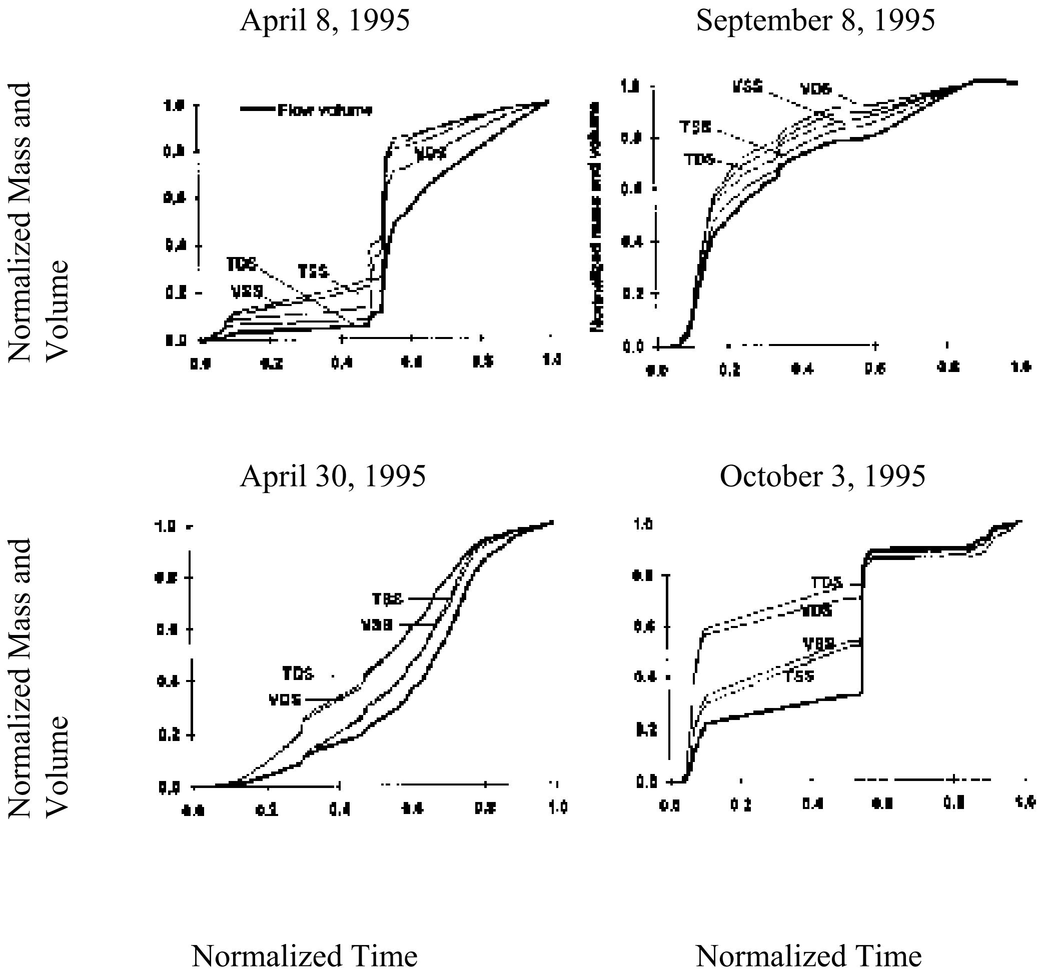
In most cases in which it was applied, the first criteria is used to determine the occurrence of first flush during a storm event. Sansalone used Criteria 1 to determine first flush for metals (1997) and suspended solids (1998) from urban roadway runoff (Figure 2.7). First flush occurred for all events for the dissolved phases of Cu and Zn, but was not well defined for particulate-bound fractions (Sansalone et al., 1997). First flush occurred for suspended solids in most events, except in events with low flowrate where weaker first flush was exhibited (Sansalone et al., 1998). Lee and Bang (2000) also used Criteria 1 to determine the first flush phenomena for 10 different constituents; BOD, COD, SS, TKN, $NO_3$-N, $PO_4$-P, TP, n-hexane extracts, Pb and Fe (Figure 2.8). Lee and Bang (2000) characterized the relative strength of the contaminant first flush as COD > n-hexane extracts > SS > $PO_4^-$-P > $NO_3^-$-N > Pb.

However, in four studies, different criteria or undefined criteria were used to define first flush. Barrett et al. (1998) and Hewitt and Rashed (1992) defined the first flush phenomena as the occurrence of higher pollutant concentrations at the beginning of a storm event. Barrett employed this definition to make broad conclusions about the first flush phenomena for all constituents in each storm event. Barrett found that the first flush effect was most evident at the commercial/residential site and least evident at the commercial/high density residential site. Hewitt and Rashed (1992) observed the first flush effect for the dissolved metals, Pb, Cu, Cd, and alkyllead compounds. Harrison and



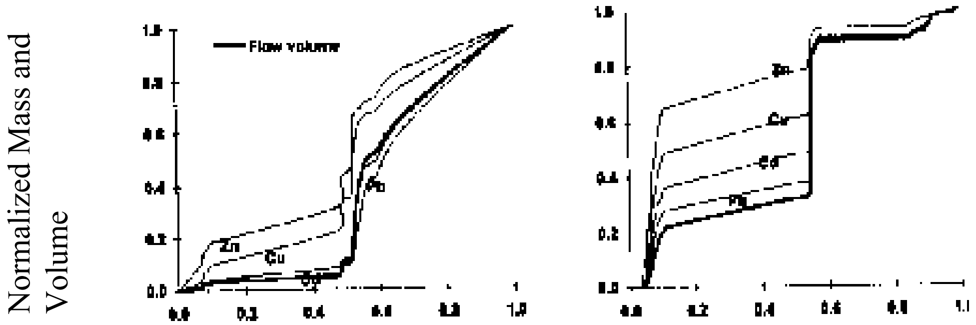
(a)

Figure 2.7. Mass and flow volume curves for (a) low intensity, low flow volume events and (b) solids fraction mass (c) high intensity, high volume events (Sansalone et al., 1997)



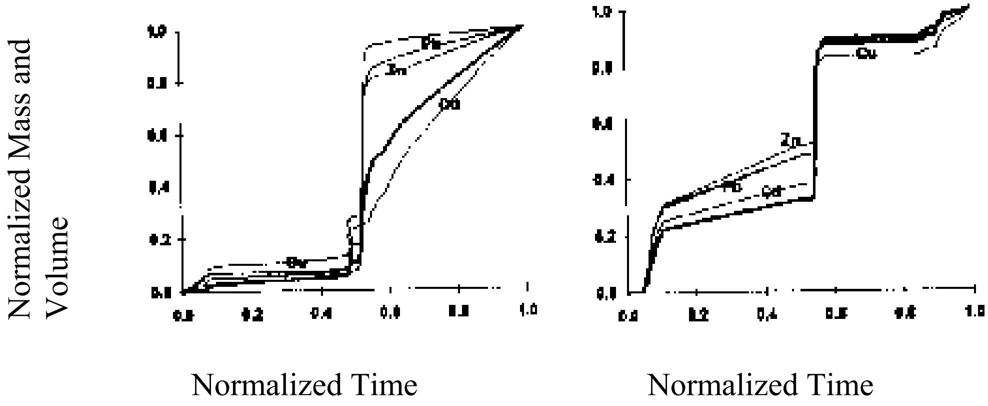
(b)

Figure 2.7. Continued



April 8, 1995
Dissolved Fraction

October 3, 1995
Dissolved Fraction

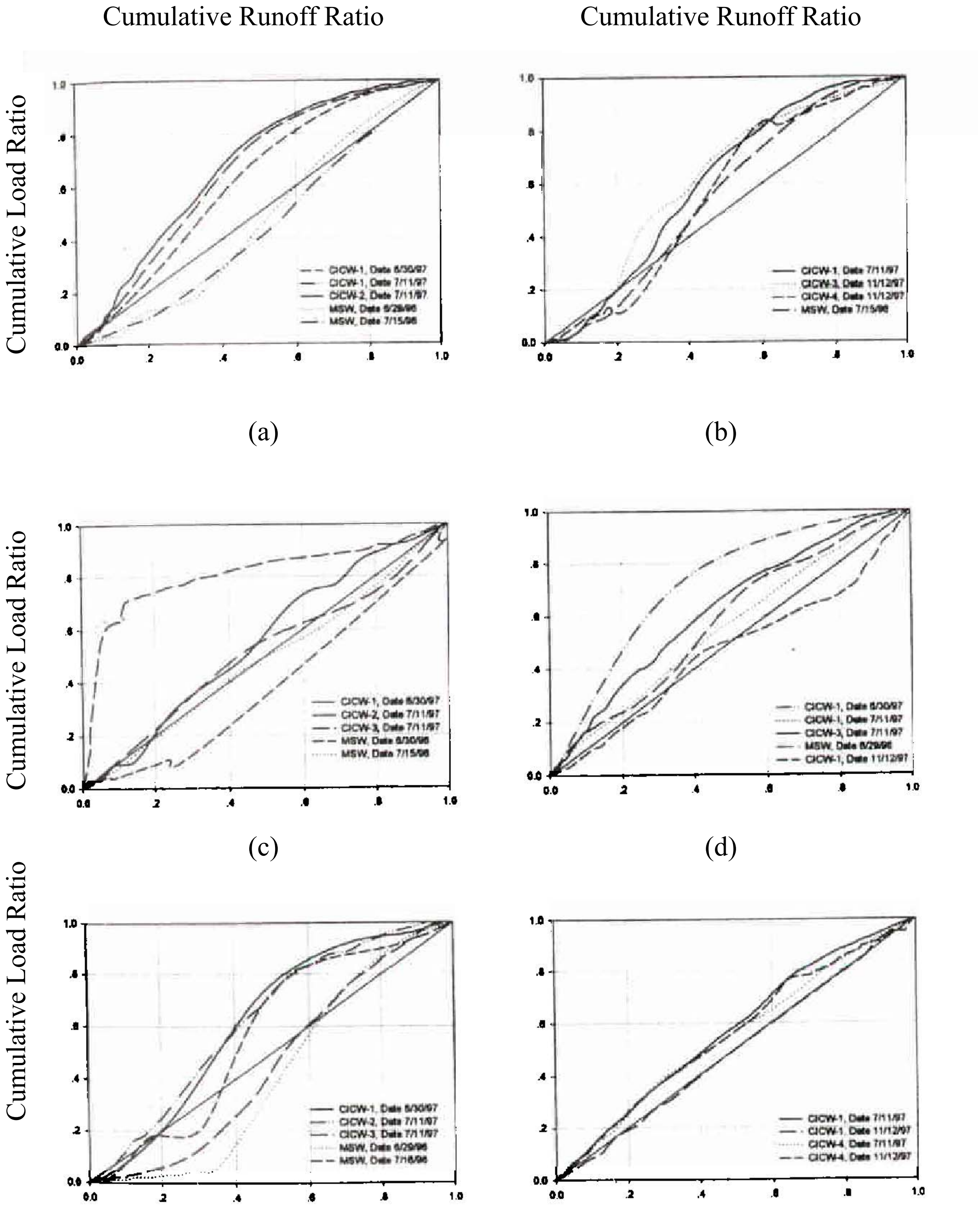


April 8, 1995
Particulate Fraction

October 3, 1995
Particulate Fraction

(c)

Figure 2.7. Continued



(a) (b)

(c) (d)

(e) (f)

Figure 2.8. Dimensionless cumulative curves for (a) COD, (b) SS, (c) $NO_3$-N, (d) $PO_4$-P, (e) n-hexane extracts, (f) Pb for selected storm events (Lee and Bang, 2000)

Wilson (1985) determined that 50% of the total mass was flushed during the first hour for the major ion constituents, $Na^+$, $Ca^{2+}$, $Cl^-$ and $SO_4^-$ and the trace metals, Pb, Fe, Mn, Cu and Cd for highway stormwater runoff in most storm events. Deletic (1997) defined first flush as the percentage of total event pollution load transported by the first 20% of the runoff volume. Deletic (1997) found that the first flush of SS and conductivity was not a regular or distinct phenomenon at either of the two study sites in Lund, Sweden and Belgrade, Yugoslavia (Figure 2.9).

In addition to establishing criteria to define first flush, a few trends have also been established for the first flush phenomenon. Dissolved constituents in stormwater almost always exhibited first flush (Harrison and Wilson, 1985; Hewitt and Rashed 1992; Sansalone and Buchberger, 1997). Particulate matter enters stormwater runoff by a two-step mechanism: (1) dislodgment of the particulate matter from its resting place by the impact of rain drops and (2) psuedo-suspension of particulate matter in the lateral sheet flow (Sartor and Boyd, 1972). As a result, mobilization of particulates and particulate-bound constituents has a greater dependence on storm characteristics, such as storm intensity and volume, than dissolved constituents. Therefore, a second trend found that flushing of particulates and particulate bound constituents is more complex and varied (Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997).

In order to better characterize flushing of particulates and particulate bound constituents, researchers studied the effects of storm characteristics, such as storm duration, storm intensity and drainage area on first flush. Long duration, lower intensity events exhibited stronger first flush of SS than short duration, high intensity storms

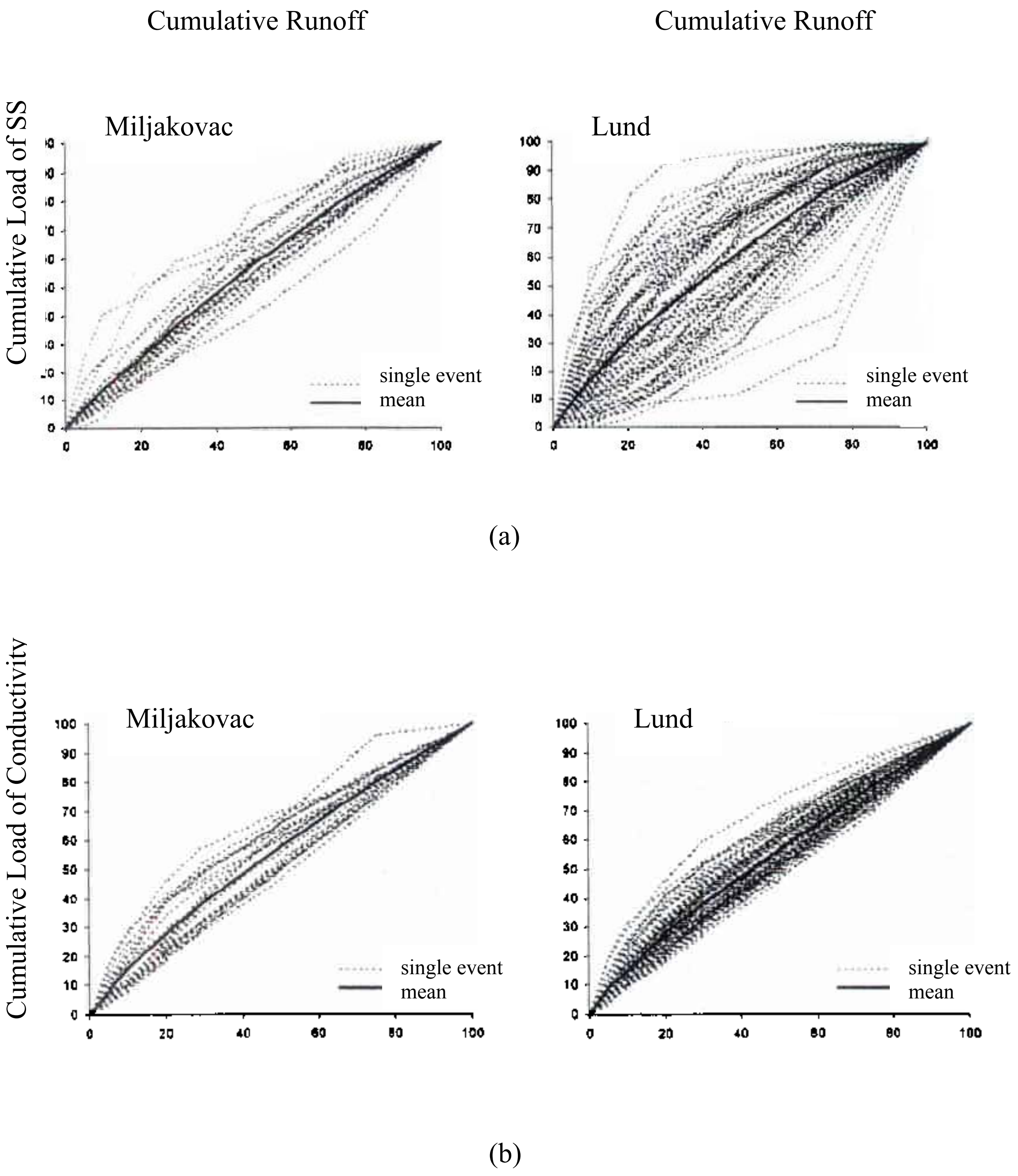


Figure 2.9. Cumulative curves of (a) suspended solids and (b) conductivity (Deletic, 1997)

(Sansalone et al., 1998). During storms of similar duration, first flush strength as defined by Criterion 1 increased with increasing rainfall intensity and decreasing drainage area (Lee and Bang, 2000).

Further characterization of flushing for the remainder of the storm was for the most part not addressed, except for a couple of studies. In one study, when one storm event exhibited two distinct hydrographs without flow between them, both hydrographs were treated and compared as the first flush of separate events (Sansalone et al., 1998). In a second study, a storm event that produced a second peak in flowrate was said to exhibit a second flush (Hoffman et al., 1984). Although for this study the second peak in flowrate corresponded with a concentration peak in a few contaminants, flowrate peaks do not always correspond with peaks in pollutant concentrations. As a consequence, peaks in flowrate do not always indicate flushing of pollutants. In conclusion, quantitative characterization of flushing throughout the storm duration would give a better understanding of pollutant loadings as function of storm duration, allowing for a more accurate understanding of the effectiveness of in-situ treatments for storm water runoff.

## 2.4 Best Management Practices

Best management practices refer to any method used to manage stormwater in the attempt to prevent flooding and/or impairment of the quality of receiving waters. For this project, the emphasis focused on understanding the quality of the stormwater runoff and the effect of a bioretention filter on the water quality. Wet detention ponds (Wu et al., 1996), infiltration ponds (Appleyard, 1993; Barbosa and Hvitved-Jacobsen, 2001) and biofiltration or bioretention filters (Mothersill et al, 2000; Lau et al., 2000; Davis et al., 2001; Davis et al., 2003) are some of the BMP's that have received focus by researchers. For all three types of BMP's, the studies focus on quantifying contaminant removal, determining the effects of operating or design parameters on contaminant removal, and/or understanding the effects of operation on the BMP or the surrounding area.

Overall pollutant removal was greater in biofiltration than wet detention ponds. Wu et al. (1996) found 93 and 80% removal of TSS and Zn, respectively, in the Lakeside, Charlotte, North Carolina, wet detention pond and 62, 32, 21 and 36% removal of TSS, Zn, TKN, and TP, respectively, in the Runaway Bay, Charlotte, North Carolina, wet detention pond. In comparison, Davis et al. (2001) found greater than 92, approximately 80, 65 to 75, and 60 to 80% removal of metals, phosphorus, TKN and $NH_4^+$, respectively, in a lab scale bioretention filter. Although removal was greater in biofiltration than in the wet detention ponds, these results reflect only two studies. In addition, Appleyard (1993) found that nutrient and metal concentrations were below the drinking water quidelines in the groundwater beneath the infiltration pond, despite heavy fertilizer use in the park upgradient of the infiltration pond. Phosphorus, $NO_3^-$-N, $NH_3$-N, Cd, Pb, Cu, and Zn did not exceed 0.01 mg/L, 1 mg/L, 0.02 mg/L, 0.001 mg/L, 0.01 mg/L, 0.02 mg/L, and 0.13 mg/L, respectively. The effectiveness of the infiltration pond was not compared to the results for the wet detention pond and bioretention filter, due to the qualitative nature of Appleyard's (1993) results. Furthermore, the infiltration pond had the greatest impact on salinity and dissolved oxygen concentration in comparison to other water quality parameters (Appleyard, 1993).

Filter depth of biofilters effected pollutant removal (Mothersill et al., 2000; Davis et al., 2001; Davis et al., 2003). The majority of nutrient removal occurred in the top 300 mm of an 800 mm deep filter bed (Mothersill et al., 2000) and in the top 180 or 250 mm of a 610 or 910 mm deep filter bed (Davis et al., 2001), but the reduction in removal between the upper and lower parts was not as significant for TKN as for TP (Davis et al., 2001). In addition, $NH_4^+$ removal occurred mainly in the bottom of the filter (Davis et al., 2001). Organic carbon and metal concentration remained constant throughout the filter depth (Mothersill et al., 2000). Runoff flowrate, storm duration and pH were three additional parameters that effected pollutant removal in biofiltration. At high flowrates and long duration, pollutant removal through the upper 180 or 250 mm of the filter bed was smaller than at low flowrate and short duration, but effluent concentrations from the bottom of the filter remain similar at either flowrate and duration (Davis et al., 2003). As a result, flowrate and duration effects are irrelevant at adequate filter bed depths. Metal speciation is pH dependent, so metal removal should be dependent on stormwater pH. However, the buffering capacity of the biofiltration material neutralizes the pH of stormwater, negating pH effects (Davis et al., 2003).

Wu et al. (1996) found that the ratio of the pond surface area to the contributing drainage area (SAR), location of inlet pipes, and detention time effected the ability of wet detention ponds to remove pollutants. Using 1-2% of the drainage area for the pond area resulted in efficient removal of contaminants. The pollutant removal curves level off at SAR's exceeding 2% (Wu et al., 1996). Inlet pipes should be located as far from outlet pipes as possible, because short circuiting occurred when inlet pipes were placed near the outlet pipes. Smaller fines exhibit smaller settling velocities and consequently require longer settling times. Therefore, determination of the pond detention time depends on the size of the fines in the stormwater runoff.

Low hydraulic conductivity and high pH were conducive to pollutant removal by infiltration ponds (Barbosa and Hvitved-Jacobsen, 2001). Stormwater runoff filters through the pond bottom more slowly at low hydraulic conductivity. Therefore, larger pond volumes are needed to capture stormwater runoff when the ponds are lined with soils of low hydraulic conductivity. A separate soil layer was necessary for plant roots that line the bottom of the infiltration ponds, in addition to the soil layer needed to filter pollutants (Barbosa and Hvitved-Jacobsen, 2001). Stormwater follows channels along the plant roots and as a consequence will not be filtered when an additional soil layer is absent from beneath the plant roots.

Operation of infiltration ponds and filtration of sediments via biofiltration impacted groundwater level and filter efficiency. Appleyard (1993) determined that peak groundwater levels occurred six to 24 hours after ponding of the infiltration pond. Hydraulic conductivity of the media in biofilters decreased with duration of filter use and increased at depths greater than 300 mm in an 800 mm deep filter (Mothersill et al., 2000). Higher hydraulic conductivity values at lower filter depth indicate that the majority of sediment collected in the top 300 mm of the biofilter (Mothersill et al., 2000). Bioretention facilities were resistant to influent stormwater variability, as a result of vertical flow and depth pathway (Davis et al., 2003).

# Chapter 3

# METHODOLOGY

## 3.1 Site Description/Sampling Protocol

Runoff samples were collected from a commercial/residential area located in Mount Rainier, Maryland, which is mostly roadway with sidewalk and some roof drainage. More specifically, the drainage area extends along Rhode Island Avenue (Route 1) between the District of Columbia line and 33$^{RD}$ Street, containing a total drainage area equal to 0.557 ha (Figure 3.1, 3.2, and 3.3). The storm water that is composed only of lateral sheet flow from the roadway empties into two inlets located on the east (Figure 3.4) and west (Figure 3.5) side of Route 1 at the intersection of Route 1 and 33$^{RD}$ Street, after being concentrated along the roadside curbs.

In the Spring of 2002, a 24-inch Palmer-Bowlus flume was installed in the existing storm drain on the west side of Route 1 (Figure 3.6). The stormwater from both inlets flows through the flume and storm drain system, eventually, emptying into the Anacostia River. A Model 6712 Isco Portable Sampler is located adjacent to the flume to automatically collect samples (Figure 3.7). A sampling protocol is pre-programmed into the 6712 Sampler to control the sampling. Precise control depends on three main programming components: (1) description of the equipment used in connection with the sampler, (2) definition of the enabling event and (3) specification of the pacing for sample collection.

An Isco Bubbler Module (Model 730) that connects to the sampler measures the water level in the flume. The level measurement converts into a properly scaled flow using the 24” Palmer-Bowlus flume conversion. Two additional accessories are

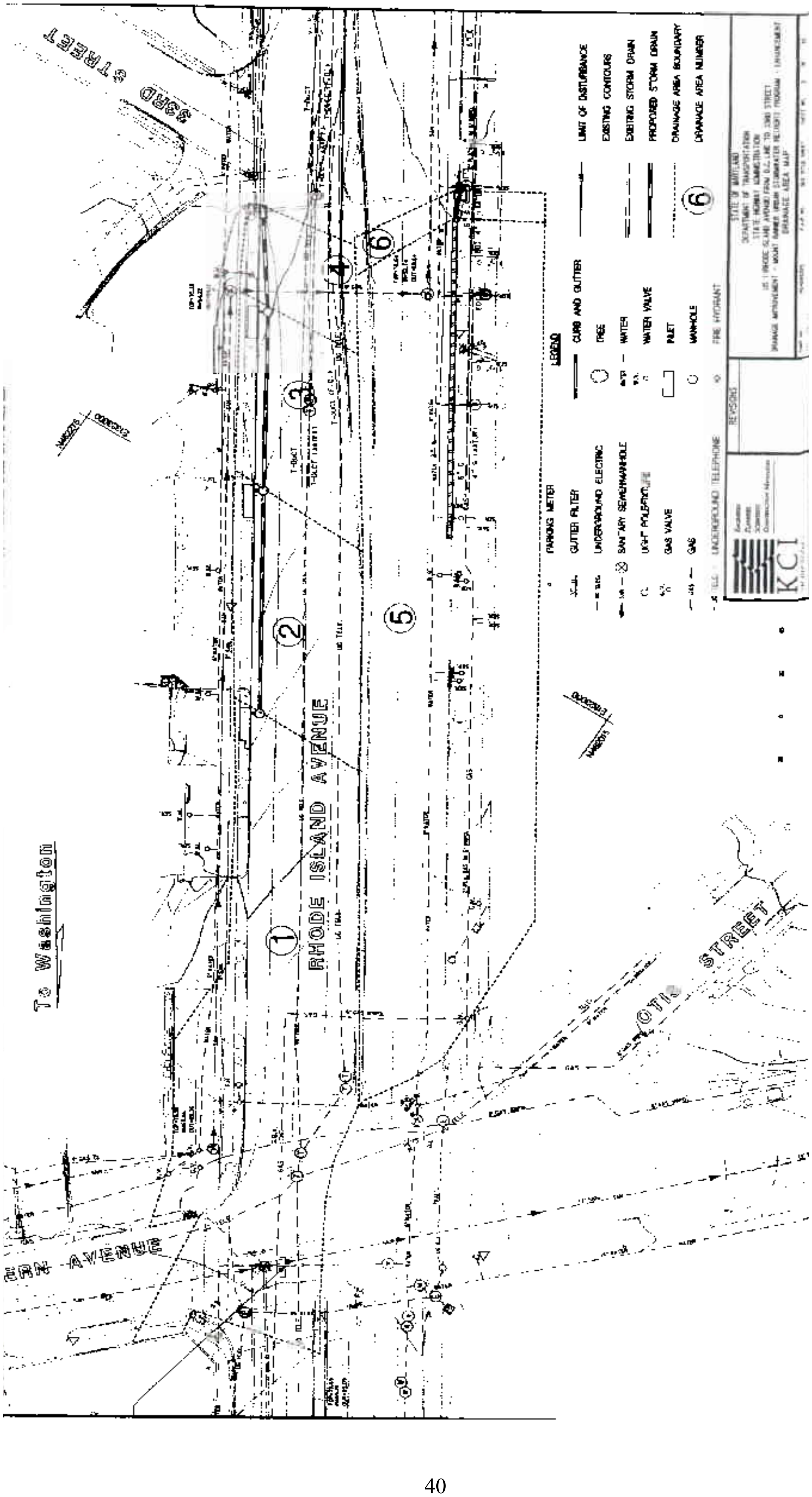


Figure 3.1. Site Map of Mt. Rainier, MD

Figure 3.2. Mt. Rainier monitoring area; east side, looking south

Figure 3.3. Mt. Rainier monitoring area; west side, looking south

Figure 3.4. East side inlet of Mt. Rainier, MD monitoring area

Figure 3.5. West side inlet of Mt. Rainier, MD monitoring area

Figure 3.6. Palmer-Bowlus 24” flume installed in storm drain on west side of Route 1, Mt. Rainier, MD monitoring site

Figure 3.7. Isco, Model 6712 Portable Sampler installed in storm drain on west side of Route 1 at Mt. Rainier, MD monitoring site

specified in the program: (1) sample bottle number and size and (2) length of sample line. Specification of the bottle number and size determines the distance that the distributor arm rotates between each bottle. The sampler uses the length of the sample line to determine the purging duration before and after collection of each sample.

In this application, a water level of 3.05 cm (1.2 in) in the flume enables sample collection, corresponding to a flow rate of 3823 $cm^3/s$ (233 $in^3/s$) and rainfall intensity of approximately 0.005 cm/min (0.002 in/min). The sampler remains enabled, during the storm duration without pause. Collection of the first sample for the storm initiates without a delay at the time of enable.

The pacing for the remaining samples is two-part and therefore non-uniform. During the first part of the storm, eight samples are collected following the storm onset at twenty-minute intervals. Three samples are subsequently collected at 1-hour intervals, after collection of the ninth sample. In summary, twelve samples are collected over a six-hour period from the storm onset (Table 3.1). Glass bottles are prepared by washing with soap and water, rinsing with deionized water, soaking in an acid bath that was prepared using concentrated $HNO_3$ for 24 hours, and finally rinsing with deionized water. Two bottles are filled with 280 mL of stormwater for each of the twelve samples. During each storm a report is generated detailing the settings that control sampling and the timing of each sampling event. As detailed above the program settings remain the same for each storm event.

Table 3.1. Automatic collection time from storm onset of Mt. Rainier, MD runoff samples

| Sample Number | Time | Sample Number | Time |
|---|---|---|---|
| 1 | 0 min | 7 | 2 hr |
| 2 | 20 min | 8 | 2 hr, 20 min |
| 3 | 40 min | 9 | 2 hr, 40 min |
| 4 | 1 hr | 10 | 3 hr, 40 min |
| 5 | 1 hr, 20 min | 11 | 4 hr, 40 min |
| 6 | 1 hr, 40 min | 12 | 5 hr, 40min |

### 3.2 Bioretention Design

Construction of a bioretention facility retrofit into the existing site at Mt. Rainier, MD described in the previous section began in October 2003 for the control of stormwater runoff at this site, utilizing detention/collection chambers, and filtration in addition to bioretention. Two similar gutter filters were installed along the curb on the east and west sides of the site, consisting of 19.4 $m^2$ (209 $ft^2$) of filtration area per unit (Figure 3.8). In addition, as shown in Figure 3.8, two detention/collection chambers with a storage capacity of 0.24 $m^3$ (8.6 $ft^3$) located at the ends of the filter media completed the gutter filter on the west side of Route 1. Similar to the gutter filters, the bioretention facility, which will be located on the west side of Rt. 1, will consist of multiple units: a pretreatment/collection chamber, bioretention chamber, and an overflow/bypass chamber (Figure 3.9). In this bioretention design, the pretreatment chamber has a storage capacity of 1.43 $m^3$ (50.5 $ft^3$) and a filtration/bioretention area equal to 1.37 $m^2$ (14.7 $ft^3$).

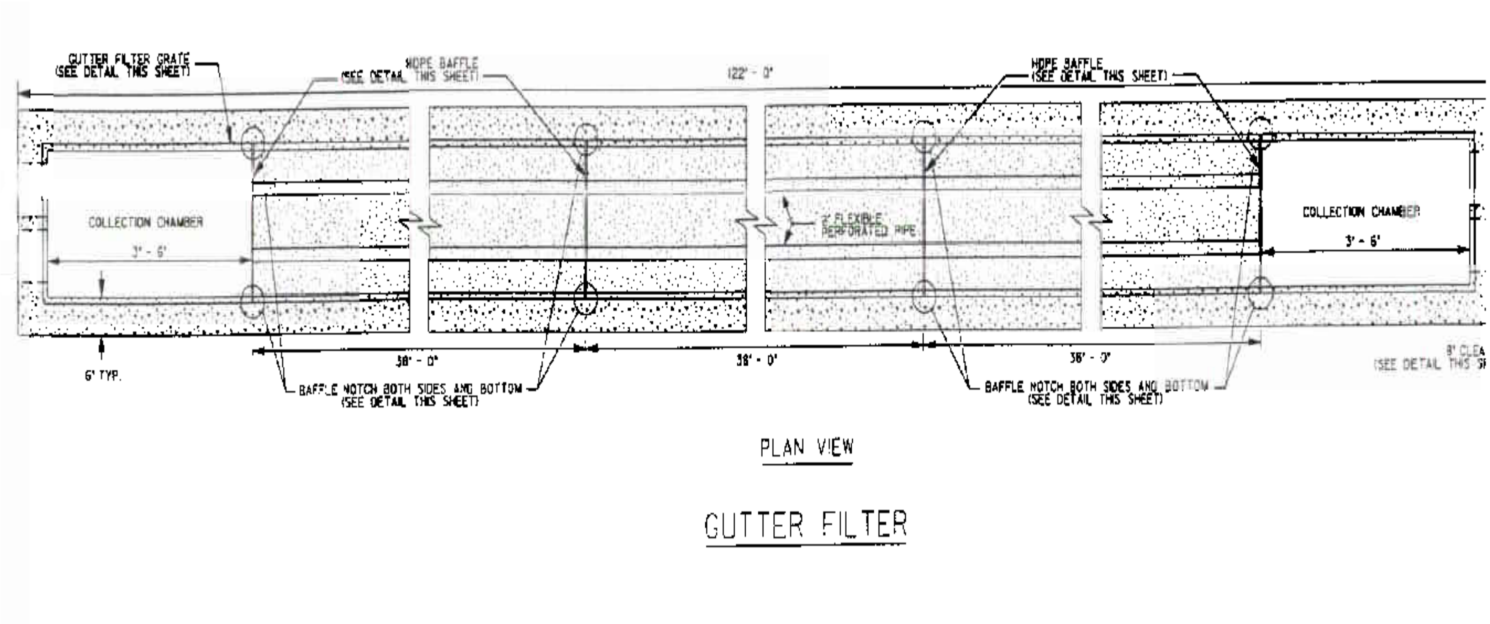


Figure 3.8. Plan view diagram of gutter filters at Mt. Rainier, MD

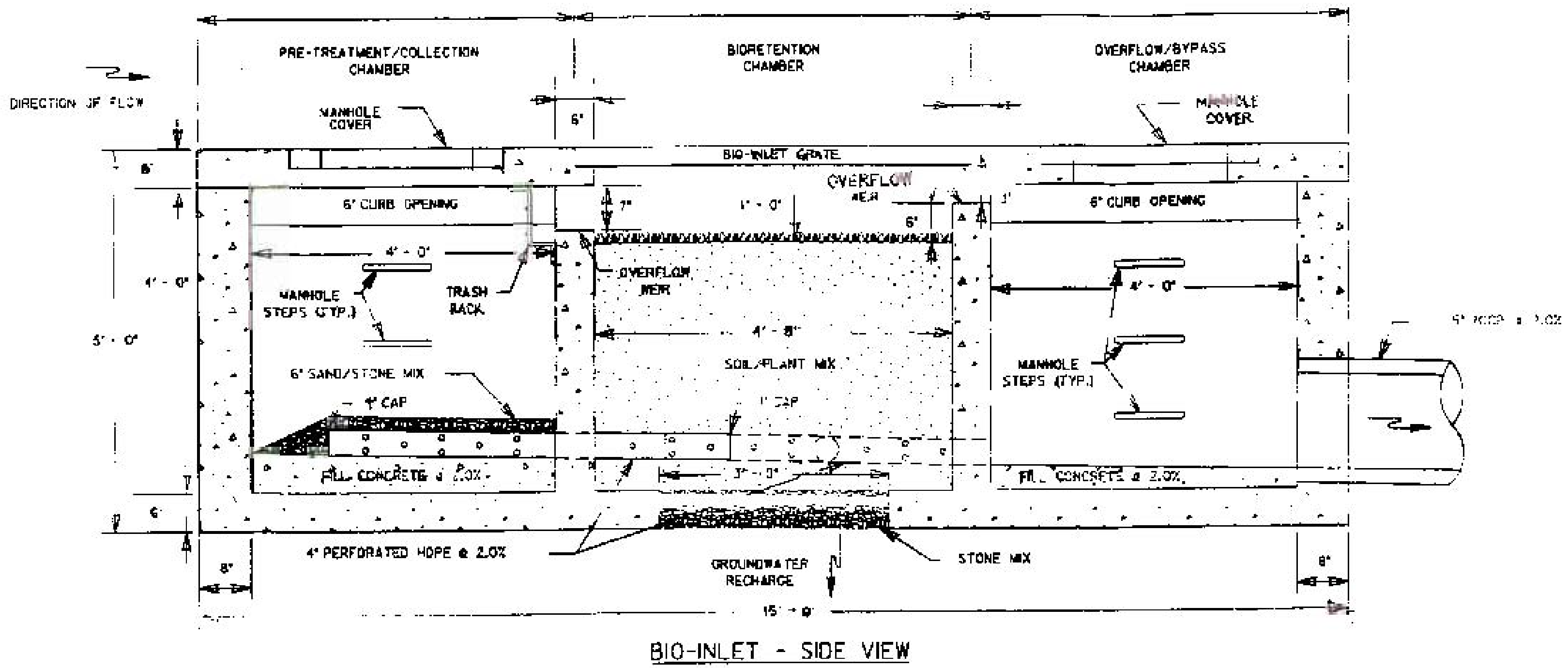


Figure 3.9. Side view diagram of bioretention retrofit at Mt. Rainier, MD

### 3.3 Weather Monitoring

In addition to monitoring flowrate conditions at the sampling site, weather conditions are also monitored at a nearby site. The weather station is located at the Mount Rainier Public Works Facility located approximately 457 m (1500 ft) from the sampling site on Wells Avenue in Mt. Rainier, Maryland. Initially, the weather monitoring station was to be installed directly across the street from the sampling location at the Mt. Rainier police station. However, due to renovation of the police station, the weather monitoring station was installed at the Mt. Rainier Public Works building.

The complete Wireless Weather Station III (Davis Instruments) consists of an anemometer, wind cups, rain collector, weather station console, field case, radiation shield, transmitter and receiver. The transmitter that connects to the outdoor sensors transmits the data to a receiver that is located indoors. The transmitter/receiver system eliminates the need for a junction box and cables to directly connect the outdoor sensors to the data logger. Inside, the receiver connects to the weather station console, which displays the current weather conditions. The console connects to a Dell computer that contains the Weatherlink software. Weatherlink temporarily stores the weather condition data every five minutes to an archive. Twice a day at noon and midnight, the data automatically downloads from the archive to a permanent file on the computer hard drive. The weather station monitors the inside temperature, outside temperature, wind chill, wind direction, wind speed, and rainfall.

### 3.4 Analytical Methodology

Samples are 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, samples are immediately analyzed for TP, $NO_3^-$, $NO_2^-$, $Cl^-$ and TSS. After completion of the initial analyses, the remaining volume of each sample is preserved and refrigerated for TKN and metals analyses. One bottle for each sample containing approximately 100 mL of stormwater is preserved for metal analyses using six drops of concentrated $HNO_3$ (EMD Chemicals OmniTrace Grade or Fisher Scientific Metal Grade for Atomic Absorption). The second bottle of each sample is preserved by adding two mL of concentrated $H_2SO_4$ (Fisher Scientific) to 200 mL of sample. Sample preservation lowers the pH of the sample to between 1 and 2. Metal and TKN digestion are completed within two weeks. Metal analyses are completed within six months. All analyses follow methods detailed in *Standard Methods for the Examination of Water and Wastewater* (APHA, et al., 1995). All filtration is 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. Also, a wide range of concentrations is found over the course of a storm event. As a result, the instrument scale and standard concentrations are chosen to measure the majority of a storm event's samples. The smallest standard concentration does not correspond to the instrument detection limit for $Cl^-$, TP, $NO_3^-$ and $NO_2^-$.

### 3.4.1 Phosphorus Analysis

Phosphorus analysis is 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 convert 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) are gently boiled on a hot plate until approximately 10 mL of the solution remains. Then, the completely digested sample is cooled, filtered, and the filtrate is diluted to 100 mL. Stannous chloride color development, Section 4500-P D (APHA, et al., 1995), follows sample digestion. Color development occurs by forming molybdophosphoric acid by addition of 4 mL of molybdate reagent to the prepared sample and reducing molybdophosphoric acid to colored molybdenum blue by addition of 10 drops of stannous chloride reagent. After 10 minutes, a Shimadzu model UV160U spectrophotometer measures the sample absorbance at 690 nm. Samples are 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).

### 3.4.2 Nitrate and Chloride Analyses

Samples are filtered before analysis. Nitrate and $Cl^-$ analyses are 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 $Cl^-$ are separated and converted to their conductive acid forms with an AS-5 separator column and an AG-5 guard column. Detection is via conductivity measurements. Nitrate and $Cl^-$ are differentiated by adjusting the flowrate to 1.4 mL/min. Nitrate is analyzed using the 10 μS scale. Chloride is measured separately, using the 30 μS scale. Samples are compared against standard concentrations of 0.14, 0.7, 1.4, and 3.08 mg/L for $NO_3$-N and 1, 3, 5, and 8 for $Cl^-$. Nitrate and $Cl^-$ standards were prepared using 0.1 M $NO_3^-$ stock solution (Orion) and 1000 mg/L $Cl^-$ stock solution (Fisher Scientific).

### 3.4.3 Nitrite Analysis

Nitrite analysis follows the colorimetric method outlined in section 4500-$NO_2^-$ B of Standard Methods (APHA, et al., 1995). Five to 15 mL of the filtrate is diluted to 50 mL, after sample filtration. Portions of the filtrate are used for both $NO_3^-$ and $NO_2^-$ analyses. Therefore, 0.2 μm membrane filters are used rather than 0.45 μm pore size filters specified in the Standard Method. Samples must be filtered with 0.2 μm filters for analysis of $NO_3^-$ using ion chromatography. Development of a reddish purple azo dye occurs upon mixing of $NO_2^-$ with diazotized sulfanilamide (J. T. Baker) and NED dihydrochloride (Fisher Scientific). Photometric measurement of the azo dye is completed using a UV-visible recording spectrophotometer, Shimadzu model UV160U. 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.

### 3.4.4 Total Suspended Solids Analysis

Total suspended solids is analyzed following Section 2540D of Standard Methods (APHA *et al.*1995). A pre-weighed standard glass-fiber filter with 47 mm diameter (Pall Corporation) filters a portion of well-mixed sample. The retained residue dries to a constant weight at 103 to 105°C for 24 hours. The filter and residue are weighed. The the mass of the residue is determined by subtracting the the mass of the pre-weighed filter from the mass of the filter and residue. Weight measurements were determined using a Mettler model AE240 scale with a precision of ± 0.1 mg. Therefore, TSS measurements are limited to 0.1 mg by the scale precision.

### 3.4.5 Total Kjeldahl Nitrogen Analysis

Total Kjeldahl Nitrogen analysis is completed following 4500-$N_{org}$, Macro-Kjeldahl Method (APHA *et al.*1995) in three steps: (1) digestion of 200 mL of sample by evaporation after addition of 50 mL of digestion regent, (2) distillation of digested sample, that is diluted to 300 mL and treated with 50 mL of $NaOH\text{-}Na_2S_2O_3\cdot5H_2O$ reagent, into boric acid indicating solution, and (3) titration of distillate with standard 0.02 N $H_2SO_4$ titrant. The titrant pipette has one mL accuracy and 200 mL of sample is used for TKN analysis. Therefore, the smallest measurable concentration is 0.14 mg/L of $NH_4^+$-N as calculated following the standard method. Determination of ammonia concentration differs from the other pollutants in that $NH_4^+$-N concentrations are not determined against standards of known concentration. Instead calculation of $NH_4^+$-N is based on the reaction between $NH_4^+$-N and $H_2SO_4$ titrant.

### 3.4.6 Cadmium, Copper, Lead, Sodium and Zinc Analyses

Metal analyses are divided into two steps. The first step involves digestion of samples by evaporation of 75 to 100 mL of sample, after addition of 5 mL of concentrated $HNO_3$ (EMD Chemicals OmniTrace Grade or Fisher Scientific Metal Grade for Atomic Absorption). The second step involves analysis of Cd, Cu and Pb on the furnace module of a Perkin Elmer Model 5100PC Atomic Absorption Spectrometer, Standard Method 3110, and Na and Zn on the flame module, Standard Method 3111 (APHA et al., 1995) after filtration and dilution to 100 mL of digested samples. Sodium was determined with the flame module in emission mode. In contrast, Zn was measured while the flame module was in the absorption mode. Cd, Cu and Pb concentrations were determined against two ranges of standard concentrations, due to the wide range of concentrations in the runoff samples. Samples with metal concentrations between 5 and 20 μg/L were determined against three standards in the range between 5 and 20 μg/L. Samples with concentrations greater than 20 μg/L were determined against three standards with concentrations between 20 and 100 μg/L . Zinc concentrations were determined against three standards ranging between 0.1 and 1 mg/L. Standards for Cd, Cu, Pb, and Zn were prepared using 1000 mg/L stock solutions (Pb, VWR Scientific; Cd, Cu, Zn, Fisher Scientific). A 1000 mg/L Na stock solution (VWR Brand) was used to prepare 20, 40 and 60 mg/L standard concentrations. 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.

## 3.5 Quality Assurance/Quality Checks

Field blanks, standard checks and replicate measurements ensure data quality. Field blanks were created by placing two extra 300 mL glass bottles in the automatic sampler at the initiation of monitoring. At the storm ending, the two empty bottles were sealed with caps along with the 24 full sample bottles. The field blanks were filled with deionized water and analyzed for all pollutants as described in Section 2.3 at the lab.

Concentration results for the field blanks are presented in Table 3.2. TP, $NO_2^-$, TKN and Cd were below their detection limits and therefore are insignificant in sample measurements. The field blanks that were collected on July 28, 2003 had slightly higher concentrations for metals than the field blanks collected on August 27,2003 and October 18, 2003. The empty bottles for the field blanks were placed on their sides in the bottom of the sampler. Some liquid collected in the bottles for the July 28, 2003 field blanks, in contrast to the sampling of the other two field blanks. The liquid that collected in the bottles for the July 28, 2003 blanks resulted in the higher concentrations of Cu, Pb, and Zn. Field blank measurements were not taken into consideration in metal sample measurements. A mean TSS concentration of 4.7 mg/L was determined for the two field blanks analyzed for TSS. The mean concentration for the TSS field blank equals approximately 2% of the median TSS value and, therefore, has no significance on sample results.

During analytical determinations, one standard was checked for all components except TKN after analysis of every 10 samples. A new calibration curve was created if the checked standard varied by ±10% of its value. Standard checks were irrelevant for

TKN measurements, because $NH_4^+$-N concentrations are not determined against standards.

Two replicates of each sample were analyzed for $NO_2^-$, TP, Cd, Cu, Na, Pb and Zn. Duplicates are reported as the arithmetic mean. The volume of sample, the cost of materials and reagents, and/or the analysis time period made duplicate replicates of TKN, TSS and $NO_3^-$ impractical. Therefore, only one replicate of each sample was analyzed for TKN, TSS and $NO_3^-$.

Table 3.2. Field blank concentrations

| Date | Cd[a] | Cu[a] | Pb[a] | Zn[b] | TSS[b] | TKN[b] | $NO_3^-$[c] | $NO_2^-$[b] | TP[b] |
|---|---|---|---|---|---|---|---|---|---|
| 7/28/03 | <2[d] | 22 | 15 | 0.81 | 2.8 | <0.14[d] | ND[c] | <0.02[e] | <0.24[e] |
| 8/16/03 | ND[c] | ND[c] | ND[c] | ND[c] | 6.6 | ND[c] | ND[c] | <0.02[e] | <0.24[e] |
| 8/27/03 | <2[d] | 4.3 | 9.9 | 0.13 | ND[c] | 0.42 | ND[c] | ND[c] | ND[c] |
| 9/18/03 | <2[d] | 3.6 | 7.4 | 0.13 | ND[c] | <0.14[d] | ND[c] | <0.02[e] | <0.24[e] |

[a]μg/L [b]mg/L [c]No Data [d]Detection Limit [e]Lowest Standard

### 3.6 Data Handling

Event mean concentrations, annual pollutant loadings and dimensionless normalized mass and volume were calculated to characterize the runoff at the Mt. Rainier site. Data from 33 storm events occurring between June 19, 2002 and October 18, 2003 were used to characterize the runoff at the Mt. Rainier site. These 33 storm events occurred before installation of the bioretention filter and therefore were used to characterize the stormwater runoff from the site before filter installation.

### 3.6.1 Event Mean Concentration

The concentrations of stormwater runoff samples vary by orders of magnitude throughout the storm duration. EMC is a simple index used to represent the pollutant concentrations over the entire storm event. The EMC is defined as follows

$$EMC = L / R = \frac{\int_0^{t_o} C(t)Q(t)dt}{\int_0^{t_o} Q(t)dt} \tag{3.1}$$

where L is the event load for a specific component and R equals the event water volume. Sequential discrete samples were collected for this project. Therefore, the event loadings were calculated by summing the cumulative mass of pollutant. Interval mass loadings were calculated by multiplying the pollutant concentration for the interval (C) by the interval volume, where the interval volume equals the interval flowrate (Q) times the interval duration (dt). Similarly, the event volumes were calculated by summing the cumulative volume over the event.

The number of intervals for each storm event corresponds to the number of samples collected and is between one and 12 intervals for this application. The midpoint of an interval corresponds to the time of sample collection. The interval length equals the time between the collection of two consecutive samples. For example, the interval length equals 20 minutes for two consecutive samples collected at the storm onset and 20 minutes into the event. Hence, the second interval began 20 minutes from the event onset and ended 10 minutes after the second sample was collected (Table 3.3).

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,

Table 3.3. Interval lengths used for data manipulation

| Sample Number | Interval Number | Collection Time | Beginning of Interval | End of Interval |
|---|---|---|---|---|
| 1 | 1 | 0 min | 0 min | 10 min |
| 2 | 2 | 20 min | 10 min | 30 min |
| 3 | 3 | 40 min | 30 min | 50 min |
| 4 | 4 | 1 hr | 50 min | 1 hr 10 min |
| 5 | 5 | 1 hr 20 min | 1 hr 10 min | 1 hr 30 min |
| 6 | 6 | 1 hr 40 min | 1 hr 30 min | 1 hr 50 min |
| 7 | 7 | 2 hr | 1 hr 50 min | 2 hr 10 min |
| 8 | 8 | 2 hr 20 min | 2 hr 10 min | 2 hr 30 min |
| 9 | 9 | 2 hr 40 min | 2 hr 30 min | 3 hr 10 min |
| 10 | 10 | 3 hr 40 min | 3 hr 10 min | 4 hr 10 min |
| 11 | 11 | 4 hr 40 min | 4 hr 10 min | 5 hr 10 min |
| 12 | 12 | 5 hr 40 min | 5 hr 10 min | 6 hr 10 min |

resulting in the volume amount that passed through the flume for each two minute interval (Table 3.4). The interval volume equals the sum of the volumes calculated for each two minute period. The mass is determined by multiplying the interval sample concentration by the volume amount that was determined for each two minute period (Table 3.4). The interval mass equals the sum of the masses calculated for each two minute period during the interval (Table 3.4). As defined in Equation 3.1, the EMC equals the sum of the mass for all intervals divided by the sum of the volume for all intervals, so for the example in Table 3.4, the Pb EMC equaled 69.5 mg/L.

In some instances, a sample concentration fell below the detection limit or the smallest standard concentration. Two EMC values were calculated for these instances. One EMC value was calculated assuming the sample concentration equals zero. The second EMC value was calculated using the detection limit or the smallest sample concentration. Therefore, a range of two EMC values was presented for events with sample concentrations that fell below the detection limit or smallest standard concentration.

### 3.6.2 Annual Pollutant Loadings

Calculation of annual pollutant loadings is important in understanding the impact of pollutants on receiving water bodies. Simply summing the total mass of pollutants contributed by the 25 storms for a one-year period and dividing by the drainage area underestimates the annual pollutant loadings because this method excludes the contribution of mass from un-sampled storms. For this research, annual pollutant

Table 3.4. Example of data manipulation for samples collected May 31, 2003, with lead as pollutant

| Date/Time | Flowrate (L/s) | Volume (L) | Accumulated Volume (L) | Concentration (μg/L) | Loading (g) |
|---|---|---|---|---|---|
| Interval I | | | | | |
| 5/31/03 19:02 | 3 | 360 | 360 | 140 | 0.05 |
| 5/31/03 19:04 | 6 | 720 | 1080 | 140 | 0.10 |
| 5/31/03 19:06 | 5 | 600 | 1680 | 140 | 0.08 |
| 5/31/03 19:08 | 5 | 600 | 2280 | 140 | 0.08 |
| 5/31/03 19:10 | 6 | 720 | 3000 | 140 | 0.10 |
| 5/31/03 19:12 | 23 | 2760 | 5760 | 140 | 0.39 |
| Interval I Sums | | | | | 0.81 |
| Interval II | | | | | |
| 5/31/03 19:14 | 59 | 7080 | 12840 | 63 | 0.45 |
| 5/31/03 19:16 | 108 | 12960 | 25800 | 63 | 0.82 |
| 5/31/03 19:18 | 107 | 12840 | 38640 | 63 | 0.81 |
| 5/31/03 19:20 | 93 | 11160 | 49800 | 63 | 0.70 |
| 5/31/03 19:22 | 63 | 7560 | 57360 | 63 | 0.48 |
| 5/31/03 19:24 | 48 | 5760 | 63120 | 63 | 0.36 |
| 5/31/03 19:26 | 39 | 4680 | 67800 | 63 | 0.29 |
| 5/31/03 19:28 | 28 | 3360 | 71160 | 63 | 0.21 |
| 5/31/03 19:30 | 15 | 1800 | 72960 | 63 | 0.11 |
| 5/31/03 19:32 | 7 | 840 | 73800 | 63 | 0.05 |
| Interval II Sums | | | | | 4.29 |
| Interval III | | | | | |
| 5/31/03 19:34 | 6 | 720 | 74520 | 38 | 0.03 |
| 5/31/03 19:36 | 7 | 840 | 75360 | 38 | 0.03 |
| 5/31/03 19:38 | 8 | 960 | 76320 | 38 | 0.04 |
| 5/31/03 19:40 | 8 | 960 | 77280 | 38 | 0.04 |
| 5/31/03 19:42 | 6 | 720 | 78000 | 38 | 0.03 |
| 5/31/03 19:44 | 5 | 600 | 78600 | 38 | 0.02 |
| 5/31/03 19:46 | 4 | 480 | 79080 | 38 | 0.02 |
| 5/31/03 19:48 | 2 | 240 | 79320 | 38 | 0.01 |
| 5/31/03 19:50 | 1 | 120 | 79440 | 38 | 0.004 |
| Interval III Sums | | | | | 0.21 |
| Event Sums | | | 79440 | | 5.31 |

loadings were calculated using the “simple method” defined by Schueler (1987). The annual pollutant loading is defined as follows

$$L = PP_j R_v (CF) C \tag{3.2}$$

where L equals the normalized annual pollutant load (kg/ha/yr), P equals the annual precipitation (in/yr), $P_j$ equals the dimensionless correction factor that adjusts for storms without runoff, $R_v$ is the dimensionless average runoff coefficient and C is the flow-weighted average concentration (mg/L).

Schueler (1987) determined that approximately 90% of rainfall events in the Washington, DC area produce runoff. Therefore, 0.9 was used for the dimensionless correction factor, $P_j$. An annual precipitation of 44.21 in/yr fell in College Park, MD in 2002 (ERH, 2003). This value was used for the annual precipitation, P, because incomplete rainfall data were recorded by the Weather Station that was installed close to the Mt. Rainier site. In addition, the College Park site specified at the website was the closest site to the Mt. Rainier site with monitored rainfall data. Summing the mass of pollutant contributed, during the 25 storm events and dividing by the total volume of runoff for the 25 events determined the flow-weighted concentration, C.

The dimensionless average runoff coefficient, $R_v$, is an indication of the site response to rainfall events and is calculated as follows

$$R_v = \frac{r}{p} = \frac{Q/A}{p} \tag{3.3}$$

where r equals the inches of storm runoff, p is the inches of rainfall runoff, Q is the runoff flowrate and A is the drainage area. The runoff coefficient can be determined by dividing the runoff volume by the rainfall volume (Wanielista and Yousef, 1993). The runoff volume equals the excess rainfall volume that results on impervious areas or pervious areas that have become saturated. A mean runoff coefficient of 0.95 was determined using data from 5 storm events (Table 3.5). The rainfall volume was determined by multiplying the inches of rainfall for the storm event by the drainage area. The runoff volume equaled the sum of 2-minute incremental flowrate data multiplied by the time increment.

Table 3.5. Runoff volumes and rainfall volumes for 5 storm events used to calculate runoff coefficient

| Date | Rainfall Volume $m^3$ ($ft^3$) | Runoff Volume $m^3$ ($ft^3$) | Runoff Coefficient $R_v$ |
|---|---|---|---|
| 10/25/02 | 1.9 (69) | 1.6 (55) | 0.80 |
| 3/6/03 | 0.30 (11) | 0.25 (10) | 0.94 |
| 3/20/03 | 2.1 (74) | 2.2 (78) | 1.05 |
| 4/7/03 | 1.09 (38) | 1.2 (42) | 1.1 |
| 4/25/03 | 0.42 (15) | 0.37 (13) | 0.88 |
| Mean $R_v$ | | | 0.95 |

The recommended range for the runoff coefficient is between 0.70-0.95 for asphalt or concrete pavement (Wanielista and Yousef, 1993). Therefore, a mean runoff coefficient of 0.95 is a reasonable value for the Mt. Rainier site, because the drainage area consists of asphalt roadway with concrete sidewalks and impervious commercial buildings lining both sides of the roadway. The only pervious area is a small plot for a tree on the east side of the street. The high percent of impervious area and urbanization justify use of the high end of the typical range for asphalt and concrete pavement. The runoff coefficient can vary with rainfall intensity and volume (Wanielista and Yousef, 1993). Therefore, five storms were chosen with high and low intensities and volumes.

### 3.6.3 Normalized Mass and Volume

The accumulated mass and water volume were determined for each interval as the total mass (m(t)) and volume (v(t)) that passed through the system from the storm onset to the interval end as shown for Pb for the August 8, 2002 event (Table 3.6). These values were normalized dividing by the total mass (M) and volume (V) during the entire storm (Equation 3.4). In Equation 3.4, C(t) represents the interval concentration, Q(t) is

$$m'(t) = \frac{m(t)}{M} = \frac{\int_0^t C(t)Q(t)dt}{\int_0^{t_D} C(t)Q(t)dt} \qquad v'(t) = \frac{v(t)}{V} = \frac{\int_0^t C(t)Q(t)dt}{\int_0^{t_D} C(t)Q(t)dt} \tag{3.4}$$

the interval flowrate, dt equals the interval length, and $t_D$ equals the storm duration. The normalized volume and mass represent the fraction of the total volume and mass that passed through the system by the end of the interval.

Plots of the normalized mass versus the normalized volume for each storm event were used to qualitatively determine the absence or occurrence of flushing throughout the storm event. In addition, the normalized mass and volume is used to quantify first flush, using the criteria described by Wanielista and Yousef (1993). By Wanielista and Yousef's definition, first flush occurs when 50% of the total mass passes through the system in the first 25% of the total storm volume. In the absence of first flush, further quantitative analysis of flushing was performed for the remainder of the storm event. Second flush will be defined as an extension of Wanielista and Yousef's criteria. Second flush occurs when 50% of the total mass passes through the system in any 25% portion of the storm volume, excluding the first 25% of the storm volume.

Table 3.6. Example calculation of normalized mass (Pb) and volume for August 3, 2002 storm

| Interval Number | Mass (g) | Cumulative Mass (g) | Normalized Mass | Volume (L) | Cumulative Volume (L) | Normalized Volume |
|---|---|---|---|---|---|---|
| 1 | 4.2 | 4.2 | 0.12 | 3000 | 3000 | 0.02 |
| 2 | 5 | 9.2 | 0.27 | 11640 | 14940 | 0.08 |
| 3 | 5.1 | 14.3 | 0.42 | 15900 | 30840 | 0.17 |
| 4 | 8.6 | 22.9 | 0.67 | 42960 | 73800 | 0.40 |
| 5 | 4.1 | 27 | 0.79 | 17760 | 94560 | 0.50 |
| 6 | 1.5 | 28.5 | 0.84 | 7980 | 99540 | 0.54 |
| 7 | 0.72 | 2902 | 0.86 | 7320 | 106860 | 0.58 |
| 8 | 1.1 | 30.3 | 0.89 | 20880 | 127740 | 0.69 |
| 9 | 1 | 31.3 | 0.92 | 17940 | 145680 | 0.79 |
| 10 | 1.4 | 32.7 | 0.96 | 19320 | 165000 | 0.90 |
| 11 | 1.4 | 34.1 | 1.0 | 19320 | 184320 | 1.0 |

## Chapter 4

## RESULTS and DISCUSSION

### 4.1 General Observations

Thirty-two storm events were sampled from the site at Mt. Rainier, MD between June 2002 and September 2003. Of the nine contaminants analyzed, only $NO_2^-$, Pb, and Cu concentrations were analyzed for all 32 storm events. For the remaining pollutants, $NO_3^-$, TKN, TSS, TP, and Zn, fewer than the total 32 storm events were analyzed for various reasons. The range of concentrations that were determined for Cd, Cu, Pb, Zn, $NO_3^-$, $NO_2^-$, TKN, TP and TSS for samples from all events are presented in Table 4.1, as well as the mean values. The lowest $NO_2^-$ and TP concentrations were not established; concentrations for these two pollutants varied outside the linear range of the standard concentrations during individual storm events. Overall, TSS exhibited the highest concentration out of all contaminants studied with TKN the second highest. Typically, $NO_3^-$ concentrations were greater than $NO_2^-$ concentrations. The mean concentration of $NO_3^-$ is 3.3 times greater than the mean $NO_2^-$ concentration. In addition, Zn concentrations generally exceeded Pb and Cu, which usually surpassed Cd.

In comparing the concentrations of each pollutant to acute and chronic fresh water concentrations or safe drinking water standard concentrations, the pollutant concentrations in the stormwater runoff from Mt. Rainier, MD generally exceed water quality standards. For instance, the mean concentration of Cd, Cu, Pb, and Zn at the Mt. Rainier site was 8, 8, 3, and 11 times the acute toxicity concentrations and 15, 11, 76, and 11 times the chronic toxicity concentrations (DSD, 2003). Nonetheless, the mean $NO_3^-$

Table 4.1. Low, high, and mean measured concentrations for all samples analyzed for the storm events occurring prior to installation of bioretention filter at the Mt. Rainier site

| | $NO_3$-N[a] | $NO_2$-N[a] | TKN[a] | TP[a] | TSS[a] | Cd[b] | Cu[b] | Pb[b] | Zn[a] |
|---|---|---|---|---|---|---|---|---|---|
| No. events w/data | 25 | 32 | 31 | 30 | 30 | 10 | 32 | 32 | 30 |
| Low | <0.14[c] | <0.02[c] | 0.28 | <0.24[c] | 32 | 6.6 | 14 | 6.4 | 0.08 |
| High | 4.3 | 4.6 | 29 | 3.6 | 10000 | 130 | 740 | 2300 | 30 |
| Mean | 0.93 | 0.28 | 3.9 | 0.59 | 405 | 34 | 100 | 190 | 1.3 |

[a]mg/L [b]µg/L [c]Low standard concentration

and $NO_2^-$concentration measured for stormwater runoff from Mt. Rainier, MD fell below the concentration limit for the safe drinking water standards for human health consumption of water (EPA, 2003). Phosphorus standards depend on the ecosystem under consideration and are not given quantitatively in the water quality criteria. In summary, heavy metal concentrations in the stormwater runoff from Mt. Rainier, MD exceeded freshwater toxicity criteria. Cu, Zn, $NO_3^-$ and $NO_2^-$ fell below drinking water standards for human health, in contrast to the mean Cd and Pb concentrations, which exceeded the standards by a factor of 7 and 13 (Table 4.2).

A few problems resulted in the loss of samples for storm events and data from the weather station. In a few instances, gravel became caught in the sampling line. Samples were lost that remained to be collected at the point that the line clogged. In addition, problems arose in securing the pumping line to the sampler base by tightening a screw. If the screw was excessively tightened, the glue for the female end of the screw was loosened, making it impossible to secure the pumping line. In contrast, if the screw was not secure, the liquid detector that is located beneath the pumping line miscalculated the

Table 4.2. Water quality criteria

| Pollutant | Highest Concentration at Mt. Rainier, MD (μg/L) | Fresh Water Aquatic Life[a] | | Human Health[b] Concentration (μg/L) |
|---|---|---|---|---|
| | | Acute (μg/L) | Chronic (μg/L) | |
| Cd | 34 | 4.3 | 2.2 | 5 |
| Cu | 100 | 13 | 9 | 1300 |
| Pb | 190 | 65 | 2.5 | 15 |
| Zn | 1300 | 120 | 120 | 5000 |
| $NO_3^-$ | 980 | --- | --- | 10000 |
| $NO_2^-$ | 280 | --- | --- | 1000 |

[a](DSD, 2003)
[b](EPA, 2003a)

amount of sample that was transferred to the sample bottles. In these instances, only one bottle (280 mL) of sample was collected, which is an inadequate amount of sample to complete analysis of all contaminants. Accumulation of larger sized sediments or large foreign objects such as carpets in the flume bottom also resulted in a loss of storm samples. The metal tubing that measured the water level in the flume with the bubble monitor clogged when large amounts of sediments or foreign objects entered the flume. As a result, the flowrate data were lost, which is needed for the calculation of pollutant loadings.

Personnel at the weather monitoring location shutting down the computer or the WeatherLink software resulted in the loss of weather data in some cases. In addition, some storms were lost, because the storm covered the area at the sampling site, yet did not extend over the weather monitoring location.

## 4.2 Hydrology

Hydrological data is important for two reasons. First, determination of the runoff coefficient for the Mt. Rainier site requires rainfall intensity data. Second, hydrological data are necessary to evaluate the effects of hydrologic parameters on water quality. Any correlations between water quality and hydrologic parameters may be used as predictors for future storm events. Table 4.3 presents the total runoff volume, storm duration, storm intensity, maximum intensity for each storm event, rainfall depth and the antecedent dry period for the 32 sampled storm events. The hydrological data are incomplete for a portion of the storm events, as a result of reasons discussed above. Complete hydrological data are available for 17 storm events out of a total 32 storm events. For the March 20, 2003, April 7, 2003 and May 16, 2003 storm events, the actual storm duration is longer than the 6-hour sampling period. In these instances, hydrological data are presented for both the 6-hour sampling period and the entire storm duration. Based on the available hydrology data, stormwater runoff volume, storm duration, storm intensity, maximum storm intensity, and antecedent dry period ranged between 2800 and 537,000 L, 20 and 840 minutes, 0.046 and 1.1 cm/hr (0.018 and 0.42 in/hr), 7.0 cm/hr (2.8 in/hr), and 19 hours and 192 hours, respectively.

Runoff flowrate is directly proportional to the rainfall intensity by the drainage area and runoff coefficient, which are both constants, as in Equation 3.3. Thus, a plot of runoff flowrate versus rainfall intensity should be linearly related by an amount equal to the product of the runoff coefficient and drainage area. The linear relationship between runoff flowrate and rainfall intensity is apparent for the November 5, 2002 storm event (Figure 4.1) and so increases in runoff flowrate are directly proportional to

Table 4.3. Hydrology data for Mt. Rainier storm events sampled before LID installation

| Date | Runoff Volume (L) | Storm Duration (min) | Storm Intensity (cm/hr) | Maximum Storm Intensity (cm/hr) | Rainfall Depth (cm) | Antecedent Dry Period (hours) |
|---|---|---|---|---|---|---|
| 6/19/02 | 30743 | 180 | ND[a] | ND[a] | ND[a] | ND[a] |
| 6/27/02 | 102000 | 180 | ND[a] | ND[a] | ND[a] | ND[a] |
| 7/26/02 | 43000 | 380 | ND[a] | ND[a] | ND[a] | ND[a] |
| 8/3/02 | 184300 | 380 | ND[a] | ND[a] | ND[a] | ND[a] |
| 9/14/02 | 7800 | 20 | ND[a] | ND[a] | ND[a] | ND[a] |
| 9/15/02 | 16100 | 20 | ND[a] | ND[a] | ND[a] | ND[a] |
| 9/26/02 AM | 54600 | 220 | ND[a] | ND[a] | ND[a] | ND[a] |
| 9/26/02 PM | 25000 | 200 | ND[a] | ND[a] | ND[a] | ND[a] |
| 10/10/02 | 49500 | 320 | ND[a] | ND[a] | ND[a] | ND[a] |
| 10/10/02 | 2800 | 90 | ND[a] | ND[a] | ND[a] | ND[a] |
| 10/25/02 | 94800 | 320 | 0.40 | 0.61 | 2.1 | 192 |
| 11/5/02 | 111000 | 300 | 0.27 | 1.2 | 1.4 | 136 |
| 11/11/02 | 88000 | 320 | ND[a] | ND[a] | ND[a] | ND[a] |
| 12/11/02 | 134000 | 320 | 0.18 | 2.4 | 0.97 | 36 |
| 12/20/02 | 89000 | 260 | 0.24 | 2.4 | 1.1 | 149 |
| 1/1/03 | 287000 | 380 | 0.30 | 1.2 | 1.6 | 136 |
| 2/4/03 | 23800 | 120 | ND[a] | ND[a] | ND[a] | ND[a] |
| 2/21/03 | 4440 | 60 | 0.05 | 0.05 | 0.05 | 58 |
| 3/6/03 | 17300 | 320 | 0.09 | 0.30 | 0.51 | 19 |
| 3/20/03 | 134040 | 380[b]<br>756 | 0.37[b]<br>0.30 | 0.61[b]<br>0.06 | 2.3[b]<br>3.9 | 156 |
| 4/7/03 | 73320 | 380[b]<br>840 | 0.20[b]<br>0.11 | 0.46[b]<br>0.46 | 1.3[b]<br>1.6 | 181 |
| 4/25/03 | 22440 | 270 | 0.11 | 0.15 | 0.46 | 165 |
| 5/10/03 | 38040 | 140 | 0.17 | 0.30 | 0.38 | 21 |
| 5/16/03 | 537120 | 380[b]<br>460 | 0.59[b]<br>0.52 | 2.1[b]<br>2.1 | 3.7[b]<br>4.0 | 117 |
| 5/31/03 | 79400 | 60 | 1.1 | 1.8 | 1.1 | 79 |
| 6/9/03 | 104000 | 260 | 0.12 | 0.61 | 0.51 | 32 |
| 8/1/03 | 27400 | 60 | ND[a] | ND[a] | ND[a] | ND[a] |
| 8/5/03 | 4680 | 40 | ND[a] | ND[a] | ND[a] | ND[a] |
| 8/16/03 | 23800 | 40 | 0.46 | 1.5 | 0.28 | 120 |
| 8/27/03 | 161800 | 100 | 0.91 | 7.0 | 1.4 | 25 |
| 9/12/03 | 102000 | 300 | 0.34 | 0.91 | 0.99 | 192 |
| 9/18/03 | 86000 | 180 | ND[a] | ND[a] | ND[a] | ND[a] |

[a] ND=No Data

[b] Values for sampling duration

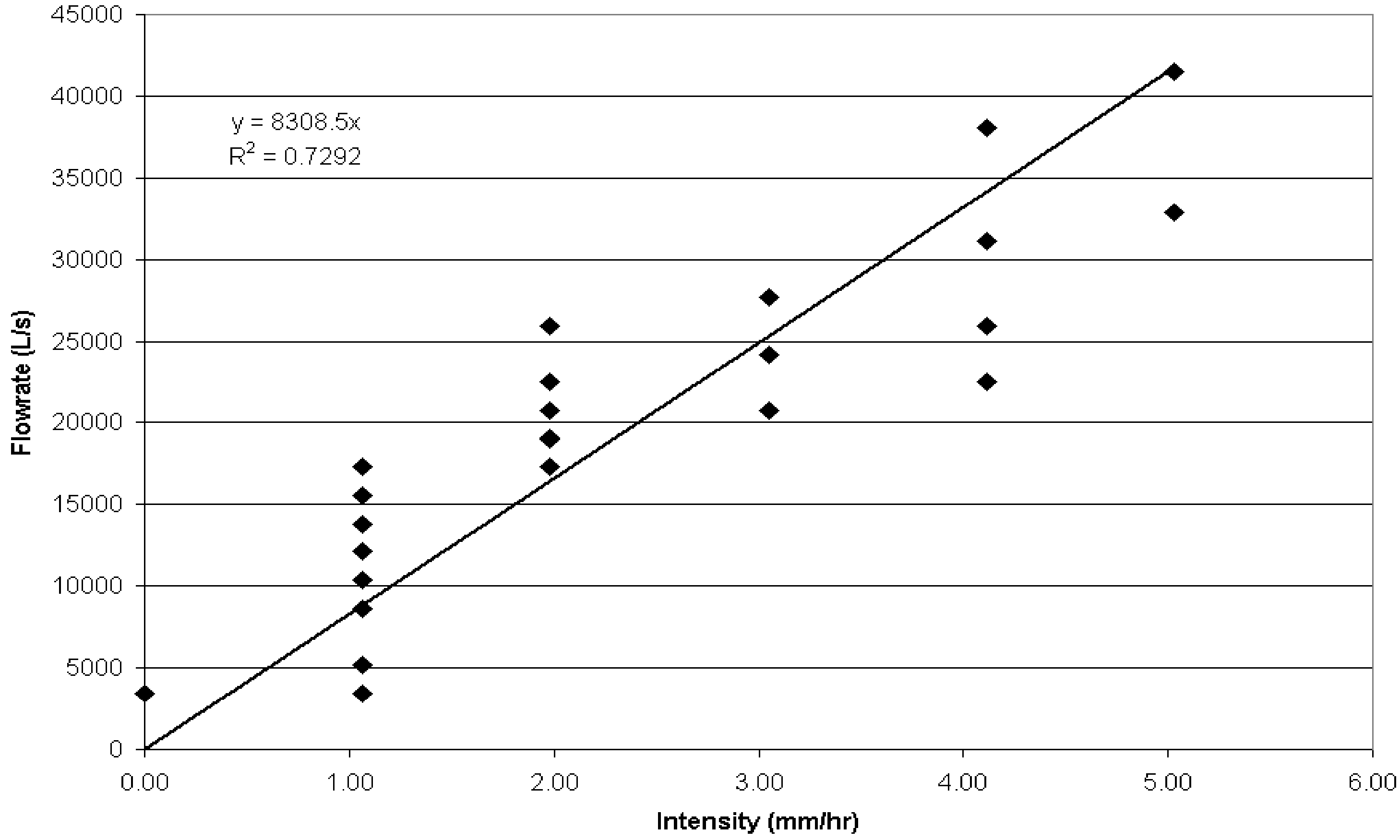


Figure 4.1. Flowrate versus rainfall intensity for November 6, 2003 Mt. Rainier storm event

increases in rainfall intensity. In Figure 4.2, the rainfall intensity and flowrate data for the November 5, 2002 storm event are plotted as a function of time. Each time the rainfall intensity increases, there is a corresponding increase in flowrate.

A final parameter, rainfall depth, is used as an indicator of storm size. The maximum and minimum rainfall depths recorded for the 17 storm events with complete hydrologic data are 4.01 cm (1.58 in) and 0.05 cm (0.02 in). For comparison purposes, a probability plot of rainfall depth was created to determine significant percentiles. Probability plots are created by ranking the observed values (in this case rainfall depth) from smallest to largest. Each value is assigned a rank from 1 to the total number of observed values. The plotting position for each value on the probability scale is determined as follows,

$$p = \frac{i}{(n+1)} \qquad \text{Eq. 4.1}$$

where $p$ equals the probability, $i$ is the ranking number and $n$ is the total number of observations. As an example, the rainfall depth, rank, and plotting position appear for available data in Table 4.4. Figure 4.3 plots the empirical probability versus the rainfall depth for each storm event. The tick marks on the probability scale are not uniform, but arranged to match the distance between the quantiles of a normal distribution. As a result, a linear distribution curve on the probability plot corresponds to a normally distributed data set. In Figure 4.3, the distribution curve is not linear, which means that the data set for rainfall depth is not normally distributed. Therefore, the probability plot can be used to determine the median value that is denoted by the 50th percentile and any other significant percentile (Berthouex and Brown, 1984).

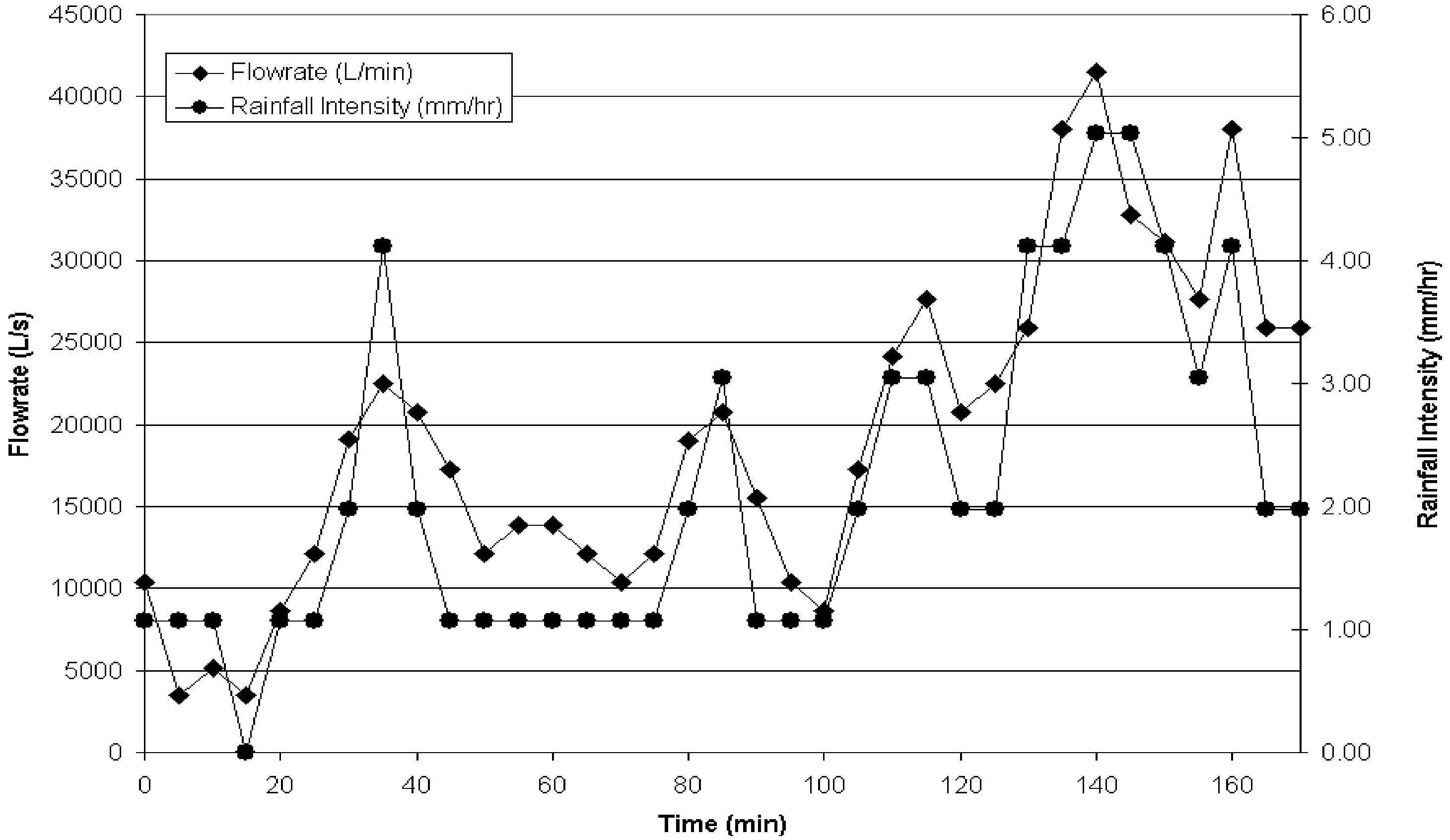


Figure 4.2. Rainfall intensity and flowrate for November 5, 2003 Mt. Rainier storm event

Table 4.4. Data for probability plot of rainfall depth

| Rank | Date | Plotting Position | Rainfall Depth cm (in) |
|---|---|---|---|
| 1 | 2/21/03 | 0.06 | 0.05 (0.02) |
| 2 | 8/16/03 | 0.11 | 0.28 (0.11) |
| 3 | 5/10/03 | 0.17 | 0.38 (0.15) |
| 4 | 4/25/03 | 0.22 | 0.46 (0.18) |
| 5 | 3/6/03 | 0.28 | 0.51 (0.2) |
| 6 | 6/9/03 | 0.33 | 0.51 (0.2) |
| 7 | 12/11/02 | 0.39 | 0.97 (0.38) |
| 8 | 9/12/03 | 0.44 | 0.99 (0.39) |
| 9 | 12/20/02 | 0.50 | 1.1 (0.42) |
| 10 | 5/31/03 | 0.56 | 1.1 (0.42) |
| 11 | 11/5/02 | 0.61 | 1.4 (0.55) |
| 12 | 8/27/03 | 0.67 | 1.4 (0.56) |
| 13 | 4/7/03 | 0.72 | 1.6 (0.62) |
| 14 | 1/1/03 | 0.78 | 1.6 (0.63) |
| 15 | 10/25/02 | 0.83 | 2.1 (0.84) |
| 16 | 3/20/03 | 0.89 | 3.9 (1.52) |
| 17 | 5/16/03 | 0.94 | 4.0 (1.58) |

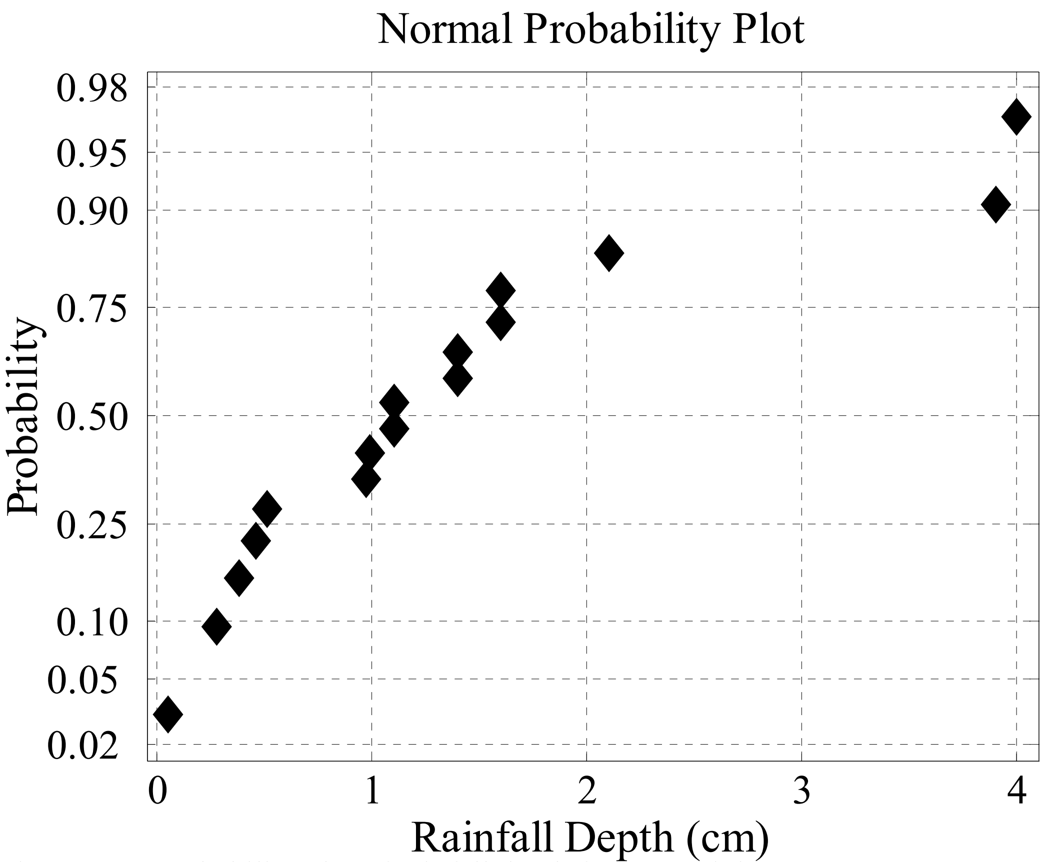


Figure 4.3. Probability plot of rainfall depth for Mt. Rainier storm events

Traditionally, probability plots of flowrate, constituent concentrations, and mass load are created to evaluate design parameters (Metcalf and Eddy, 2003). In this application, the probability plots were used to estimate significant percentiles for comparison purposes. Based on the available data, the median rainfall depth is 1.1 cm (0.43 in) at the Mt. Rainier site. In addition, the rainfall depth will be less than or equal to approximately 3.3 cm (1.3 in) at the Mt. Rainier site on average, 90% of the time.

The storm duration and rainfall depth of the events that were used to determine the median rainfall depth were compared to the storm characteristics for 15 stations in Maryland. Table 4.5 shows the frequency of storm events at Mt. Rainier, MD for various rainfall depths. 5.8% of the storm events at Mt. Rainier, MD were less than 2.54 mm,

Table 4.5. Frequency of storm events for Mt. Rainier, MD and 15 stations in MD

| Event Duration | Rainfall Depth (mm) | | | | | Total | |
|---|---|---|---|---|---|---|---|
| | <2.54 | 2.54 to 6.35 | 6.35 to 12.7 | 12.7 to 25.4 | > 25.4 | Mt. Rainier, MD | 15 Stations in MD |
| 1 hr | 0.0588 | 0.0588 | 0.0588 | | | 0.1764 | 0.3290 |
| 2 hr | | 0.0588 | | 0.0588 | | 0.1176 | 0.0756 |
| 3 hr | | | | | | 0.0 | 0.0627 |
| 4-6 hr | | 0.1765 | 0.1765 | 0.1176 | | 0.4706 | 0.1234 |
| 7-12 hr | | | | 0.0588 | 0.0588 | 0.1176 | 0.1818 |
| 13-24 hr | | | | 0.0588 | 0.0588 | 0.1176 | 0.1616 |
| Total: Mt. Rainier, MD | 0.0588 | 0.2941 | 0.2353 | 0.2940 | 0.1176 | 1.0 | 1.0 |
| Total: 15 Stations in MD[a] | 0.3288 | 0.1461 | 0.2131 | 0.1747 | 0.1373 | 1.0 | |

[a](Kreeb, 2003)

whereas 33% of the storm events analyzed for 15 stations in Maryland were less than 2.54 mm. The number of storms with rainfall depth less than 2.54 mm may be underrepresented by the data sets for Mt. Rainier, MD. In addition, the frequency of storm events in the 2.54 to 6.35 mm and 12.7 to 25.4 mm ranges at the Mt. Rainier site were higher in comparison to the frequency of storms for the 15 stations sampled in Maryland. Finally, the frequency of storm events at Mt. Rainier, MD in the 6.35 to 12.7 mm range and that were greater than 25.4 mm were similar to the frequency for the 15 stations sampled in Maryland. For the purpose of this study, which involves analyzing concentration changes through event duration, the frequency of storms represented for rainfall depths greater than 2.54 mm at Mt. Rainier, MD is adequate in comparison to the 15 stations sampled in Maryland.

### 4.3 Event Mean Concentration

EMC's were calculated for each storm event monitored at the Mt. Rainier site. The EMC results for the 2002 and 2003 storm events are presented in Tables 4.6a and 4.6b. In addition, the range, median, and mean values of the EMC's for all sampled events are presented in Table 4.6b. Overall, the median, mean and range of the EMC's that were determined for samples from the Mt. Rainier site exceeded values found in other studies (Table 4.7). TSS, TP, TKN, and Cd median and mean EMC values at the Mt. Rainier siter were greater than the values found in stormwater runoff from other urban and rural highways. TSS and Cd EMC values were between 2.4 to 8.6 and 9 to 350 times greater than the values determined for other sites. The difference between TP and TKN was not as great as for TSS and Cd. TP and TKN were 1.1 to 1.4 and 1.5 to 2.9 times greater than at other sites. In addition, EMC's for Cu, Pb, and Zn at Mt. Rainier were higher than those determined for runoff from rural highways, yet the EMC's were comparable to values determined for urban highway runoff from other sites. Exceptions for this overall trend were mainly for nitrogen in the forms of $NO_3^-$ and $NO_2^-$, which were comparable to values found in runoff from urban and rural sites in other studies.

Stotz and Krauth (1994) determined the average EMC of $NO_3^-$ and $NO_2^-$ for the winter and summer season for a porous section of the Weinsberg Exchange in Baden-Wurttemberg, Germany. The average EMC's were 3.11 mg/L and 0.29 mg/L for $NO_3^-$-N and $NO_2^-$-N in winter and 0.85 mg/L and 0.14 mg/L for $NO_3^-$-N and $NO_2^-$-N in summer. The combined mean EMC for $NO_{3+2}^-$-N of 0.96 mg/L at the Mt. Rainier site falls between the winter and summer values found for $NO_3^-$-N alone at the Weinsberg Exchange. In addition, Wu et al. (1998) determined the mean value of $NO_{3+2}^-$-N for all

Table 4.6a. Event mean concentration of pollutants for storm events occurring in 2002 at Mt. Rainier, MD site

| | Pollutant (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|
| Date | Cu | Pb | Zn | TSS | TKN | $NO_{3+2}^{-}$-N | TP |
| 6/19/02 | 0.10 | 0.015 | ND | 70 | 2.3 | 1.4 | 0.55 |
| 6/27/02 | 0.065 | 0.026 | ND | 170 | 2.7 | 0.67 | 0.48 |
| 7/26/03 | 0.13 | 0.23 | 0.99 | 1600 | 1.9 | 4.22[b] | 0.2 |
| 8/3/02 | 0.19 | 0.19 | 2.1 | 760 | 3.7 | 0.85-1.18 | ND[a] |
| 9/14/02 | 0.10 | 0.12 | 1.1 | 410 | 10 | 0-0.16 | 1.9 |
| 9/15/02 | 0.093 | 0.10 | 0.75 | 530 | 7.5 | 0.030-0.17 | 0.81 |
| 9/26/02 AM | 0.085 | 0.10 | 0.95 | 86 | 2.9 | 0.60 | 0.61 |
| 9/26/02 PM | 0.024 | 0.044 | 0.18 | 41 | 1.1 | 0.28-0.32 | 0.032-0.23 |
| 10/10/02 AM | 0.11 | 0.088 | 0.66 | 210 | 6.2 | 1.4 | 0.03 |
| 10/10/02 PM | 0.050 | 0.043 | 0.36 | 430 | 2.9 | 0.62 | 0.43 |
| 10/25/02 | 0.059 | 0.10 | 0.42 | 75 | 1.2 | 0.34-0.35 | 0.11-0.31 |
| 11/5/02 | 0.074 | 0.081 | 0.88 | 115 | 2.5 | 0.49 | 0.54-0.61 |
| 11/11/02 | 0.057 | 0.058 | 0.36 | 85 | 2.5 | 0.45 | 0.46 |
| 12/11/02 | 0.032 | 0.028 | 0.89 | 120 | 2.2 | 0.35[b] | ND[a] |
| 12/20/02 | 0.14 | 0.033 | 1.29 | 590 | 2.5 | 0.028[b] | 0.38-0.41 |

[a] ND=No Data

[b] Based on $NO_2^-$ only

Table 4.6b. Event mean concentration of pollutants from storm events occurring in 2003 at Mt. Rainier, MD

| Date | Pollutant (mg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cd | Cu | Pb | Zn | TSS | TKN | NO$_{3+2}^-$-N | TP |
| 1/1/03 | ND[a] | 0.075 | 0.075 | 0.59 | 120 | 1.2 | 4.32-4.33 | 0.18-0.32 |
| 2/3/03 | ND[a] | 0.29 | 1.22 | 6.03 | 800 | 4.6 | 0.92 | 0.86 |
| 2/21/03 | ND[a] | 0.18 | 0.30 | 2.01 | 840 | 2.2 | 0.82 | 0.45 |
| 3/6/03 | ND[a] | 0.18 | 0.38 | 1.9 | 1300 | 5.9 | 2.38 | 1.12 |
| 3/20/03 | ND[a] | 0.072 | 0.13 | 0.64 | 738 | 1.6 | 0.45 | 0.85 |
| 4/6/03 | ND[a] | 0.087 | 0.73 | 1.50 | 185 | 2.2 | 0.46 | 0.13-0.31 |
| 4/24/03 | ND[a] | 0.10 | 0.16 | 1.12 | 830 | 6.3 | 0.70 | 0.74-0.77 |
| 5/10/03 | 0.093 | 0.10 | 0.12 | 0.71 | 190 | 2.9 | 0.69 | 0.24-0.30 |
| 5/16/03 | 0.017 | 0.047 | 0.059 | 0.37 | 180 | 2.2 | 0.47-0.48 | 0.32-0.38 |
| 5/31/03 | 0.016 | 0.054 | 0.067 | 0.55 | 230 | 0.8 | 1.33 | 0.31-0.33 |
| 6/9/03 | 0.018 | 0.061 | 0.040 | 0.41 | ND[a] | ND[a] | 0.22-0.25 | 0.2-0.32 |
| 8/1/03 | 0.047 | 0.22 | 0.25 | 2.07 | 410 | 3.4 | 0.79-0.80 | 1.26 |
| 8/5/03 | 0.013 | 0.10 | 0.047 | 0.51 | ND[a] | 1.9 | 2.84 | 0.58 |
| 8/15/03 | 0.040 | 0.28 | 0.75 | 2.59 | 430 | 8.7 | 0.088-0.10[b] | 0.76 |
| 8/27/03 | 0.026 | 0.15 | 0.65 | 0.69 | 420 | 3.7 | 0.049[b] | 0.74-0.85 |
| 9/12/03 | 0.017 | 0.081 | 0.17 | 0.71 | 360 | 1.4 | 0.031[b] | 0.21-0.29 |
| 9/18/03 | 0.063 | 0.075 | 0.73 | 2.13 | 400 | 4.9 | 0.024-0.038[b] | 0.21-0.27 |
| No. of Events | 10 | 32 | 32 | 32 | 30 | 31 | 32 | 30 |
| Range | 0.013-0.093 | 0.024-0.29 | 0.015-1.22 | 0.18-6.03 | 41-1600 | 0.8-10 | 0-4.33 | 0.032-1.9 |
| Median | 0.022 | 0.089 | 0.1 | 0.88 | 400 | 2.5 | 0.67 | 0.46 |
| Mean | 0.035 | 0.11 | 0.22 | 1.18 | 420 | 3.4 | 0.96 | 0.56 |

[a] ND=No Data

[b] Based on NO$_2^-$ only

Table 4.7. EMC data for studies concerning highway stormwater runoff

| Reference | Site | Area ($m^2$) | ADT[f] | Land Use | TSS[d] | Cd[e] | Cu[e] | Pb[e] | Zn[e] | $NO_3$-N[d] | $NO_2$-N[d] | TKN[d] | TP[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deletic & Maksimovic (1998)[a] | Miljak., Sweden | 211 | 435 | Resid/ Commer. | 96-673 | | | | | | | | |
| | Lund, Sweden | 270 | 15-20 | Carpark | 5-417 | | | | | | | | |
| Stotz & Krauth (1994)[b] | Weins., FRG | 550 | 34675 | | 64 | 0.9 | 49 | 137 | 441 | 0.85 | 0.14 | | |
| | | | | | 49 | 2.5 | 88 | 58 | 737 | 3.11 | 0.29 | | |
| Legret & Pagotto (1999)[b] | Nantes, France | 3200 | 12000 | Bypass, Rural | 77 | 1 | 45 | 58 | 356 | | | 2.3 | |
| Wu et al. (1998)[b] | HB, NC | 1497 | 25000 | Rural/Res. | 283 | | 24.2 | 21.0 | | 2.25 | | 1.42 | 0.43 |
| | NC49, NC | 2307 | 21500 | Rural/Res. | 93 | | 11.5 | 13.9 | | 0.22 | | 1.18 | 0.52 |
| | I85, NC | 4452 | 5500 | Rural/Res. | 30 | | 4.6 | 6.5 | | 0.14 | | 1.00 | 0.47 |
| Barrett et al. (1998)[c] | W35, TX | 5341 | 58150 | Com./Res. | 129 | | 37 | 53 | 222 | 1.07 | | | 0.33 |
| | CH, TX | 526 | 8780 | Rural/Res. | 91 | | 7 | 15 | 44 | 0.71 | | | 0.11 |
| | WC, TX | 104600 | 47240 | Com./Res. | 19 | | 12 | 3 | 24 | 0.37 | | | 0.10 |
| Stotz (1987) | A81, FRG | 13000 | 41000 | Rural | 137 | 5.9 | 97 | 202 | 360 | | | | 0.25 |
| | A6, FRG | 25200 | 47000 | Rural | 181 | 5.9 | 117 | 245 | 620 | | | | 0.35 |
| | A8, FRG | 250000 | 52100 | Rural | 252 | 2.8 | 58 | 163 | 320 | | | | 0.31 |
| Sansalone & Buchberger (1997)[a] | Millcreek, Ohio | 300 | 150000 | Urban | | 5-11 | 43-325 | 37-97 | 459-15244 | | | | |

[a] EMC range [b] Mean of EMC [c] Median EMC [d] Units in mg/L [e] Units in µg/L [f] Units in vehicles/day

storm events to be 2.25 mg/L for W.T. Harris Blvd. in North Carolina. This value is greater than the mean EMC of 0.96 mg/L that was determined for the Mt. Rainier site. Two additional studies found median concentrations for $NO_{3+2}^{-}$-N that were comparable to or higher than the median value of 0.67 mg/L for the Mt. Rainier site. The median value for $NO_{3+2}^{-}$-N was 0.68 mg/L for the Nationwide Urban Runoff Program (NURP) (Athayde, 1983). Also, the median EMC value for $NO_3^-$ alone was 1.07 for Convict Hill Rd. in Austin, Texas (Barrett et al., 1998), which is greater than the median EMC for $NO_3^-$-N and $NO_2^-$-N combined at the Mt. Rainier site.

Another exception to the trend of higher EMC's at the Mt. Rainier site involved heavy metals. The median EMC for Cu, Pb, and Zn at Mt. Rainier was 0.09 mg/L, 0.1 mg/L, and 0.88 mg/L, respectively. These values are comparable to the values determined by the NURP (Athayde, 1983) for the 90th percentile urban site. NURP determined the median values of Cu, Pb, and Zn to be 0.09 mg/L, 0.35 mg/L, and 0.5 mg/L, respectively (Athayde, 1983). The EMC values ranged between 0.04 and 0.33 mg/L for Cu, 0.03 and 0.1 mg/L for Pb, and 0.46 and 15 mg/L for Zn at Millcreek Expressway in Cincinnati, Ohio (Sansalone and Buchberger, 1997). The EMC ranges found at the Millcreek Expressway are comparable to Mt. Rainier, where the EMC values ranged between 0.02 and 0.29 mg/L for Cu, 0.01 and 1.22 mg/L for Pb, and 0.18 and 6.03 mg/L for Zn.

The extent of imperviousness of the drainage area and the surrounding area contributes to the magnitude of the EMC's. Wu et al. (1998) studied two sites in Charlotte, North Carolina where one site was 100% impervious with an ADT of 25,000 and the second site was 61% impervious with and ADT of 21,500. Wu et al. (1998)

found that the mean EMC's were higher for TSS, $NH_3$-N, and TKN at the site with a greater degree of imperviousness. Barrett et al. (1998) found similar findings for two sites in Austin, Texas. One site had an impervious area of 83% with an ADT of 58,150. The second site contained an impervious area of 40% and an ADT of 47,240. Barrett et al. (1998) found that the median EMC's for TSS, $NO_3^-$-N, TP, Cu, Pb, and Zn were greater at the site with a greater extent of imperviousness. As determined in Section 3.6.2, the Mt. Rainier site is 95% impervious. The high degree of imperviousness at the Mt. Rainier site is one factor that contributes to the generally higher EMC's.

In addition, the area surrounding the drainage area at the Mt. Rainier site differs from the majority of sites studied recently. Mt. Rainier is a highly urbanized area in comparison to the sites studied by Wu et al. (1998) and Barrett et al. (1998), which are highways located in rural areas. For instance, the area lining the east side of the drainage area for the Mt. Rainier site consists of impervious rooftops and sidewalks, as does the west side in addition to asphalt driveways and some pervious vegetative area. In contrast, the site that was studied by Wu et al. (1998) consisted of a 69% wooded surrounding area and the sites that were studied by Barret et al. (1998) consisted of a grassed surrounding area. It may be possible that transboundary inflow of contaminants from the impervious area surrounding the Mt. Rainier site contributes to higher EMC's. The percent of pervious area that can act as a sink for contaminants is limited at the Mt. Rainier site in comparison to the rural sites. Deletic and Maksimovic (1998) found that transboundary inflow of sediments from nearby grassed catchments did not exist at the Miljakovac site in Belgrade, Yugoslavia. Although transboundary inflow was not exhibited from a pervious grassed area, transboundary inflow from impervious surfaces may occur as a result of different parameters that do not influence movement of sediments from pervious areas.

Differences in the sources of contaminants may also contribute to the higher EMC's at the Mt. Rainier site. Wear of tires and brake pads are a source of Cd, Cu, Pb, and Zn (Makepeace et al., 1995) and contribute to the deposition of metal contaminants at both rural and urban highways. Another source of Cd, Cu, and Zn is corrosion of buildings and metals (Makepeace et al., 1995). Corrosion of buildings is an additional source of heavy metals in urban areas, in contrast to some rural highways, which can be predominantly surrounded by vegetation. In addition, dustfall has been found to contribute greater amounts of pollutants in urban areas than in rural areas (Gupta et al., 1981).

## 4.4 Concentration Profiles

As mentioned previously, the EMC is a simple index that represents the pollutant concentration over the entire storm event. Due to the order of magnitude variation in pollutant concentration that may occur during a storm event, the EMC does not completely characterize a storm event. In addition to calculating EMC's, concentration profiles were created in order to characterize each storm event in more detail. Using the concentration profiles, correlations were identified between storm characteristics and pollutant concentrations as well as correlations between various contaminants.

Concentration profiles were plotted as a function of storm duration for 24 storm events. Figures 4.4 and 4.5 are examples of the concentration profiles for the May 10, 2003 event. Zn, TKN, TP, $NO_3^-$, and $NO_2^-$ are plotted on one profile in Figure 4.4 and

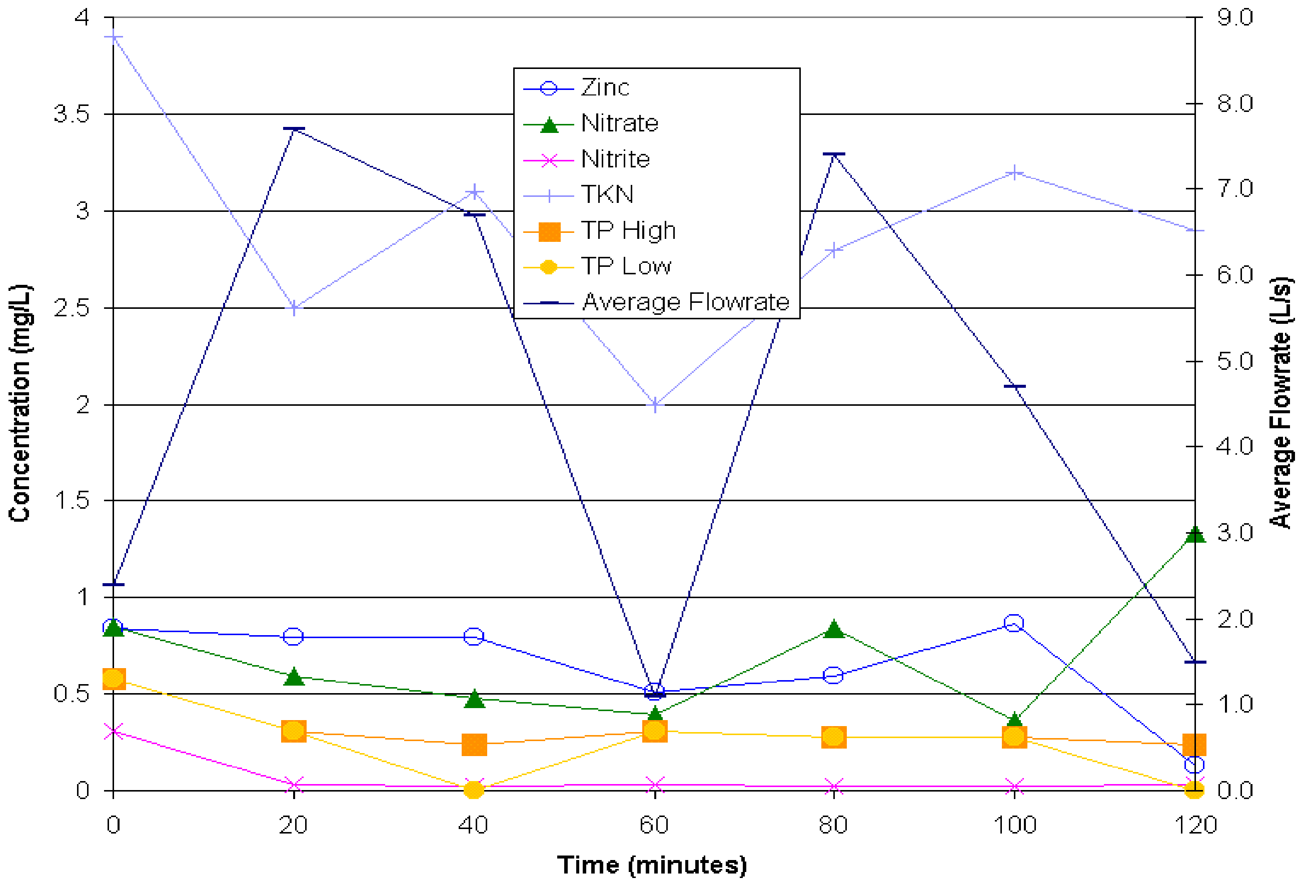


Figure 4.4. Concentration profile for TKN, $NO_3^-$, $NO_2^-$, TP, and Zn for May 10, 2003 Mt. Rainier storm event

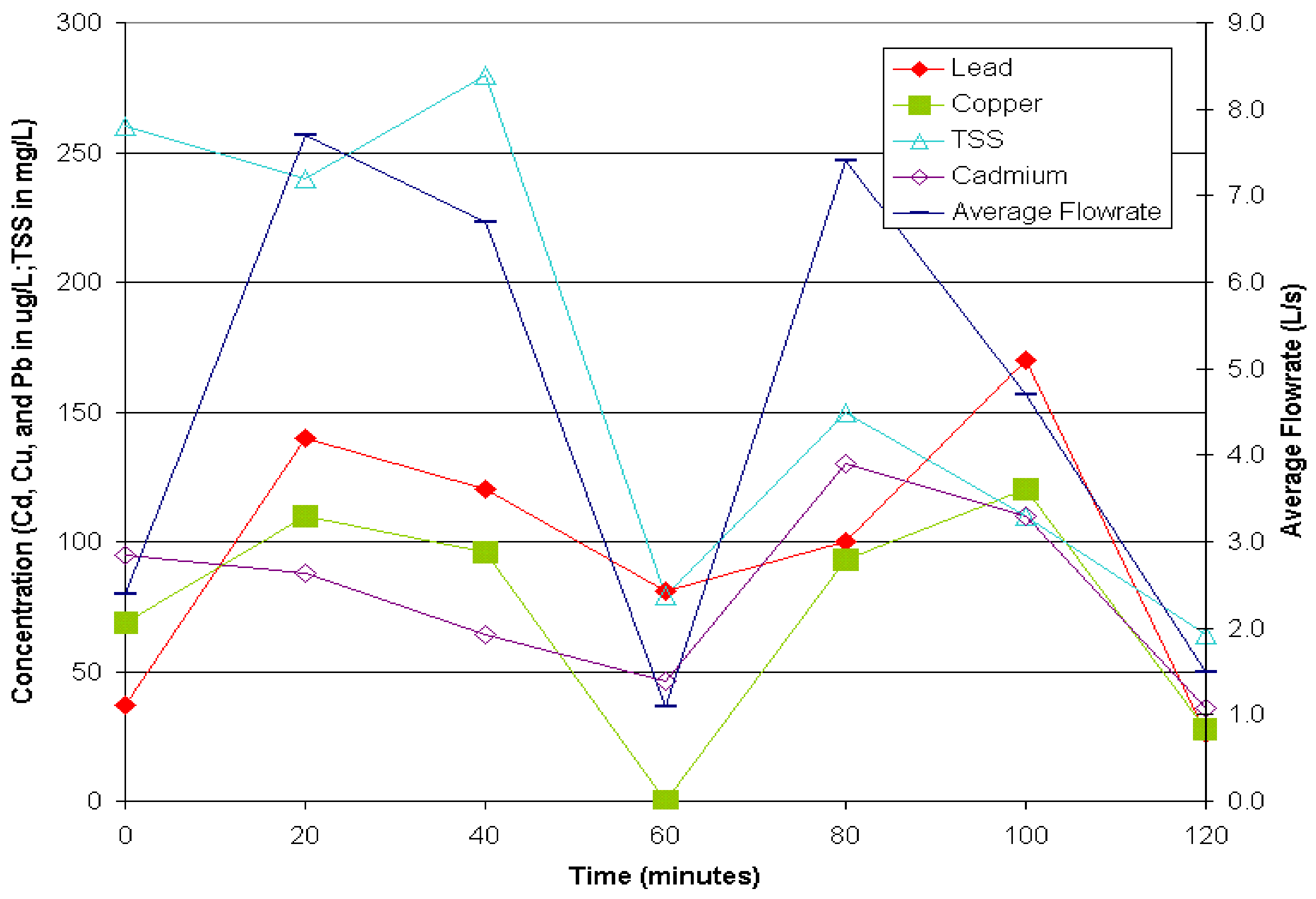


Figure 4.5. Concentration profile for Cd, Cu, Pb, and TSS for May 10, 2003 Mt. Rainier storm event

Cd, Cu, Pb, and TSS are plotted on a second profile (Figure 4.5), due to the variation in the scales. Also, the average flowrate for each interval was also plotted on the secondary y-axis of both concentration profiles to establish any correlation between rainfall intensity and concentration.

Overall, the correlation of pollutant concentrations with flowrate peaks was another predominant phenomenon. For example, peaks in Cd, Cu, Pb, and TSS concentration occurred at 20 and 80 minutes from the storm onset during the May 10, 2003 storm event. These peaks corresponded to the same points as the two flowrate peaks (Figure 4.5). As noted above, an increase in runoff flowrate is a result of an increase in rainfall intensity. A concentration peak that correlates with a peak in runoff flowrate correlates with rainfall intensity. In addition, $NO_3^-$ and Zn concentrations peaked at 80 minutes and at 100 minutes. Similarly, TKN had a concentration peak at 100 minutes in addition to a second concentration peak that occurred 30 minutes into the storm. In contrast to Cd, Cu, Pb, TSS and $NO_3^-$, the concentration peaks in TKN and Zn lagged the flowrate peaks. Overall, concentration peaks correlated with the flowrate peaks, although in some instances concentration peaks lagged or preceded the flowrate peaks. Table 4.8 quantifies the incidences that the concentration peaks preceded, correlated or lagged the flowrate peak.

The concentration profiles demonstrated 13 incidences for Pb and 12 incidences for TSS in which their concentration profiles followed the flowrate profiles. Sansalone et al. (1998) also documented the dependence of TSS on rainfall intensity, in which TSS profiles followed the intensity profiles. In addition, Pb concentration profiles have been

Table 4.8. Concentration peaks occurring during 24 storm events at Mt. Rainier, MD

| Number of Incidence | Cd[a] | Cu | Pb | Zn | TSS | TKN | $NO_3^-$ | $NO_2^-$ | TP |
|---|---|---|---|---|---|---|---|---|---|
| Precede | 1 | 1 | 3 | 1 | 3 | 5 | 1 | 1 | 1 |
| Correlate | 1 | 14 | 13 | 12 | 12 | 5 | 4 | 2 | 4 |
| Lag | 0 | 0 | 1 | 0 | 3 | 2 | 1 | 0 | 0 |
| Total | 2 | 15 | 17 | 13 | 18 | 12 | 6 | 3 | 5 |

[a] Based on 6 storm events

found to largely follow TSS profiles (Morrison et al., 1984; Hoffman et al., 1985; Hewitt and Rashed, 1992), due to the predominant association of Pb with particulate fractions (Morrison et al., 1984; Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997).

In contrast to Pb, partitioning of Cd, Cu, and Zn in stormwater runoff varied among the other studies. Cd, Cu, and Zn were found predominantly in the dissolved phase (Sansalone and Buchberger, 1997), equally distributed between the dissolved and particulate phases (Morrison et al., 1984; Harrison and Wilson, 1985), and Cu has been found predominantly particulate-bound (Hewitt and Rashed, 1992). In 14 incidences the concentration profile of Cu mirrored flowrate profiles, at the Mt.Rainier site (Table 4.6). The number of occurrences in which Cu profiles correlated with flowrate profiles is greater than Pb by one incidence. In addition to Cu, Zn also exhibited a high number of incidences (12) in which its concentration profile copied that of TSS. The predominant correlation of Cu concentration profiles with the profiles of TSS is consistent with Hewitt and Rashed's (1992) findings.

Also, the tendency for TKN concentration peaks to precede a flowrate peak was as frequent as its tendency to correlate with flowrate peaks. The behavior of TKN concentration profiles appeared to have a complex nature at the Mt. Rainier site. During two storm events, the peak in TKN concentration occurred before the flowrate peak began (Figure 4.6). In another storm event, the TKN concentration peaked when the flowrate was increasing, but does not correspond to the maximum flowrate (Figure 4.7). During the March 20, 2003 storm event, three peaks in flowrate occurred with the largest peak occurring at the end of the storm event. In this incidence, the peak TKN concentration transpired between the first two smaller flowrate peaks and remained constant at the end (Figure 4.8). During the May 16, 2003 storm event, multiple peaks in TKN occurred in the concentration profile (Figure 4.9). Based on past studies and this study, no apparent or obvious parameters explain the complexity of the TKN concentration profiles.

Except for $NO_2^-$, TP exhibited the fewest occurrences in which its concentration profile correlated with the TSS profile. Two possible explanations are apparent for the independence of TP on TSS concentration. One possibility is that TP predominated in the dissolved phase as ortho-phosphate. The first explanation is supported by other studies in which the dissolved phases almost always exhibited first flush (Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997). A second explanation is that TP was associated predominantly with smaller particles. Sartor and Boyd (1972) found particulate-bound phosphorus mainly associated with particles smaller than 104 μm. Although studies determined positive correlations between rainfall intensity and TSS concentration, quantitative analysis of the dependence between

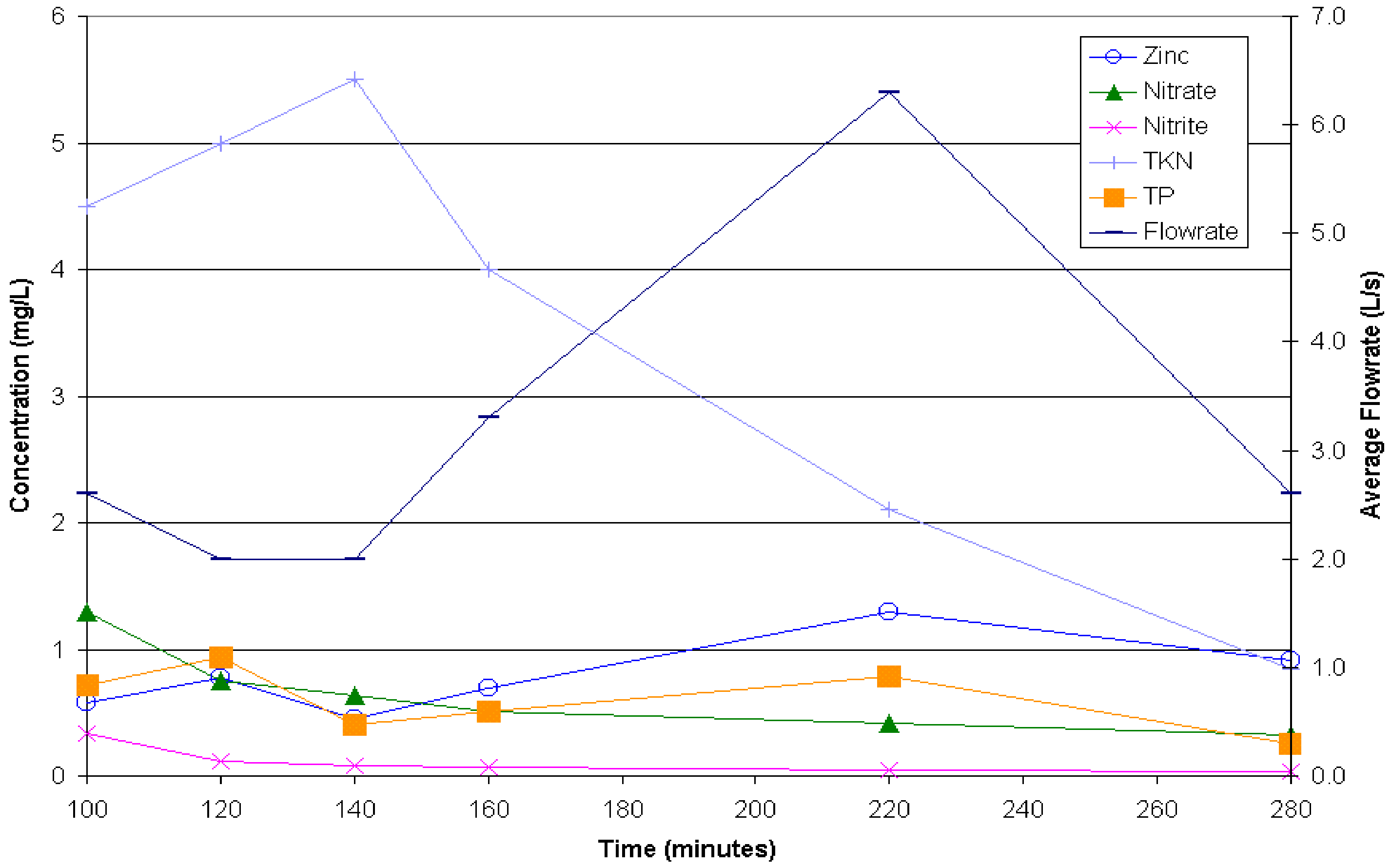


Figure 4.6. Concentration profile for TKN, $NO_3^-$, $NO_2^-$, TP, and Zn for the morning September 26, 2002 Mt. Rainier storm event

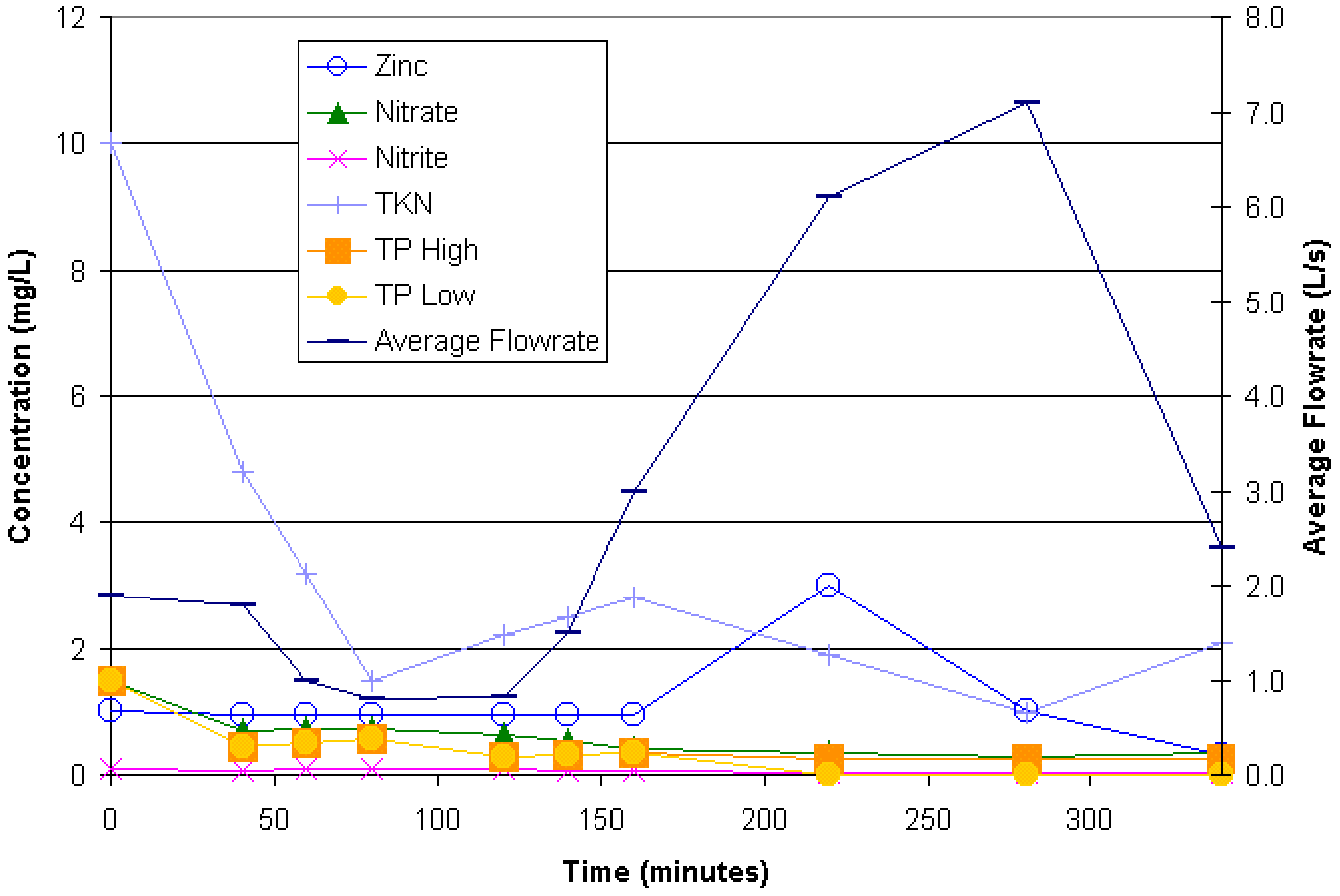


Figure 4.7. Concentration profile for TKN, $NO_3^-$, $NO_2^-$, TP, and Zn for April 6, 2003 Mt. Rainier storm event

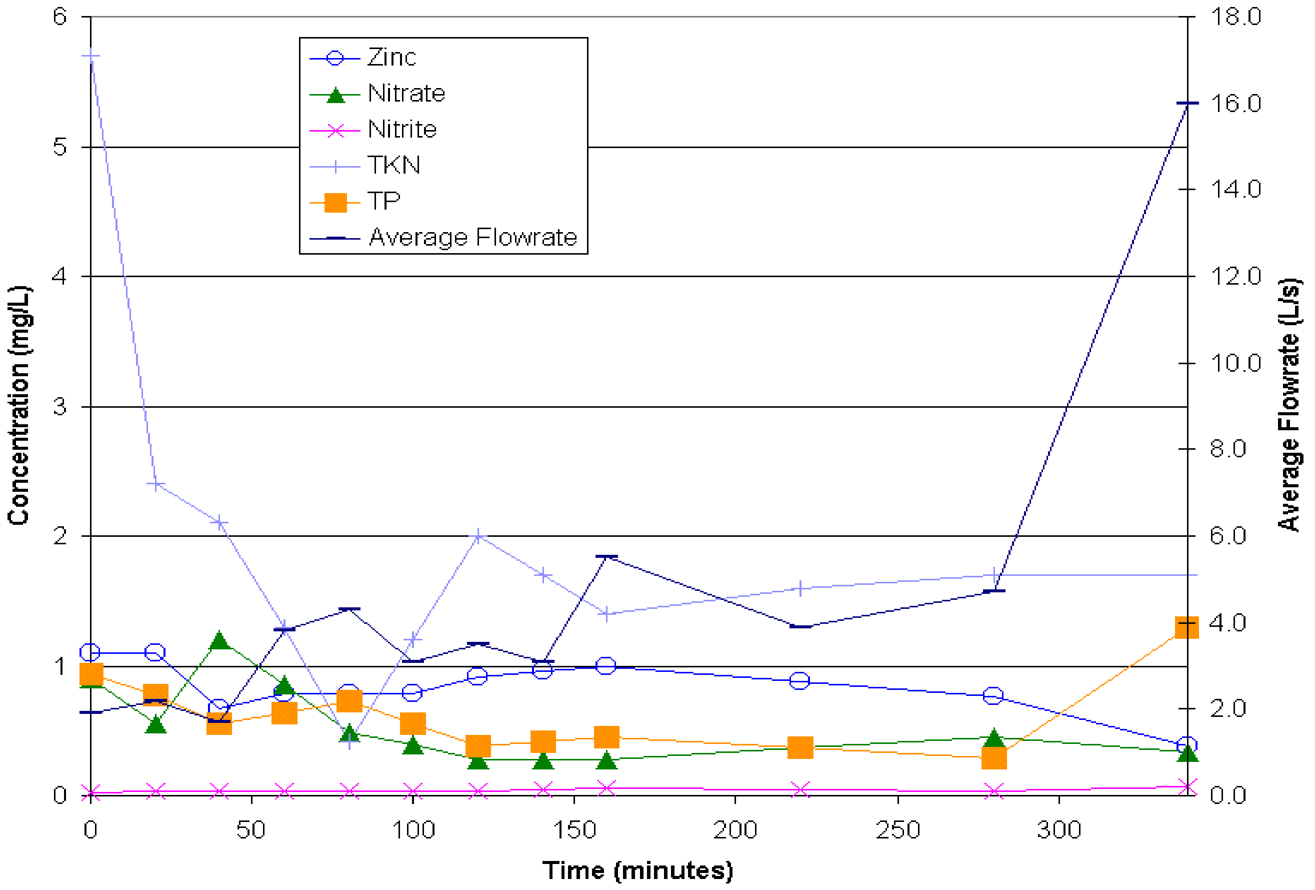


Figure 4.8. Concentration profile for TKN, $NO_3^-$, $NO_2^-$, TP, and Zn for March 20, 2003 Mt. Rainier storm event

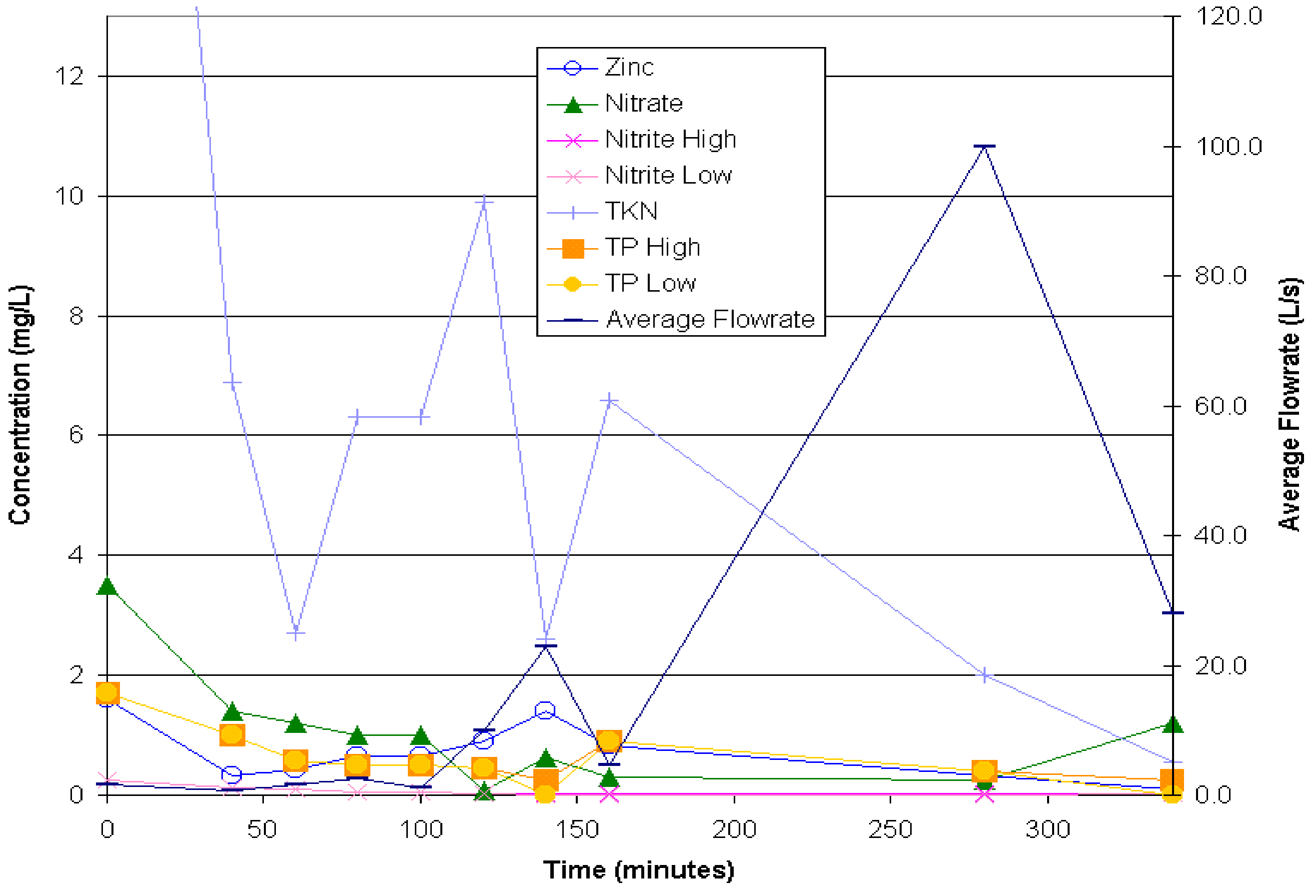


Figure 4.9. Concentration profile for TKN, $NO_3^-$, $NO_2^-$, TP, and Zn for May 16, 2003 Mt. Rainier storm event

particulate size fractions and rainfall intensity has not been studied. If particulates smaller than 104 μm are flushed by low intensity storms, than flushing TP that is bound predominantly to smaller particles may exhibit a propensity for first flush similar to dissolved constituents in stormwater runoff. In this study, TP exhibited a strong first flush and weak flushing during later portions of storm events at Mt. Rainier, MD.

Finally, the $NO_2^-$ concentration profiles correlated with the TSS profiles in only two storm events. These results coincide with previous studies in which $NO_2^-$ was found in the dissolved phase without association to particulate fractions (Sansalone and Buchberger, 1997; Hewitt and Rashed, 1992; Harrison and Wilson, 1985).

### 4.5 Pollutant Loads

Annual pollutant loads were calculated as detailed in Section 3.5.2 and presented in Table 4.9. The annual pollutant loads for all the contaminants, Cd, Cu, Pb, Zn, TSS, TKN, $NO_{3+2}^-$, and TP were greater than the loadings determined in four other studies with sampling locations in the US and Europe (Table 4.9). Annual pollutant loadings are directly proportional to the annual precipitation, runoff coefficient, and the EMC. In order to better understand the factors contributing to the higher loadings at the Mount Rainier site, the parameters effecting annual pollutant loads were compared for the various studies.

In Table 4.9, the pollutant loadings are expressed in units of kg/ha/yr. As a result, the pollutant loadings in Table 4.9 are normalized with respect to the drainage area of the sampling locations. Barrett et al. (1998) collected samples from West 35$^{TH}$ St. in Austin, Texas, which contained a drainage area of 0.53 ha. The drainage area at West

Table 4.9. Annual pollutant loadings for Mt. Rainier, MD and other studies

| Reference | Site | Area (ha) | ADT | Annual Rainfall mm(in) | Runoff Coeff. | $Cd^c$ | $Cu^c$ | $Pb^c$ | $Zn^c$ | $TSS^c$ | $TP^c$ | $TKN^c$ | $NO_3^{-c}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| This Study[a] | Mt. Rainier, MD | 0.56 | 20375[d] | 1123(44)[e] | 0.95 | 0.24 | 0.84 | 1.7 | 8.5 | 3100 | 3.9-4.6 | 25 | 11.2-11.6 |
| Wu et al., 1998[a] | W.T.Harris | 0.15 | 25000 | | 1.0 | 0.03 | 0.22 | 0.20 | | 2678 | 3.5 | 15.6 | 28.9 |
| | NC49 | 0.23 | 21500 | | 0.61 | 0.01 | 0.07 | 0.07 | | 528 | 4.8 | 9.3 | 2.0 |
| | I85/US29 | 0.45 | 5500 | | 0.45 | 0.05 | 0.10 | 0.13 | | 612 | 9.1 | 19.4 | 2.0 |
| Barrett et al., 1998[a] | West 35TH | 0.53 | 58150 | 825(32) | 0.83 | | 0.23 | 0.47 | 1.3 | 1306 | 2.0 | | 5.4[b] |
| | Convict | 0.05 | 8780 | | 0.93 | | 0.08 | 0.20 | 0.45 | 977 | 0.8 | | 8.7[b] |
| | Walnut | 10.5 | 47240 | | 0.40 | | 0.02 | 0.01 | 0.06 | 101 | 0.2 | | 0.7 |
| Pagotto et al., 2000[a] | Nantes, France | 0.32 | 12000 | 698(27) | 0.84 | 0.0073 | 0.20 | 0.32 | 1.8 | 380 | | | |
| Stotz, 1987[a] | Pleidelsheim | 1.3 | 41000 | 520(20) | 1.0 | 0.037 | 0.621 | 1.332 | 2.329 | 873 | 1.62 | | |
| | Heilbronn | 2.52 | 47000 | 297(12) | 0.86 | 0.029 | 0.544 | 1.155 | 2.892 | 848 | 1.45 | | |
| | Ulm-West | 25 | 52100 | 566(22) | 0.4 | 0.007 | 0.130 | 0.360 | 0.715 | 479 | 0.63 | | |
| Wong et al., 1997 | Santa Monica Bay, CA | 2845 | | | 0.66 | | 0.27 | 0.91 | 0.91 | 544 | 1.8 | 5.4 | 2.7[b] |

[a] ADT=Average Daily Traffic (vechicles/day)

[b] Values for $NO_3^-$

[c] Annualpollutant loadings in kg/ha-yr

[d] (SHA, 2002)

[e] (ERH, 2003)

35$^{TH}$ St. compares the most closely with the drainage area of 0.56 ha at Mt. Rainier. Although the drainage areas are similar at both the Mt. Rainier site and West 35$^{TH}$ St. locations, the normalized annual pollutant loadings at Mt. Rainier exceed those at West 35$^{TH}$ St. Therefore, the annual pollutant loadings at Mt. Rainier, MD are higher than other sites of similar drainage area.

The average daily traffic count has been found to positively correlate with pollutant loading during low-volume storm events (Sansalone et al., 1998). As a result, a location exposed to a larger traffic count than another site should contain a higher pollutant loading. However, the West 35$^{TH}$ St. location contained lower pollutant loadings, despite an ADT approximately two times greater than the ADT at the Mt. Rainier site. In addition, as discussed in Section 4.2, the EMC's for all pollutants were higher at Mt. Rainier, MD than at the other sites referenced in Table 4.9, except $NO_{3+2}^-$. Therefore, different and/or additional sources are contributing to pollutant deposition at Mt. Rainier, resulting in the higher EMC's and annual pollutant loading.

Another parameter that contributed to the higher annual pollutant loading at the Mt. Rainier site was the annual rainfall. The average annual precipitation at College Park, MD, which is the closest location to Mt. Rainier with weather monitoring stations, is 44 inches (ERH, 2003). In comparison to the other locations referenced in Table 4.6 Mt. Rainier experienced the greatest annual rainfall. The higher annual rainfall contributed to the higher loadings at Mt. Rainier, as a result of the pollutant loadings direct dependence on annual rainfall.

### 4.6 Predictive Models

Predictive stormwater models are another tool that can be implemented to determinediscrete concentrations, pollutant loadings or any other stormwater characteristic of interest. Researchers have developed models to determine TSS concentration (Barrett et al., 1998) and the Pb load (Hewitt and Rashed, 1992) at any point during a storm event. The ability of these models to predict TSS concentration and Pb loading was evaluated for the storm events that occurred in Mt. Rainier.

Development of a predictive model for TSS concentration centered around the theory that the initial portion of the storm event volume contains the majority of the pollutant load. Therefore, Barrett et al (1998) developed a predictive model for TSS concentration in which TSS concentration is described by a simple exponential function dependent only on the runoff volume (Equation 4.1).

$$C = 372e^{-0.34r} \tag{4.1}$$

In Equation 4.1, r equals the cumulative runoff volume at any point in the storm in mm and C is the TSS concentration in mg/L.

Because Equation 4.1 can be used to determine TSS concentration at any point during the duration of a storm event, the equation was used to predict TSS concentrations for the first and last sampling intervals for storm events occurring at Mt. Rainier, MD (Table 4.10). The first sampling interval is 10 minutes in duration as described in Section 3.6.1. Therefore, rainfall data were used only for storm events in which the rainfall data was recorded in 5 minute increments, because the rainfall data

Table 4.10. TSS Concentrations calculated using predictive model developed by Barrett et al. (1998)

| Date | 1<sup>ST</sup> Sampling Interval | | | Last Sampling Interval | | |
|---|---|---|---|---|---|---|
| | Rainfall cm (in) | Predicted Conc. (mg/L) | Actual Conc. (mg/L) | Rainfall cm (in) | Predicted Conc. (mg/L) | Actual Conc. (mg/L) |
| 10/25/02 | 0.10 (0.04) | 263 | 190 | 2.1 (0.84) | 0.26 | 43 |
| 11/5/02 | 0.03 (0.01) | 341 | 180 | 1.4 (0.55) | 3.2 | 57 |
| 12/20/02 | 0.05 (0.02) | 313 | 80 | 1.1 (0.42) | 9.9 | 32 |
| 1/1/03 | 0.05 (0.02) | 313 | 170 | 1.6 (0.63) | 2.3 | 22 |
| 8/16/03 | 0.13 (0.05) | 242 | 950 | 0.28 (0.11) | 144 | 130 |
| 8/27/03 | 0.51 (0.2) | 66 | 1100 | 1.4 (0.56) | 3.0 | 51 |
| 9/12/03 | 0.05 (0.02) | 313 | 200 | 0.99 (0.39) | 13 | 130 |

recorded every 30 minutes would overestimate the total rainfall for the first sampling interval.

The model over-predicted the TSS concentration at the storm onset for all the storm events except for the storms that occurred on August 16 and 27 of 2003 (Table 4.10). The two storms that were underestimated exhibited the greatest rainfall during the first interval. Higher rainfall intensities contributed to the larger rainfall values for the two storms in August. Flowrate, which is proportional to intensity, affects the delivery of solids fractions (Sansalone et al., 1998). As a result of the high rainfall intensity occurring at the storm onset of the August 27, 2003 event, the TSS concentration was high during this interval. The TSS predictive model does not account for variations in rainfall intensity. In addition from Table 4.10, comparison of the predicted and actual TSS concentrations at the storm end show that the model under-predicts the final concentration. Both, the over-prediction of the concentration at the storm onset and the under-prediction at the storm end demonstrate that TSS concentration as a function of storm duration is not well described by an exponentially decreasing function. TSS concentration would be described more accurately by a function that decreases more gradually than an exponential function and that incorporates storm characteristics that correlate with TSS concentration into the predictive model.

Another model was developed using a simplistic regression analysis to predict Pb loadings as shown in Equation 4.2 (Hewitt and Rashed, 1992).

$$Pb = 0.201Q + 0.74ADP - 21.9 \tag{4.2}$$

In Equation 4.2, Q equals the total discharge in cubic meters, ADP is the antecedent dry period in hours, and Pb represents the total Pb load in grams. The predictive model overestimates the total load for Pb for all storm events, except the March 6, 2003, May 10, 2003, and August 27, 2003 storm events (Table 4.11). The three events with under-predicted Pb loads correspond to the events with the three smallest ADP's out of the 17 storm events that were evaluated. For storms with large total runoff volumes, the first and second terms in the predictive model have similar magnitudes. For example, in the August 27, 2003 storm event, the first and second terms equal 33 and 21. In contrast, for storms with small total runoff volumes, the second term predominates. For instance, the first term equals 3.5 for the March 6, 2003 storm event, yet the second term is 4 times greater with a value of 14. Overall, ADP has a greater impact on the prediction of Pb load by this model than total runoff volume, due to the fact that the term containing ADP is larger than the term for events with small runoff volume and of similar magnitude for events with large runoff volume.

Table 4.11. Pb loads calculated using predictive model developed by Hewitt and Rashed (1992)

| Date | Event Volume (L) | ADP[a] (hr) | Predicted Load (g) | Actual Load (g) |
|---|---|---|---|---|
| 10/25/02 | 94800 | 192 | 140 | 9.0 |
| 11/5/02 | 111000 | 136 | 100 | 9.0 |
| 12/11/02 | 134000 | 36 | 32 | 3.8 |
| 12/20/02 | 89000 | 149 | 110 | 3.0 |
| 1/1/03 | 287000 | 136 | 136 | 22 |
| 2/21/03 | 4400 | 58 | 22 | 1.3 |
| 3/6/03 | 17300 | 19 | -4.4 | 6.6 |
| 3/20/03 | 134040 | 156 | 120 | 17 |
| 4/7/03 | 73320 | 181 | 127 | 54 |
| 4/25/03 | 22440 | 165 | 105 | 3.6 |
| 5/10/03 | 38040 | 21 | 1.3 | 4.4 |
| 5/16/03 | 537120 | 117 | 173 | 32 |
| 5/31/03 | 79400 | 79 | 53 | 5.3 |
| 6/9/03 | 104000 | 32 | 23 | 4.2 |
| 8/16/03 | 23800 | 120 | 72 | 18 |
| 8/27/03 | 161800 | 29 | 29 | 105 |
| 9/12/03 | 102000 | 192 | 141 | 17 |

[a] ADP=Antecedent dry period

In the predictive model for Pb loading, ADP was the parameter that correlated the strongest with Pb load for stormwater runoff from a rural highway in Cambria, England

(Hewitt and Rashed, 1992). Based on the results presented in Table 4.9, a predictive model that is predominantly affected by ADP does not predict the Pb loading in stormwater runoff from Mt. Rainier, MD. The loading of Pb depends on the total runoff discharge in this model. In a manner similar to the predictive model for TSS concentration, this model does not include a term that accounts for the rate of change a rainfall intensity that is the delivery of the runoff discharge. As explained in the discussion of the concentration profiles, Pb concentrations peaked as an indirect result of peaks in rainfall intensity. A model that incorporates the effects of storm duration and rainfall intensity may result in better prediction of total Pb load in stormwater runoff from Mt. Rainier, MD.

### 4.7 Flushing

Flushing of pollutants from impervious surfaces occurs when the pollutants wash from the surface in a greater proportional amount than the rainfall runoff volume. In order to qualitatively characterize flushing throughout the storm events, plots of the mass loading ratio versus the runoff volume ratio were created and analyzed for each storm event. In addition to qualitative analysis, quantitative analysis was completed. Quantitative evaluation of first flush and second flush allows one to support or refute the theory that the majority of a storm's pollutant load is contained in the initial portion of a storm event's volume. As part of flushing analysis the percent of the total pollutant mass contained in the first 25% of the storm event volume was determined for each storm event. The occurrence of first flush was based on the criterion defined by Wanielista and Yousef (1993) in which first flush occurs when 50% of the total event pollutant mass flushes within the first 25% of the event runoff volume. Further analysis of flushing included determining the maximum percent of the total pollutant mass that flushed in any subsequent 25% portion of the event volume (other than the first 25 % portion) that corresponded with a concentration peak. A second flush was said to have occurred when 50% of the total event pollutant mass flushed in any 25% portion of the event volume beyond the first 25% portion.

### 4.7.1 Quantitative

#### 4.7.1.1 First Flush

Using the 50% mass in 25% volume definition, first flush occurred in 8 storm events for $NO_2^-$, 6 storm events for TP, 5 storm events for Cu and TKN, 4 storm events for TSS and $NO_3^-$, and 3 storm events for Pb and Zn (Tables 4.12a and 4.12b). Based on a limited set of data, no incidences of first flush occurred for Cd. In summary, $NO_2^-$ exhibited first flush in 33% of the storm events, TP in 27% of the events, $NO_3^-$ and TKN in 22% of the events, Cu in 21% of the events, TSS in 17% of the storm events, and Pb and Zn in 13% of the storm events. Therefore, $NO_2^-$ exhibited the greatest frequency of first flush. Overall, the occurrence of first flush was not a predominant phenomenon at the Mt. Rainier site.

Due to the none predominant occurrence of first flush, probability plots of the percent of the total pollutant load that flushes during the first 25% of the event volume were created for comparison purposes, as described in Section 4.1. The probability that

Table 4.12a. Percent of total mass flushed in the 1$^{ST}$ 25% of the event volume for storm events in 2002

| Date | 25%[a] | Cu | Pb | Zn | TKN | TP | $NO_2^-$ | $NO_3^-$ | TSS |
|---|---|---|---|---|---|---|---|---|---|
| 6/19/02 | 7140 | ***51*** | 40 | ND | 37 | 40 | 34 | 35 | 39 |
| 6/27/02 | 23520 | 24 | 26 | ND | 22 | 22 | 27 | 7 | ***53*** |
| 7/26/02 | 11280 | 40 | 40 | 26 | 28 | 34 | 28 | ND | 31 |
| 8/3/02 | 48480 | ***52*** | ***52*** | 46 | ***57*** | ND | 7 | ***64*** | 32 |
| 9/26/02 AM | 13680 | 19 | 30 | 16 | 42 | 25 | ***50*** | 39 | ***51*** |
| 9/26/02 PM | 6600 | 33 | 41 | 32 | 18 | 14 | 23 | 11 | 32 |
| 10/10/02 AM | 12720 | 40 | 33 | 36 | ***59*** | ***51*** | ***53*** | 41 | 26 |
| 10/25/02 | 24120 | 26 | 15 | 24 | 49 | ***57*** | ***68*** | ***56*** | 33 |
| 11/5/02 | 27720 | 42 | 45 | 39 | ***59*** | ***61*** | ***67*** | ***51*** | 33 |
| 11/11/02 | 22440 | 47 | ***53*** | 40 | ***59*** | 39 | 17 | ***51*** | 36 |
| 12/11/02 | 33600 | 38 | 31 | 27 | ***60*** | ND | 11 | ND | 25 |
| 12/20/02 | 22440 | 36 | 33 | 26 | 26 | 36 | ***50*** | ND | 25 |

[a] 25% of total storm volume in Liters

[ND] No Data

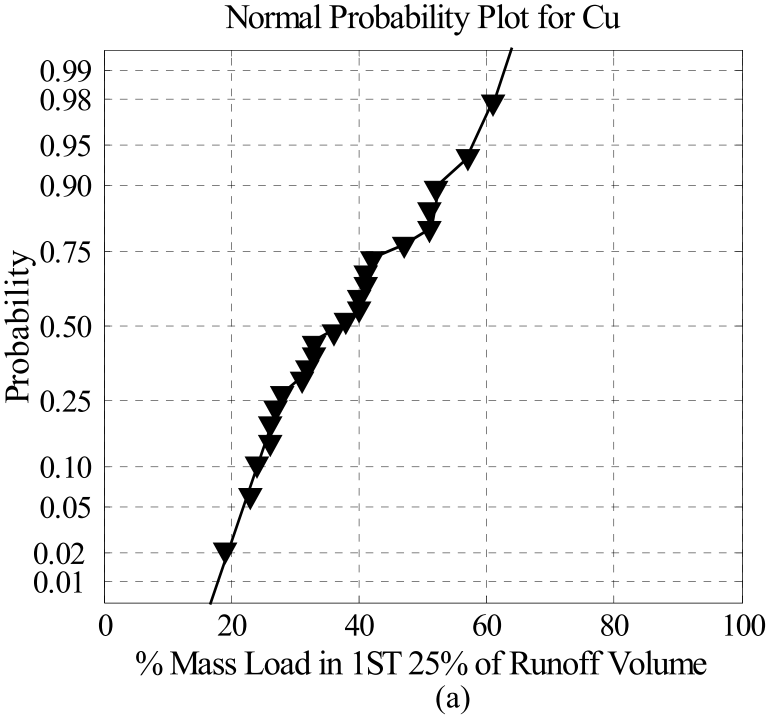
Table 412b. Percent of total mass flushed in the $1^{ST}$ 25% of the event volume for storm events in 2003

| Date | 25%[a] | Cd | Cu | Pb | Zn | TKN | TP | $NO_2^-$ | $NO_3^-$ | TSS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/1/03 | 71400 | ND | ***61*** | 47 | ***55*** | 49 | ***58*** | 42 | 25 | 48 |
| 2/3/03 | 6360 | ND | ***51*** | 47 | ***54*** | 49 | 45 | 40 | 36 | ***60*** |
| 3/6/03 | 4680 | ND | 31 | 33 | 32 | ***55*** | ***56*** | 38 | 40 | ***66*** |
| 3/20/03 | 33360 | ND | 31 | 43 | 34 | 26 | 17 | 17 | 33 | 10 |
| 4/6/03 | 18120 | ND | 28 | 4 | 18 | 46 | ***59*** | 39 | 41 | 30 |
| 4/25/03 | 5640 | ND | 27 | 29 | 40 | 20 | 42 | 36 | 30 | 27 |
| 5/10/03 | 9720 | 25 | 26 | 29 | 29 | 20 | 37 | ***64*** | 26 | 35 |
| 5/16/03 | 13200 | 34 | 41 | 24 | 45 | 43 | 29 | 31 | 22 | 29 |
| 6/9/03 | 26520 | 38 | ***57*** | 32 | ***59*** | ND | 35 | ***53*** | 29 | ND |
| 8/27/03 | 17640 | 40 | 41 | ***66*** | 40 | 39 | 42 | 32 | ND | 39 |
| 9/12/03 | 25440 | 41 | 33 | 43 | 35 | 24 | 27 | 22 | ND | 20 |
| 9/18/03 | 21510 | 11 | 23 | 29 | 12 | 28 | 40 | ***70*** | ND | 14 |

[a] 25% of total storm volume in Liters
[ND] No Data

first flush will occur for each pollutant at the Mt. Rainier site was determined using Figures 4.10a through 4.10i. Typically, the y-scale represents the probability that the value represented by the x-axis will be less than or equal to the x-axis value corresponding to that probability. As a result, Figure 4.10a was used to determine that there was a 79% probability that the Cu pollutant load in the first 25% of the event volume will be less than or equal to 50%. In order to determine the probability that the percent of the pollutant load will be greater than 50% in the first 25% of the event volume (first flush), the excedence probability (1-0.79) = 21% is used. Therefore, there exists a 21% probability that first flush of Cu will occur at the Mt. Rainier site. The probability that the other pollutants will exhibit first flush was determined in the same manner as Cu. $NO_2^-$ exhibited the highest probability of 28% for the occurrence of first flush. Furthermore, TP demonstrated a 25% probability to exhibit first flush, TKN a 24% probability, $NO_3^-$ a 19% probability, TSS a 17% probability, Zn a 15% probability, and Pb a 12% probability (Table 4.13).

Typically, first flush of dissolved constituents almost always occurs, in contrast to the more varied and complex flushing of particulates and particulate-bound constituents, which have a greater dependence on storm characteristics (Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997). In correspondence with previous research, $NO_2^-$ exhibited the highest observances of first flush for all storm events and the greatest probability that first flush will occur. Similarly, Pb which has been found predominantly associated with the particulate fractions, demonstrated the lowest probability to exhibit first flush of all constituents (Morrison et al., 1984; Harrison and Wilson, 1985; Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997).



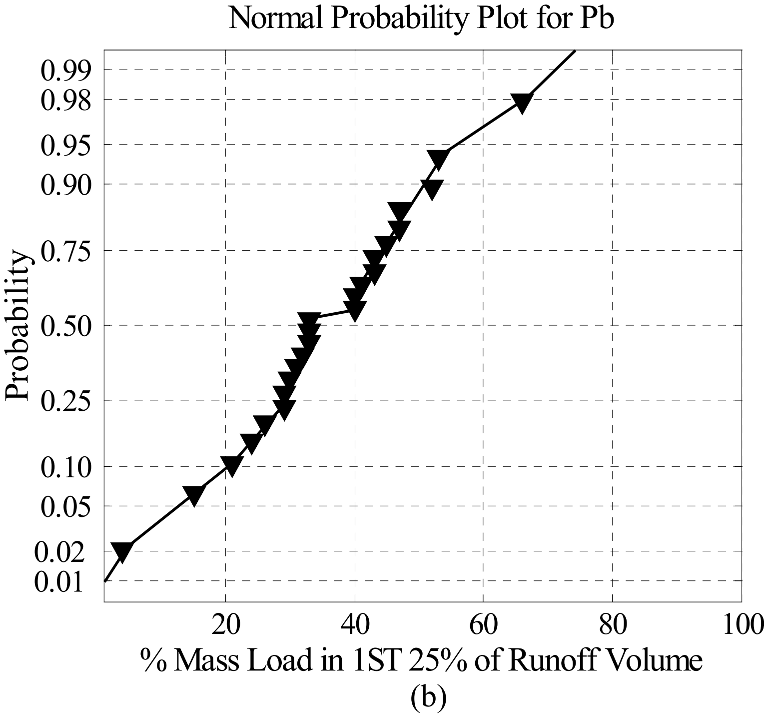
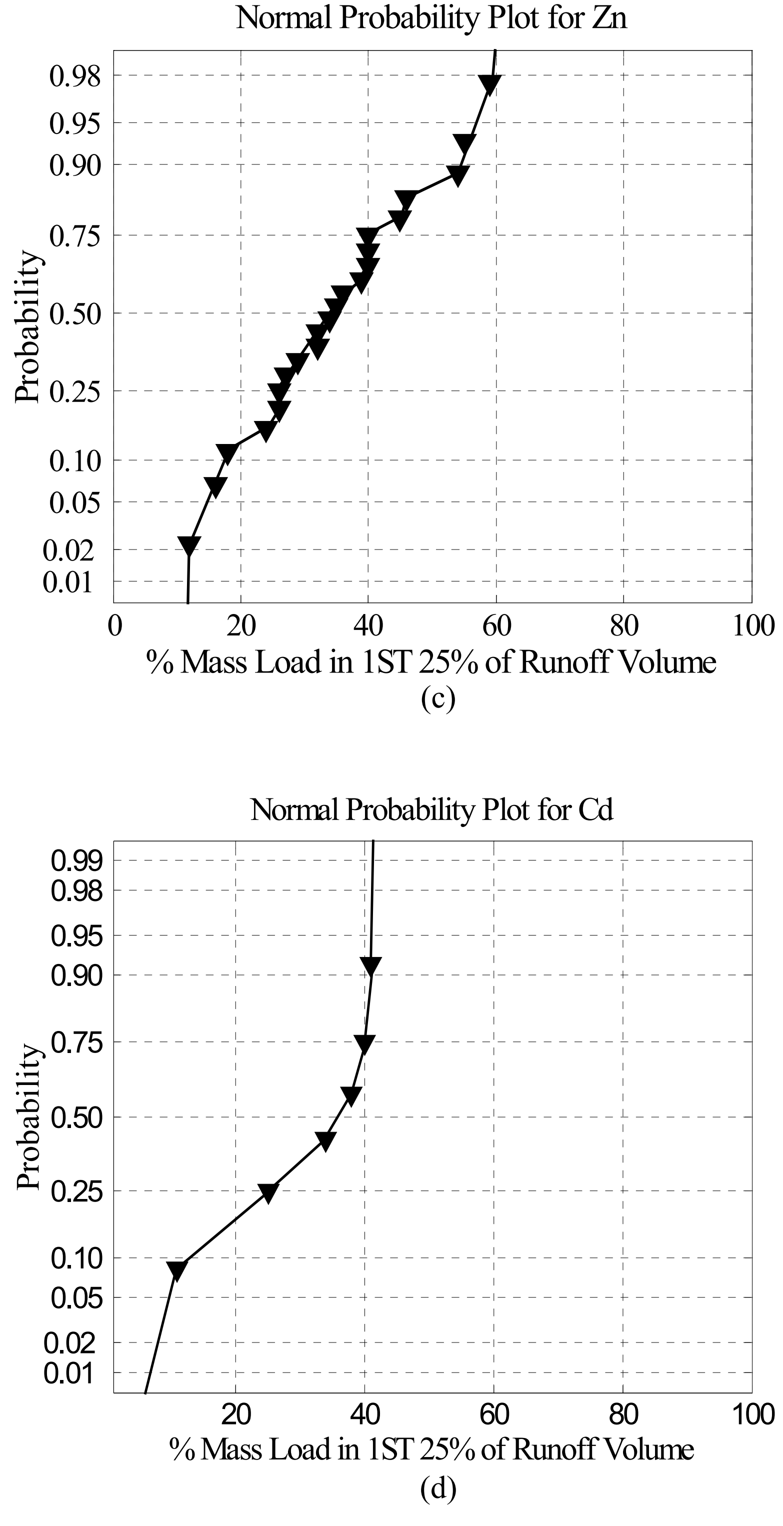


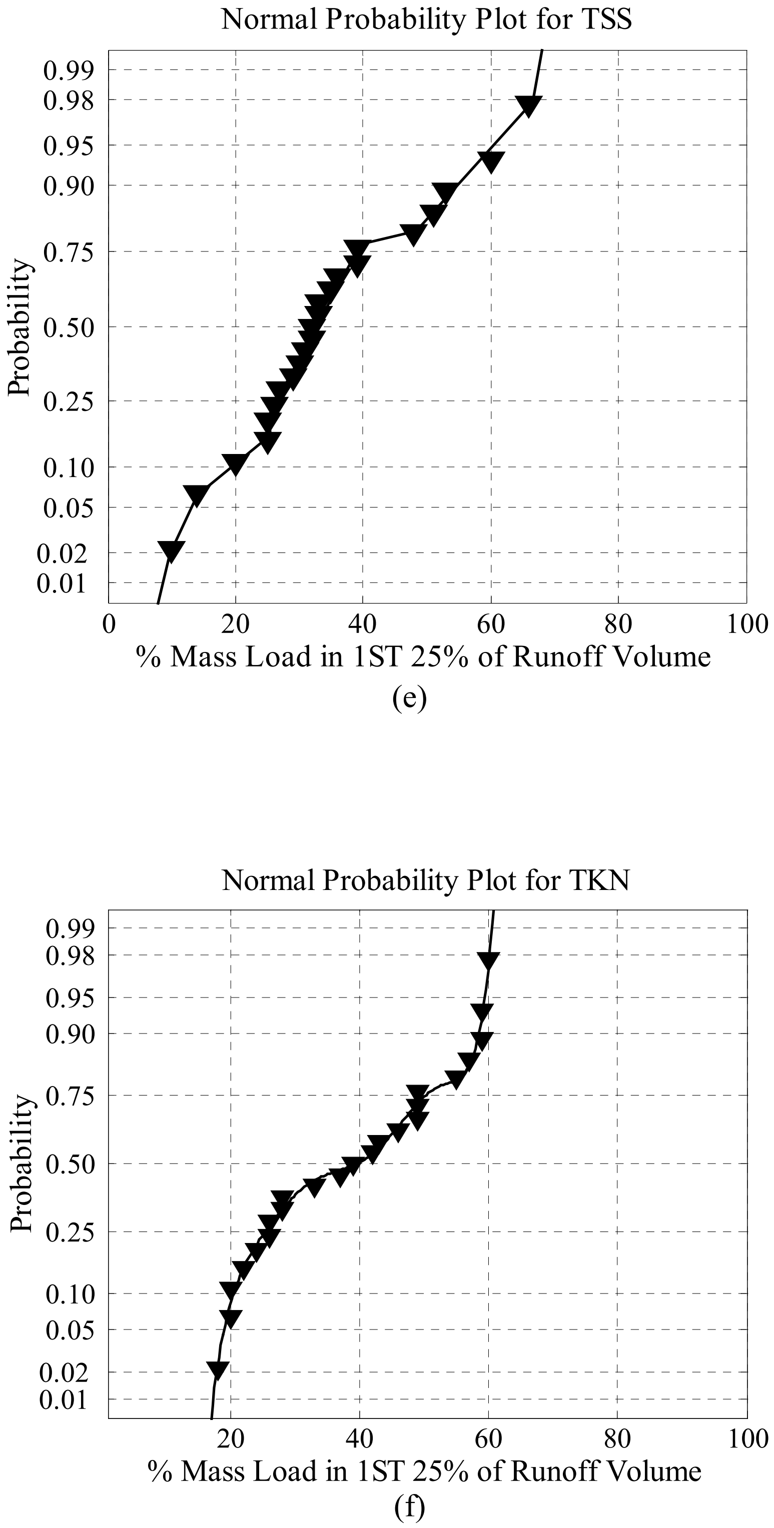
Figure 4.10. Probability plots of the percent of the total mass of (a) Cu, (b) Pb, (c) Zn, (d) Cd, (e) TSS, (f) TKN, (g) $NO_3^-$, (h) $NO_2^-$, (i) TP that flushes in the $1^{ST}$ 25% of the event volume at the Mt. Rainier, MD site



(c)

(d)

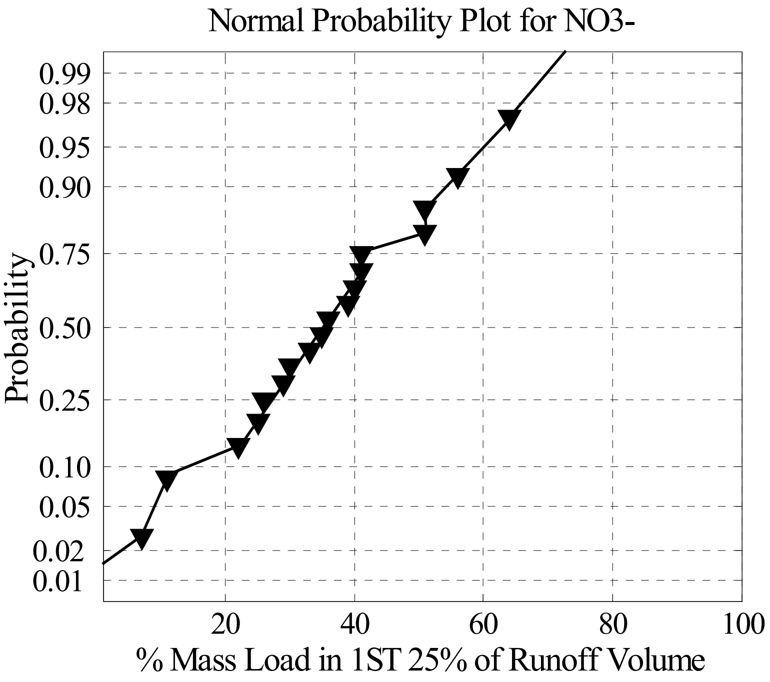
Figure 4.10. Continued



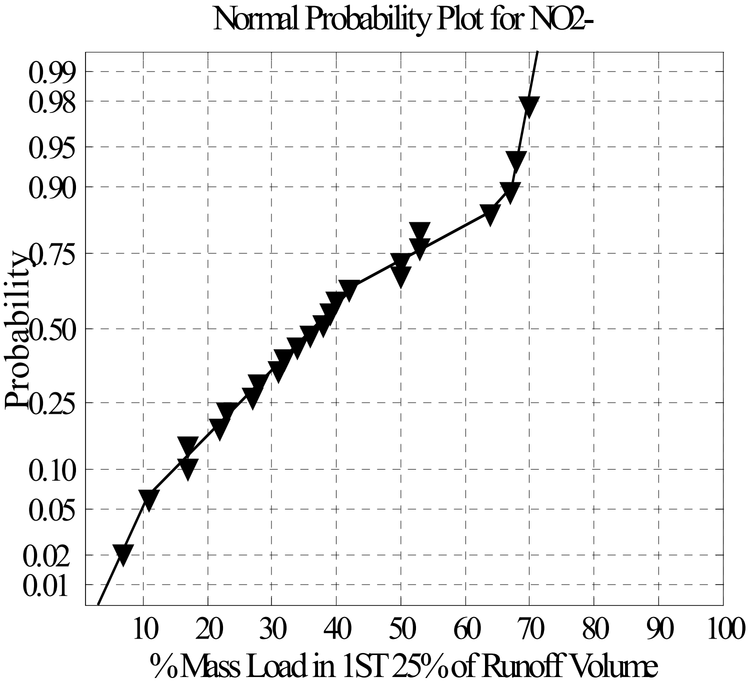
(e)

(f)

Figure 4.11. Continued

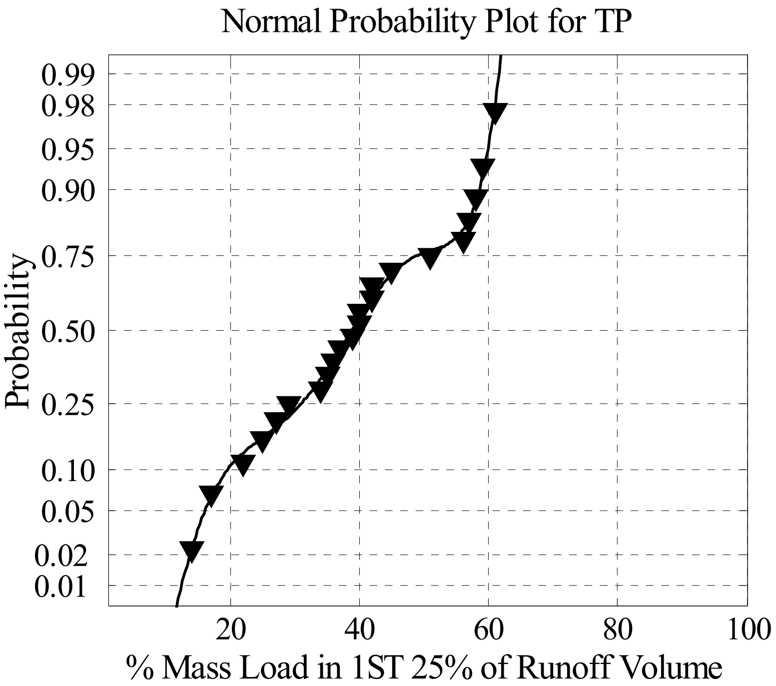


(g)



(h)

Figure 4.10. Continued



(i)

Figure 4.10. Continued

Table 4.13. Probabilty that each pollutant will exhibit first flush at Mt. Rainier

| | Cd[a] | Cu | Pb | Zn | TKN | TP | $NO_2^-$ | $NO_3^-$ | TSS |
|---|---|---|---|---|---|---|---|---|---|
| Probability of First Flush Occurrence | <8 | 21 | 12 | 15 | 24 | 25 | 28 | 19 | 17 |

[a]Based on limited data set of 6

In addition, finding that TKN and TP displayed the same propensity as $NO_2^-$ for exhibiting first flush may have implications as to the forms of nitrogen and phosphorus that were present in the stormwater runoff. TKN is a combined measurement of both $NH_4^+$ and organic nitrogen. Similarly, TP is a combined measurement of both orthophosphate and organically-bound phosphorus. Therefore, TKN and TP exhibiting a similar propensity for flushing as $NO_2^-$ indicates that the dissolved forms of nitrogen and phosphorus, $NH_4^+$ and orthophosphate, were present in higher concentrations and may dominate these measurements.

Another indication that TP existed predominantly in the dissolved phase is the lack of dependence of first flush on rainfall intensity. Rainfall intensity has been shown to influence the strength or first flush of particulates and particulate-bound constituents for storms of similar duration (Lee and Bang, 2000). In order to discern the effects of rainfall intensity on flushing strength, Table 4.14 is a compilation of the maximum flowrate that occurred during the 25% portion of the event volume that corresponded to the first flush and the maximum flowrate for the entire event. For this discussion low flowrates are less than 7 L/s, moderate flowrates are greater than or equal to 7 L/s and less than 20 L/s, and high flowrates are greater than or equal to 20 L/s.

Comparison of first flush events of TP for November 5, 2002 and January 1, 2003

Table 4.14. Maximum flowrate occurring in $1^{ST}$ 25 % of event volume for storm events that exhibited first flush of various pollutants at Mt. Rainier, MD site

| | Maximum Flowrate (L/s) | | % Pollutant Load in $1^{ST}$ 25% of the Runoff Volume | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | $1^{ST}$ 25% Volume | Storm Event | Cu | Pb | Zn | TKN | TP | $NO_2^-$ | $NO_3^-$ | TSS |
| 6/19/02 | 13 | 13 | 51 | --- | --- | --- | --- | --- | --- | --- |
| 6/27/02 | 83 | 120 | --- | --- | --- | --- | --- | --- | --- | 53 |
| 8/3/02 | 41 | 41 | 52 | 52 | --- | 57 | --- | --- | 64 | --- |
| 9/26/02 AM | 4 | 13 | --- | --- | --- | --- | --- | 50 | --- | 51 |
| 10/10/02 | 7 | 7 | --- | --- | --- | 59 | 51 | 53 | --- | --- |
| 10/25/02 | 8 | 25 | --- | --- | --- | --- | 57 | 68 | 56 | --- |
| 11/5/02 | 6 | 14 | --- | --- | --- | 59 | 61 | 67 | 51 | --- |
| 11/11/02 | 10 | 11 | --- | 53 | --- | 60 | --- | --- | 51 | --- |
| 1/1/03 | 36 | 52 | 61 | --- | 55 | --- | 58 | --- | --- | --- |
| 2/3/03 | 8 | 8 | 51 | --- | 54 | --- | --- | --- | --- | 60 |
| 3/6/03 | 10 | 11 | --- | --- | --- | 55 | 56 | --- | --- | 66 |
| 4/7/03 | 4 | 12 | --- | --- | --- | --- | 59 | --- | --- | --- |
| 5/10/03 | 12 | 12 | --- | --- | --- | --- | --- | 64 | --- | --- |
| 5/16/03 | 215 | 267 | --- | --- | --- | --- | --- | --- | 51 | --- |
| 6/9/03 | 60 | 60 | 57 | 66 | 59 | --- | --- | 53 | --- | --- |
| 9/18/03 | 6 | 44 | --- | --- | --- | --- | --- | 70 | --- | --- |

---No first flush

storm events shows that first flush occurred during events that demonstrated maximum flowrates of 6 L/s and 36 L/s, respectively. This confirmed that first flush of TP occurred during both low and high initial flowrates. As shown in Section 4.4, variations in flowrate result from variations in rainfall intensity. Therefore, first flush of TP during the November 5, 2002 and January 1, 2003 storm events occurred during storms exhibiting both high and low intensity rainfall. TP may have predominated in the dissolved phase, which would explain the lack of dependence of first flush on rainfall intensity. Similarly, TKN showed first flush for the August 3, 2002 and November 5, 2002 storm events, which displayed maximum flowrates of 41 L/s and 6 L/s, respectively. In a similar manner to TP, TKN exhibited first flush during low and high intensity rainfall, which may indicate a predominance of dissolved $NH_4^+$ over organic nitrogen.

If the independence between first flush of TP and TKN and rainfall intensity is used to support the concept that these pollutants are predominantly in the dissolved phase at Mt. Rainier, than it follows that the first flush of pollutants found predominantly particulate-bound (Cu, Pb, and Zn) in Section 4.4 should be dependent upon rainfall intensity. In Table 4.14, 3 out 5 incidences of first flush of Cu occurred during storms with high rainfall intensities during the first part of the storm events. In contrast, moderate rainfall intensities occurred during the June 19, 2002 and February 3, 2002 storm events in which there was first flush of Cu. Although the rainfall intensities were moderate during these two events, the maximum rainfall intensity during the first 25% of the runoff volume was also the maximum rainfall intensity for the entirety of the events. Therefore, despite the moderate values of the rainfall intensities during the first part of the storm, they were still the maximum event rainfall intensities. As a result, particulate-bound Cu exhibited a high loading during the first portion of the storm, due to the highest rainfall intensity occurring during the first portion of the storm.

In addition to Cu, first flush of Pb and Zn also occurred during storm events with high rainfall intensities during the first 25% portion of the runoff volume in two out of three incidences. In contrast to Cu, first flush occurred during the November 11, 2002 storm event for Pb and the January 1, 2003 storm event for Zn, in which the maximum rainfall intensity during the first 25% of the runoff volume in these two events was not the maximum event rainfall intensity.

For $NO_2^-$ and $NO_3^-$, first flush was independent of the maximum rainfall intensity during the first 25% of the event volume. $NO_2^-$ exhibited first flush during storms with moderate rainfall intensities during the first portion of the event for 6 out of 7 first flush incidences. Furthermore, $NO_3^-$ first flush was independent of rainfall intensity. First flush of $NO_3^-$ occurred during storms with moderate rainfall intensities during the first portion of the event for 3 out of 5 first flush occurrences.

Overall, previous research has focused on characterizing flushing qualitatively rather than quantitatively. In one study, the pollution load carried in the first 20% of the event volume was determined for TSS at two sites in Lund and Miljakovac, Sweden (Deletic and Maksimovic, 1998). The Lund drainage area is a parking lot for the Department of Water Resources Engineering that is used by approximately 15 to 20 cars per day. The Miljakovac drainage area is a section of roadway in a residential area that has an ADT of approximately 435. At the Lund site, the percent load carried by the first 20% of the event volume varied between 2% and 100%, and between approximately 15% and 50% at the Miljakovac site. The percent of TSS event load contained in the first 25% of the event volume ranged between 10% and 66% (Tables 4.12a and 4.12b) at the Mt. Rainier site. The range for the percent of the TSS event load in the Mt. Rainier first flush is similar to the Miljakovac site, but not the Lund site. The small number of vehicles that traffic the Lund site may limit the deposition of pollutants on the carpark surface. Therefore, if the pollutant load on the road is limited than it would be possible to wash 100% of the pollutants from the surface in the first 20% portion of the runoff volume. In contrast, depletion of the pollutants is more difficult at the more heavily trafficked Miljakovac and Mt. Rainier sites.

#### 4.7.1.2 Second Flush

Using the 50% mass in 25% volumn beyond the first 25% definition, second flush occurred less frequently than first flush. None of the storm events exhibited a second flush for Cd, Cu, TKN, or TP (Table 4.15). Only one storm event exhibited second flush for $NO_2^-$, Pb, and Zn. Of all the pollutants, $NO_3^-$ and TSS exhibited the highest incidences of second flush with 2 incidences for $NO_3^-$ and 3 incidences for TSS.

Although the incidences of second flush were infrequent, occurrences in which the percent of the pollutant load in a second fraction of the runoff volume were greater than the percent of the pollutant load in the first 25% of the runoff volume was more frequent. For instance, during the March 20, 2003 storm event, 17% of the TP pollutant load flushed from the surface in the first 25% of the runoff volume, yet 40% of the TP pollutant load flushed from the surface in a later 25% portion of the runoff volume. The pollutant load was greater in a second 25% portion of the runoff volume during 9 storm events for TSS, 6 events for $NO_2^-$, Cu, and Zn, 5 events for $NO_3^-$, and 4 events for TKN,

Table 4.15. Percent of the total mass flushed in a 25% portion of the runoff volume beyond the first 25 %

| Date | 25%[a] | Cu | Pb | Zn | TKN | TP | $NO_2^-$ | $NO_3^-$ | TSS |
|---|---|---|---|---|---|---|---|---|---|
| 6/19/02 | 7140 | --- | --- | ND | --- | 18[c] | 33[c] | 26[c] | --- |
| 6/27/02 | 23520 | --- | --- | ND | 18[c] | 21[c] | --- | ***73***[b] | --- |
| 7/26/02 | 11280 | --- | --- | 33[c] | --- | 19[c] | 20[c] | ND | 20[c] |
| 8/3/02 | 48480 | --- | 28[c] | 32[c] | 24[c] | ND | ***84***[b] | --- | ***50***[b] |
| 9/26/02 AM | 13680 | 33[b] | 26[c] | 33[b] | --- | 32[c] | --- | --- | --- |
| 9/26/02 PM | 6600 | 25[c] | 20[c] | 26[b] | 33b | 28[b] | 25[b] | 23[b] | 22[c] |
| 10/10/02 AM | 12720 | 25[c] | 26[c] | 27[c] | --- | --- | --- | 25[c] | 30[b] |
| 10/25/02 | 24120 | 34[c] | 42[c] | 31[c] | 23c | --- | --- | --- | 29[c] |
| 11/5/02 | 27720 | --- | --- | 25[c] | --- | --- | --- | --- | --- |
| 11/11/02 | 22440 | 18[c] | 17[c] | 26[c] | 16c | 21[c] | 42[b] | 17[c] | 27[c] |
| 12/11/02 | 33600 | 27[c] | 25[c] | 25[c] | --- | ND | 34[b] | ND | 32[c] |
| 12/20/02 | 22440 | --- | --- | 28[c] | --- | --- | --- | ND | 30[c] |
| 1/1/03 | 71400 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2/3/03 | 6360 | --- | --- | 32[c] | --- | --- | --- | --- | --- |
| 3/6/03 | 4680 | --- | --- | --- | --- | --- | --- | --- | --- |
| 3/20/03 | 33360 | --- | 33[c] | 33[c] | --- | 40[b] | 33[b] | --- | 42[b] |
| 4/6/03 | 18120 | 34[b] | ***60***[b] | ***50***[b] | --- | --- | --- | --- | 37[b] |
| 4/25/03 | 5640 | 30[c] | 28[c] | 24[c] | 32[c] | --- | --- | 33[b] | 32[c] |
| 5/10/03 | 9720 | 27[b] | 30[b] | 25[b] | 25[c] | --- | --- | 30[c] | 19[c] |
| 5/16/03 | 13200 | --- | --- | --- | --- | --- | --- | ***51***[c] | 29[c] |
| 6/9/03 | 26520 | 18[c] | --- | --- | ND | 29[c] | --- | 30[b] | ND |
| 8/27/03 | 17640 | --- | --- | --- | --- | --- | --- | ND | --- |
| 9/12/03 | 25440 | 25[c] | 29[c] | 24[c] | 22[c] | 36[c] | 30[b] | ND | ***56***[b] |
| 9/18/03 | 21510 | 33[c] | 28[b] | 37[b] | 34[c] | 27[c] | --- | ND | ***50***[b] |

[a] 25% of total storm runoff in liters

[b] Concentration peak greater than concentration at storm onset

[c] Concentration less than concentration at storm onset

[---] No second flush corresponding to concentration peak

[ND] No data

TP, and Pb. This corresponds to 39% of the storm events for TSS, 33% for Cd, 28% for $NO_3^-$, 27% for Zn, 25% for $NO_2^-$ and Cu, 18% for TP, and 17% for Pb and TKN.

A higher pollutant load in a second 25% portion of the runoff volume other than the $1^{ST}$ 25% part results from a concentration peak in the pollutant during a later part of the storm event. In most instances, the strength of the second flush exceeded the first flush strength as a result of the maximum event pollutant concentration occurring in a later portion of the runoff volume other than the first 25% as illustrated for the pollutant loading of TP throughout the March 20, 2003 event. During the March 20, 2003 event, the highest event concentration of 1.3 mg/L for TP occurred during the last ($12^{TH}$) sampling interval (Table 4.16). In addition, the last 25% of the event volume collected during the last sampling interval, as seen in the column for accumulated volume in Table 4.15 and was used as the 25% portion of the event volume for the calculation of second flush. Furthermore for this event, the first 25% of the event volume accumulated over the first 8 sampling intervals with the highest concentration during these 8 intervals occurring during the first sampling interval, with a value of 0.94 mg/L (Table 4.16). Therefore, the second flush contained 40% of the total TP pollutant load, which exceeds the pollutant load of TP contained in the first flush, which was 15%. In this event, the strength of the second flush exceeded the first flush as a result of the maximum event TP concentration occurring during a portion of the event volume beyond the first 25%.

Table 4.16. Normalized event TP pollutant load and runoff volume for March 20, 2003 storm event at Mt. Rainier

| Sample Interval | Accumulated Volume (L) | % Total Volume | Concentration TP (mg/L) | Accumulated Mass of TP (g) | % Total TP Mass Load |
|---|---|---|---|---|---|
| 1 | 2280 | 0.02 | ***0.94*** | 2.1 | 0.02 |
| 2 | 4920 | 0.04 | 0.78 | 4.2 | 0.04 |
| 3 | 6960 | 0.05 | 0.58 | 5.3 | 0.05 |
| 4 | 11520 | 0.09 | 0.64 | 8.2 | 0.07 |
| 5 | 16680 | 0.12 | 0.73 | 12 | 0.11 |
| 6 | 20400 | 0.15 | 0.56 | 14.1 | 0.12 |
| 7 | 24600 | 0.18 | 0.38 | 15.7 | 0.14 |
| 8 | 28320 | 0.21 | 0.42 | 17.3 | 0.15 |
| 9 | 41520 | 0.31 | 0.45 | 23.2 | 0.20 |
| 10 | 55560 | 0.41 | 0.37 | 28.4 | 0.25 |
| 11 | 72600 | 0.54 | 0.29 | 33.3 | 0.29 |
| 12 | 134040 | 1.0 | ***1.3*** | 113.3 | 1.0 |

However in all the remaining storm events, a higher pollutant load in a later 25% portion of the event volume (second flush) resulted from a concentration peak that was weaker than the maximum concentration found in the first 25% of the event volume, which is illustrated using Zn for the October 25, 2002 event. A peak in Zn concentration occurred during the 7$^{TH}$ sampling interval. As a result, a 25% portion of the event volume that partially accumulated over the 7$^{TH}$ sampling interval, in addition to the 8$^{TH}$ and 9$^{TH}$ intervals was evaluated for second flush. For this event, the second flush contained 31% of the total event Zn load, which exceeded the percent of the total pollutant load in the first flush of 23% (Table 4.17). Even though the peak concentration

Table 4.17. Normalized event Zn pollutant load and runoff volume for October 25, 2002 storm event at Mt. Rainier

| Sample Interval | Accumulated Volume (L) | % Total Volume | Concentration Zn (mg/L) | Accumulated Mass Zn (g) | % Total |
|---|---|---|---|---|---|
| 1 | 1800 | 0.02 | ***1.6*** | 2.9 | 0.07 |
| 2 | 5760 | 0.06 | 0.38 | 4.4 | 0.11 |
| 3 | 10920 | 0.12 | 0.29 | 5.9 | 0.15 |
| 5 | 16680 | 0.18 | 0.27 | 7.5 | 0.19 |
| 6 | 23280 | 0.25 | 0.24 | 9.1 | 0.23 |
| Total Mass & Volume for Intervals1-6 | 23280 | | | 9.1 | |
| Flow-weighted Concentration | | | | $\frac{9.1}{23280} = 0.39$ | |
| 7 | 36120 | 0.38 | ***0.61*** | 16.9 | 0.43 |
| 8 | 38640 | 0.41 | 0.48 | 18.1 | 0.46 |
| 9 | 39480 | 0.42 | 0.48 | 18.5 | 0.47 |
| Total Mass & Volume for Intervals 7-8 | $39480 - 23280 = 16200$ | | | $18.5 - 9.1 = 9.4$ | |
| Flow-weighted Concentration | | | | $\frac{9.4}{16200} = 0.58$ | |
| 10 | 59040 | 0.62 | 0.35 | 25.3 | 0.64 |
| 11 | 80400 | 0.85 | 0.4 | 33.8 | 0.85 |
| 12 | 94800 | 1.0 | 0.4 | 39.6 | 1.0 |

of 0.61 mg/L for the second flush was less than the peak concentration of 1.6 mg/L occurring during the first flush, the second flush still contained a higher percent of the pollutant load as a result of the higher flow-weighted concentration for the 3 sampling intervals that contain the second 25% portion of the event volume. The flow-weighted concentration for the first six intervals that contain the first 25% of the event volume is 0.39 mg/L, while the flow-weigthed concentration for the $7^{TH}$, $8^{TH}$, and $9^{TH}$ sampling intervals is 0.58 mg/L. In summary, a higher pollutant mass load in a second 25%

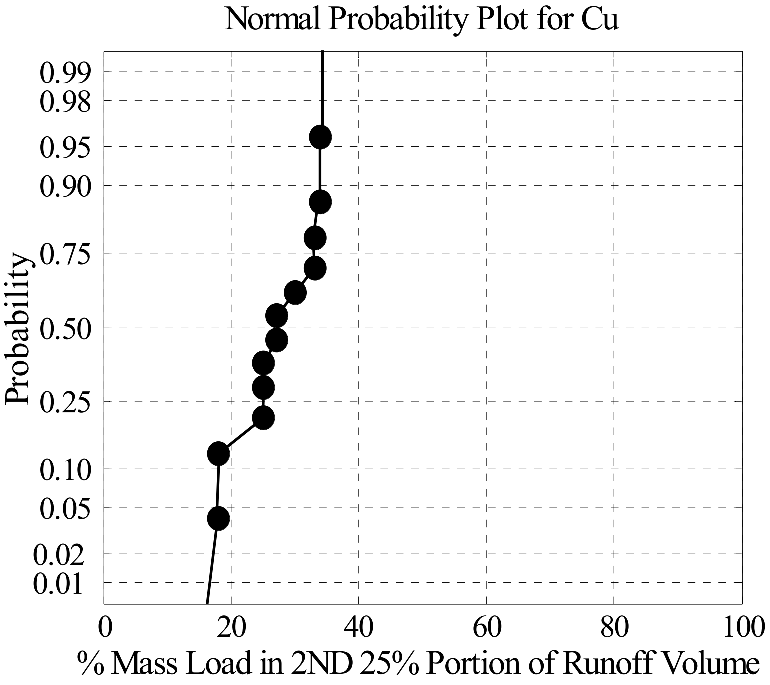
fraction of the event volume beyond the first 25% can result from a concentration peak in a second portion of the event volume that is greater than or less than the peak concentration occurring during the first 25% of the runoff volume and depends on the corresponding flowrate.

In a manner similar to first flush, probability plots were created for the percent of the mass pollutant load in a second portion of the runoff volume for all storm events. Due to the limited number of data points for events in which the percent pollutant load was greater than or equal to 50% in the second 25% fraction, the plots will not be used to interpret extreme probabilities. The probability plots for second flush in Figures 4.11a through 4.11i were used to determine the median values of the percent load in the second flush for all pollutants. Table 4.18 presents the median values for the percent of the load that is contained in the first flush from Figures 4.10a to 4.10i and second flush for each contaminant.

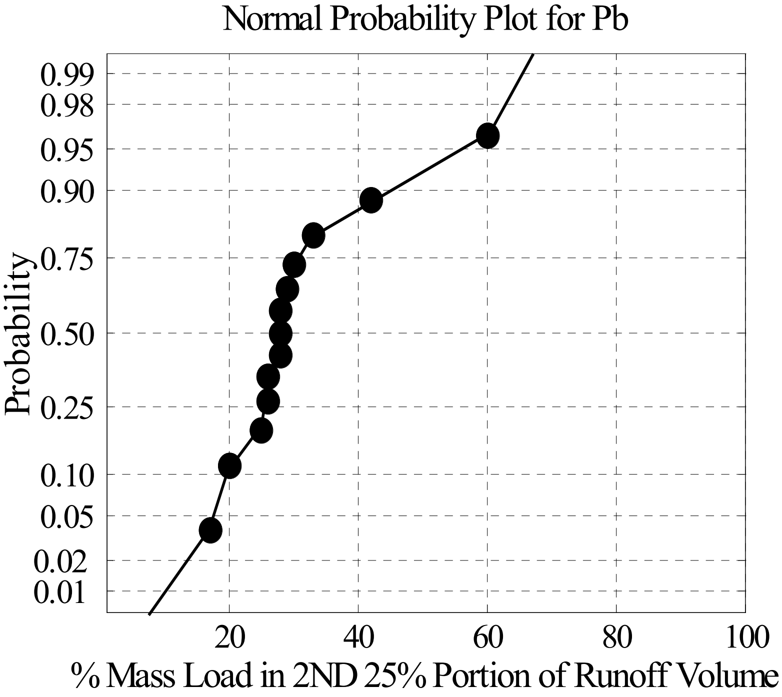
Table 4.18. Median values for % mass pollutant load flushed in the $1^{ST}$ 25% and a second 25% portion of the runoff volume

| | TSS | Cd | Cu | Pb | Zn | TKN | $NO_3^-$ | $NO_2^-$ | TP |
|---|---|---|---|---|---|---|---|---|---|
| $1^{ST}$ | 33 | 32 | 39 | 36 | 34 | 38 | 34 | 38 | 40 |
| $2^{ND}$ | 34 | 32 | 27 | 28 | 28 | 27 | 31 | 34 | 28 |

The median value for the first flush is greater than the second flush for all contaminants, except for TSS and Cd. This indicates that overall, the strength of the first flush is greater than second flush, although upon analyzing individual events the second flush can be stronger. In addition, although overall the amount of the pollutant load

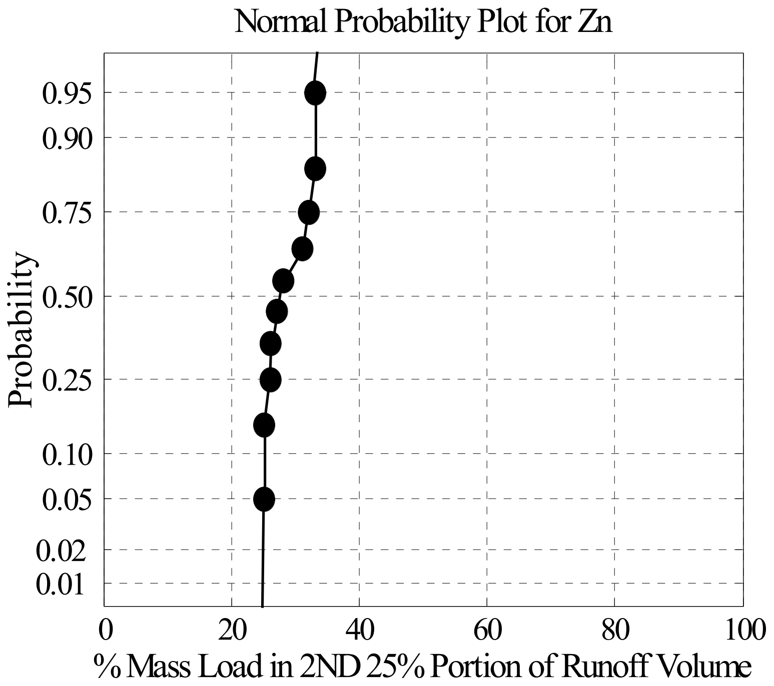


(a)

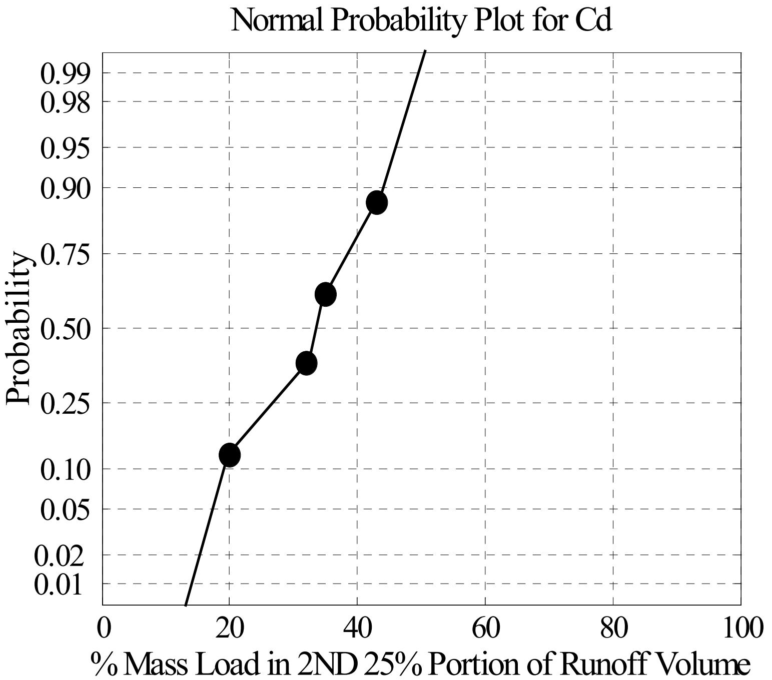


(b)

Figure 4.11. Probability plots of the percent of the total mass of (a) Cu, (b) Pb, (c) Zn, (d) Cd, (e) TSS, (f) TKN, (g) $NO_3^-$, (h) $NO_2^-$, (i) TP that flushes in a $2^{ND}$ 25% portion of the event volume at the Mt. Rainier, MD site

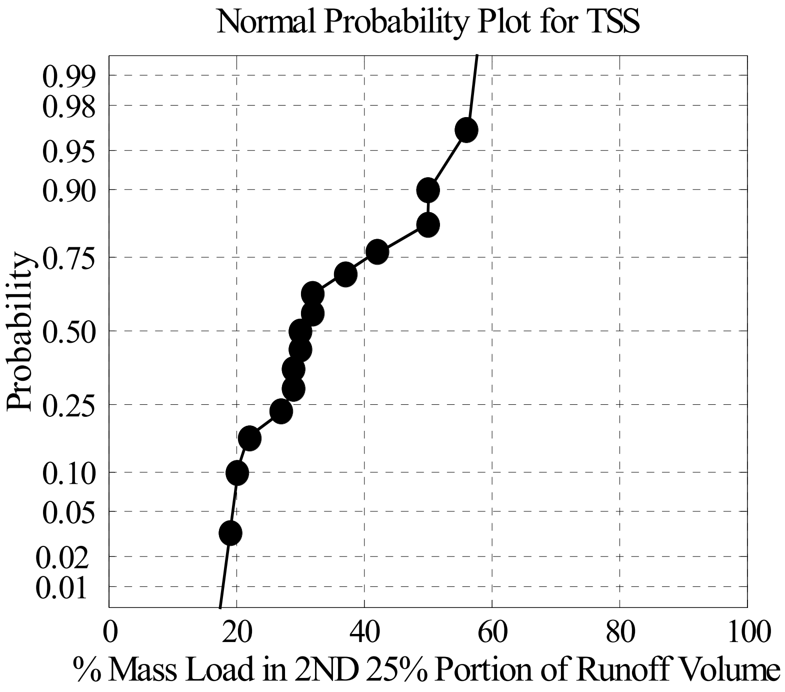


(c)

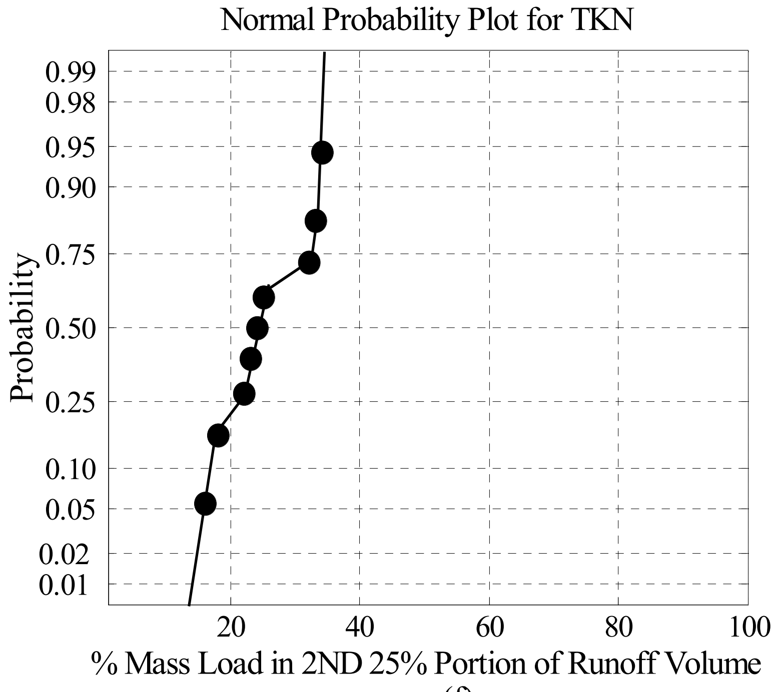


(d)

Figure 4.11. Continued

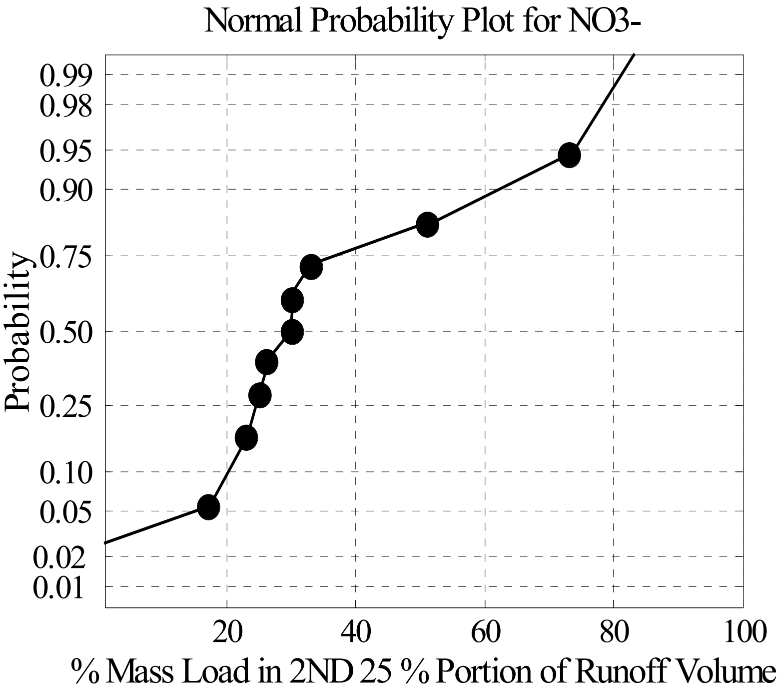


(e)

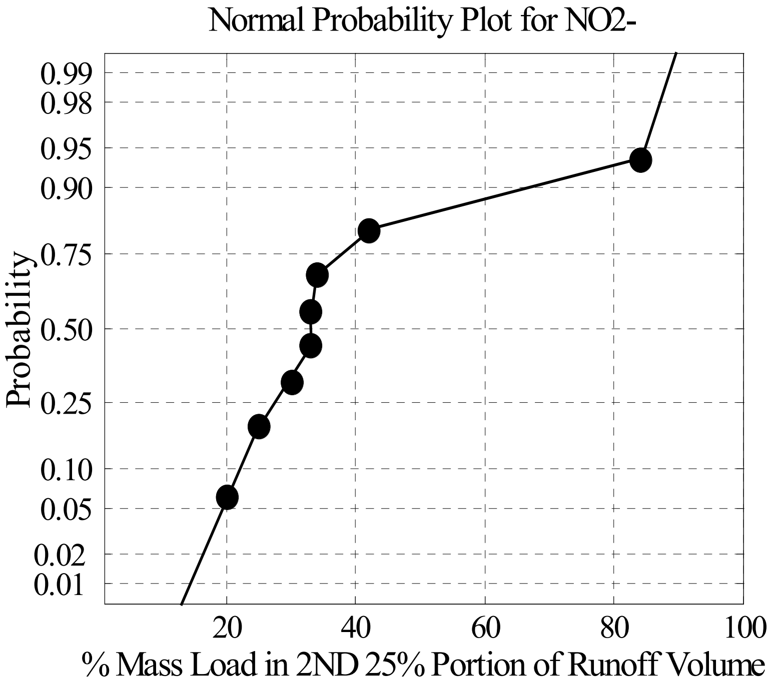


(f)

Figure 4.11. Continued

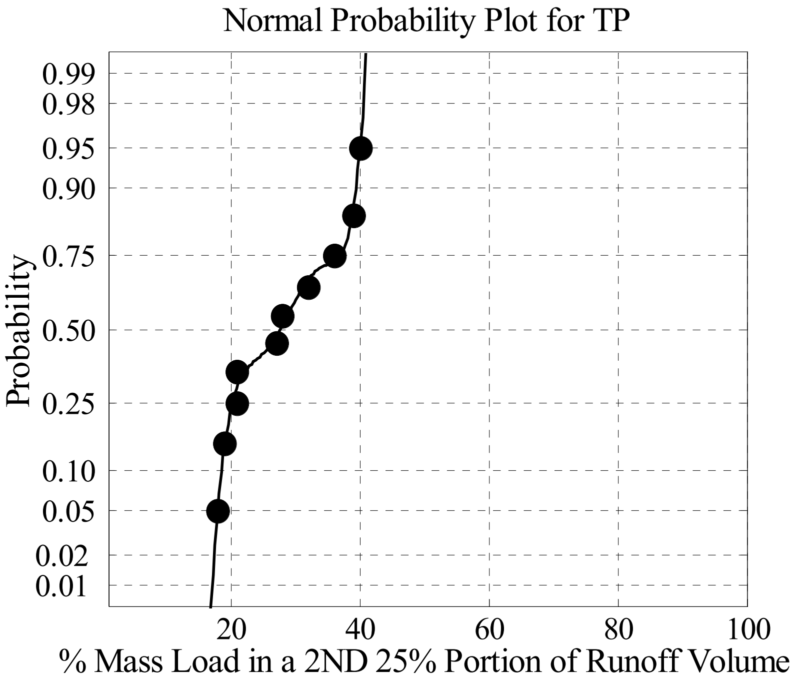


(g)



(h)

Figure 4.11. Continued



(i)

Figure 4.11. Continued

contained in the first 25% portion exceeds the amount of the pollutant load contained in a second 25% portion of the event volume, the second flush still contains a significant portion of the pollutant load, as indicated by the median values for the percent of the pollutant loads, which range between 34% for $NO_2^-$ and TSS and 27% for TKN and Cu. As a result, current bioretention facilities, which are designed to capture the first portion of the event volume may not treat a significant part of the pollutant load. Ideally, the most effective bioretention design would be capable of treating the entire event runoff volume. Effective bioretention design would be capable of treating the entire event runoff volume.

### 4.7.2 Correlations with Storm Characteristics

Plots of the fraction of the total pollutant mass contained in the first 25% of the runoff volume as well as later 25% portions beyond the first versus storm characteristics were created to evaluate any correlations. In Figure 4.12, the fractions of the total TSS pollutant load in the first 25% of the runoff volume were plotted against the antecedent dry period, storm duration, 25% of the total runoff volume, and the peak flowrate occurring during the first 25% of the runoff volume for the 13 storm events with complete hydrology data and concentration profiles. The correlation coefficient for the linear fit between the fraction of the TSS pollutant load in the first 25% of the runoff volume and the storm duration is –0.015, indicating that the pollutant loading in the first 25% of the event volume does not correlate with storm duration. Similarly, the correlation coefficients between TSS mass loading and ADP, peak flowrate, and 25% runoff volume were –0.26, -0.0017, and –0.0092, indicating that the mass loading of TSS does not correlate with these storm characteristics. Table 4.19 presents the correlation coefficients between the pollutant load in the first 25% and a second 25% portion beyond the first and each storm characteristic for each pollutant.

From Table 4.19, the largest correlation coefficient for the fraction of mass in the first 25% of the runoff volume for any pollutant and the storm characteristics was for the relationship between TSS mass loading and ADP, which was –0.26. All other correlation coefficients between the mass loading of other pollutants and storm characteristics were less than this value. Overall, the mass loading in the first 25% of the runoff volume does not correlate with any of the storm characteristics for all pollutants.

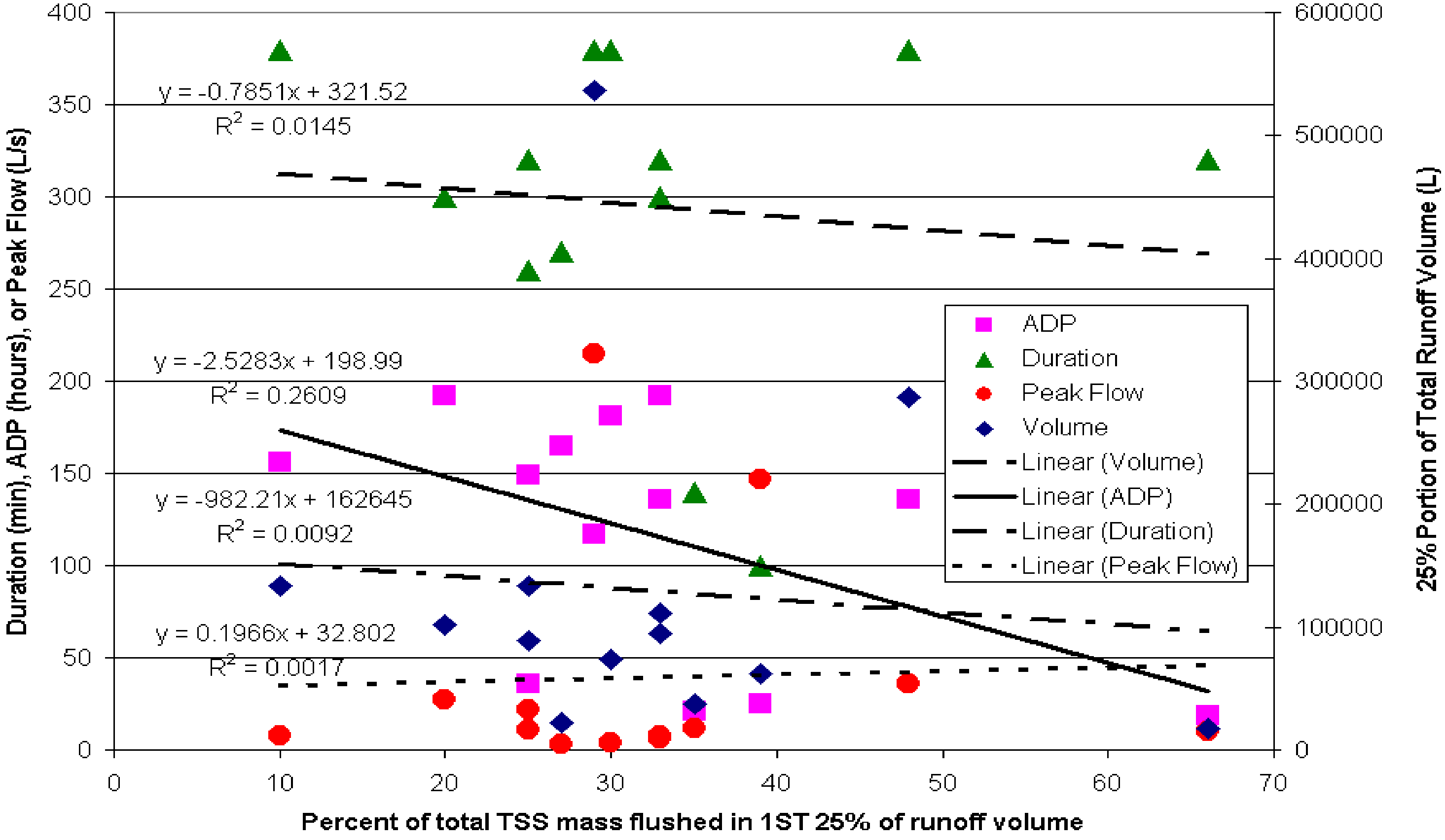


Figure 4.12. Relationships between storm characteristics and % total TSS pollutant mass in First 25% of the runoff volume

Table 4.19. Correlation between storm characteristics and % mass in 1ST 25% and later 25% of runoff volume

| | Number of Storm Events | Storm Characteristic | | | |
|---|---|---|---|---|---|
| | | Event Duration | Antecedent Dry Period | 25% of Runoff Volume | Peak Flowrate |
| % Mass in $1^{ST}$ 25% of event volume | | | | | |
| Cu | 14 | -0.01 | -0.060 | +0.19 | +0.12 |
| Pb | 14 | -0.19 | -0.094 | -0.0017 | +0.059 |
| Zn | 14 | -0.0002 | -0.056 | +0.17 | +0.18 |
| TSS | 13 | -0.015 | -0.26 | -0.0092 | -0.0017 |
| TKN | 13 | +0.13 | -0.048 | +0.041 | +0.0012 |
| $NO_3^-$ | 14 | +0.15 | +0.17 | +0.0005 | -0.040 |
| $NO_2^-$ | 10 | -0.075 | +0.0006 | -0.039 | -0.036 |
| TP | 13 | +0.011 | +0.0006 | -0.043 | -0.096 |
| % Mass in later 25% portion of event volume | | | | | |
| Cu | 7 | +0.18 | +0.39 | -0.085 | +0.018 |
| Pb | 7 | +0.22 | +0.22 | -0.0058 | -0.12 |
| Zn | 9 | +0.34 | +0.13 | +0.0007 | -0.0084 |
| TSS | 9 | +0.21 | +0.35 | -0.0045 | -0.028 |
| TKN | 4 | -0.023 | -0.0066 | -0.75 | -0.029 |
| $NO_3^-$ | 3 | +0.70 | +0.20 | +0.93 | +0.99 |
| $NO_2^-$ | 3 | +0.25 | -0.70 | +0.94 | +0.23 |
| TP | 4 | +0.88 | +0.55 | +0.70 | +0.95 |

In contrast, the fraction of the pollutant load in a second 25% of the runoff volume beyond the first exhibited similar trends between constituents. The three heavy metals, Cu, Pb, and Zn, and TSS demonstrated positive correlations of at least 0.13 with antecedent dry period and at least 0.18 with event duration. Although these four pollutants all exhibited positive correlations with ADP and event duration, the correlations were very weak. In addition, their correlation coefficients with 25% runoff volume and peak flowrate were smaller than with storm duration and ADP, indicating that Cu, Pb, Zn, and TSS do not correlate with 25% of the event volume or peak flowrate.

The nutrients, $NO_3^-$, $NO_2^-$, and TP showed high positive correlations with some storm characteristics. For instance, the pollutant mass of $NO_3^-$ in a later portion of the runoff volume beyond the first resulted in a correlation coefficient of +0.70, +0.93, and +0.99 with event duration, 25% runoff volume, and peak flowrate. In addition, the mass loading of TP demonstrated correlation coefficients of +0.88, +0.55, +0.70, and +0.95 with event duration, ADP, 25% runoff volume, and peak flowrate, respectively. Finally, TKN and $NO_2^-$ showed correlations of –0.75 and +0.94 with 25% runoff volume, respectively. $NO_2^-$ also negatively correlated with ADP, with a coefficient of 0.70.

The correlation coefficients for TKN, $NO_3^-$, $NO_2^-$, and TP were determined using only 3 or 4 data points. If a larger data set was available and plotted, more reliable information could be obtained. Although there were a limited number of data points, very weak correlation coefficients were determined for TKN, $NO_3^-$, and $NO_2^-$. For example, TKN exhibited very weak correlations with event duration, ADP, and peak flowrate (-0.023, -0.0066, -0.029), yet its correlation coefficient with 25% runoff volume was –0.75.

### 4.7.3 Qualitative

In order to qualitatively characterize flushing throughout the entire storm event, plots of mass loading ratio versus runoff volume ratio were made for each of the pollutants. Due to the large number of data sets, one plot each was made for the storm events occurring in 2002 and 2003 for each of the pollutants. Figure 4.13 and 4.14 present the normalized loading ratio of $NO_3^-$ versus the normalized runoff volume ratio for the storm events occurring in 2002 and 2003. In Figures 4.13 and 4.14, the flushing curves that are labeled as high represent flushing when the lowest standard concentration or detection limit was used for samples with concentrations below the lowest standard or detection limit. In contrast, storm events that are labeled as low represent flushing when zero concentration is used for samples with concentrations that are below the limits.

Qualitatively, flushing occurs when the mass loading ratio is proportionally greater than the runoff volume ratio, which is distinguished by the 45 degree line on the plots. Flushing occurs throughout the entire storm for all pollutants for all storm events with only a few exceptions, as seen in Figures 4.13 and 4.14 in which the June 19 and 27, 2002, the September 26, 2002 high and low storm events, and the May 16, 2003 high and low curves lie below the 45 degree line. Three storm events out of a total of 18 storm events did not exhibit flushing for $NO_3^-$, which corresponds to 22% of the storms. Table 4.20 lists the number of storm events that exhibit flushing and the corresponding percent of storm events. Flushing throughout each event occurred in the highest percent of the

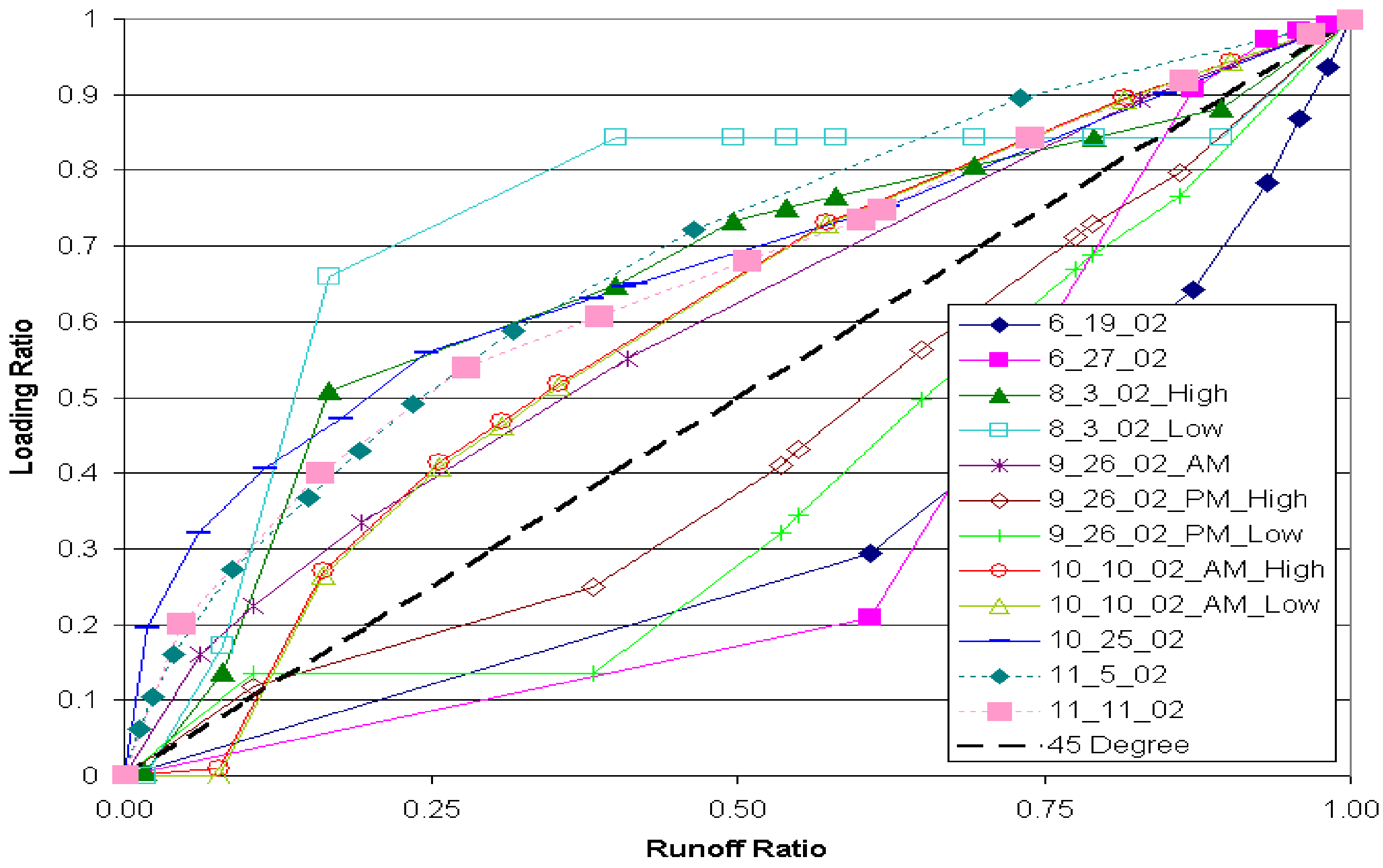


Figure 4.13. Normalized loading ratio of $NO_3^-$ versus runoff ratio for storm events occurring in 2002 at Mt. Rainier, MD site

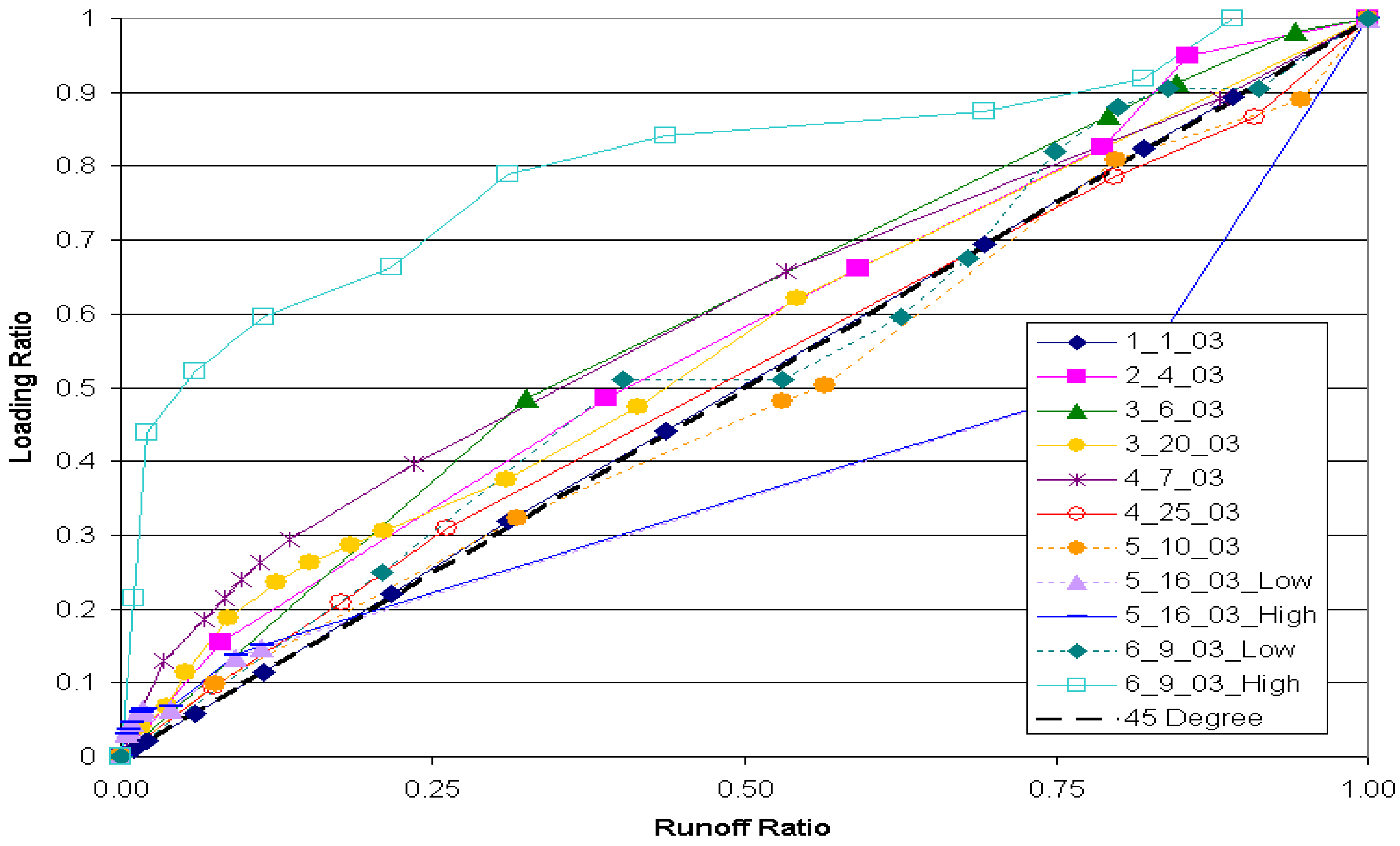


Figure 4.14. Normalized loading ratio of $NO_3^-$ versus runoff ratio for storm events occurring in 2003 at Mt. Rainier, MD site

Table 4.20. Storm events characterized by pollutant loads that flushed in proportionally smaller amounts than the runoff volume at the Mt. Rainier, MD site

| Pollutant | TSS | Cd | Cu | Pb | Zn | TKN | $NO_3^-$ | $NO_2^-$ | TP |
|---|---|---|---|---|---|---|---|---|---|
| Number of Storm Events | 23 | 6 | 24 | 24 | 22 | 23 | 18 | 24 | 22 |
| Number of Events Exhibiting Flushing | 19 | 4 | 22 | 20 | 19 | 20 | 14 | 16 | 18 |
| % Events Exhibiting Flushing | 83 | 67 | 92 | 83 | 86 | 86 | 78 | 83 | 83 |

storms for Cu at 92% and in the smallest percent of the storms for Cd at 67%. The results for Cd may be skewed based on the limited number of 6 data sets, whereas the results for the other pollutants are based on at least 18 storm events.

Overall, using both the detection limit or lowest standard concentration and zero for samples below the detection range did not effect flushing results, qualitatively. Both the curves exhibit or do not exhibit flushing for all events except the storm occurring on the evening of November 26, 2003. The exception occurred for TP during this storm event in which TP demonstrated flushing only when the sample concentration was represented as the lowest standard concentration. In summary, flushing occurred throughout the event duration in at least 67% of the events for all pollutants. These results further support the importance of treating the runoff volume throughout the storm duration as opposed to treating only the initial portion in its entirety.

Three other research studies have qualitatively characterized flushing for roadway stormwater runoff from rural areas. One researcher, Deletic (1997), plotted cumulative loading/cumulative runoff curves for suspended solids at two sites, Lund and Miljakovac, Sweden (Figure 4.15). Flushing of TSS occurred for the majority of storm events with the mean flushing curve at both sites falling above the 45-degree line. Deletic's findings are consistent with flushing of TSS at the Mt. Rainier site, where TSS consistently exhibited flushing throughout storm events.

Lee and Bang (2000) characterized flushing for COD, SS, $NO_3^-$, $PO_4^-$, n-hexane extracts, and Pb using normalized loading/normalized runoff curves for samples collected in Chongju City and Taejon City, South Korea. Lee and Bang were interested in determining the effects of different site parameters on rainfall characteristics. Therefore, these researchers analyzed a few storms from combined sewer systems for multiple sites and presented flushing data for only one or two storms. Due to the limited number of data sets and the use of samples from combined sewer systems, direct comparison of Mt. Rainier data with the data from Lee and Bang's study is not beneficial.

Finally, Sansalone and Buchberger (1997) analyzed flushing of TSS and the dissolved and particulate bound fractions of Cd, Cu, Pb, and Zn for four storm events by plotting the normalized mass and volume against the normalized time (Figures 4.16). Therefore, flushing results when the curves for normalized mass exceed the normalized volume. Overall, flushing occurred for all constituents for all storm events. Exceptions to the predominance of flushing resulted for the particulate bound fractions of Cd, Cu, and Pb, during the September 8, 1995 storm event and for particulate bound Cd during the April 20, 1995 storm event and the second half of the April 8, 1995 storm event.

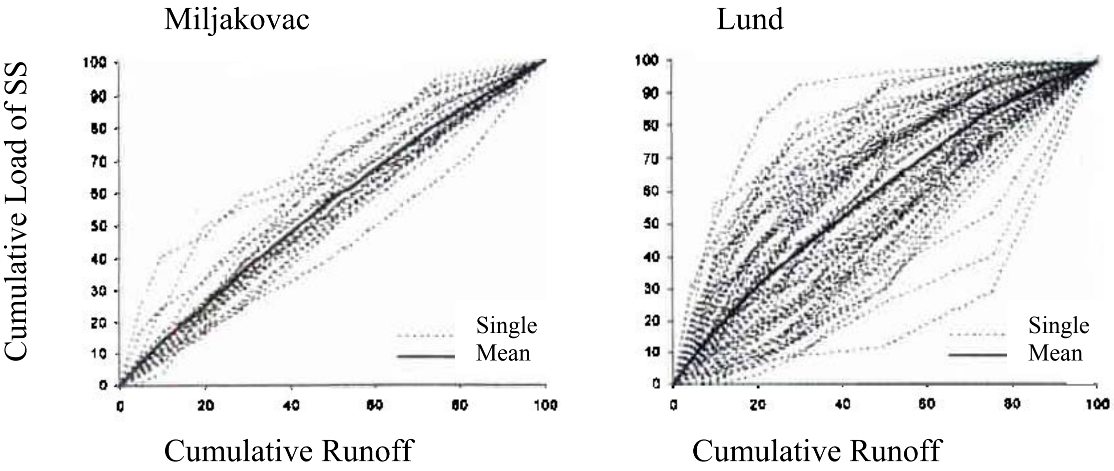
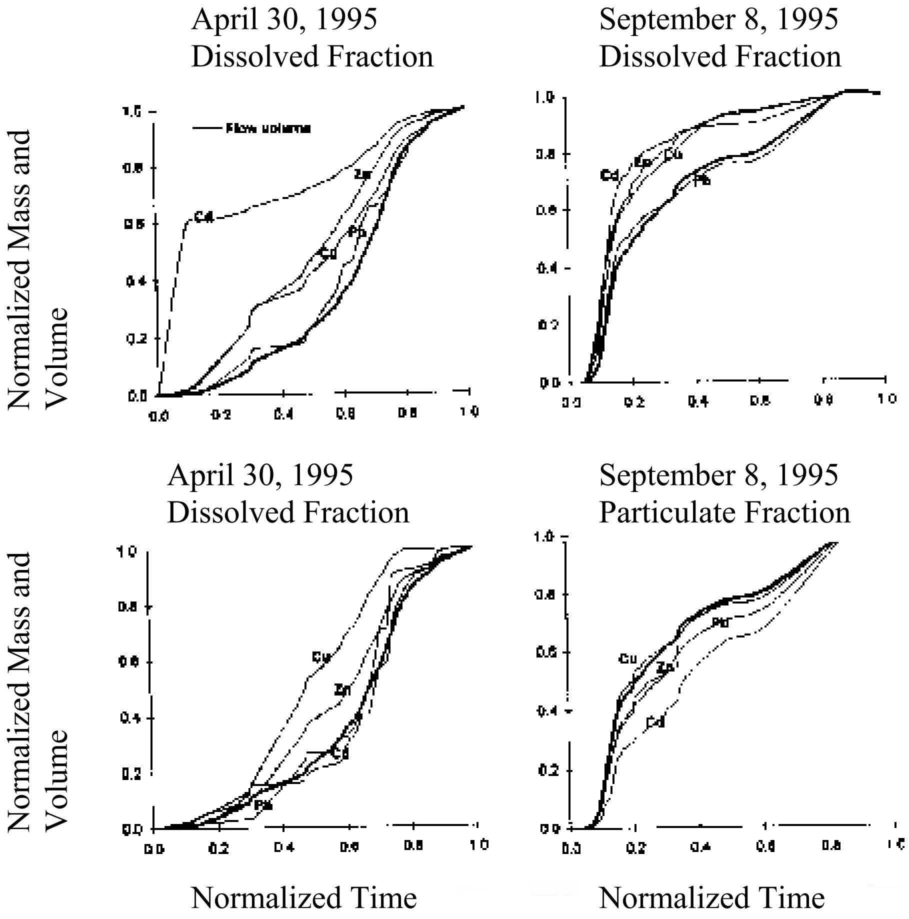
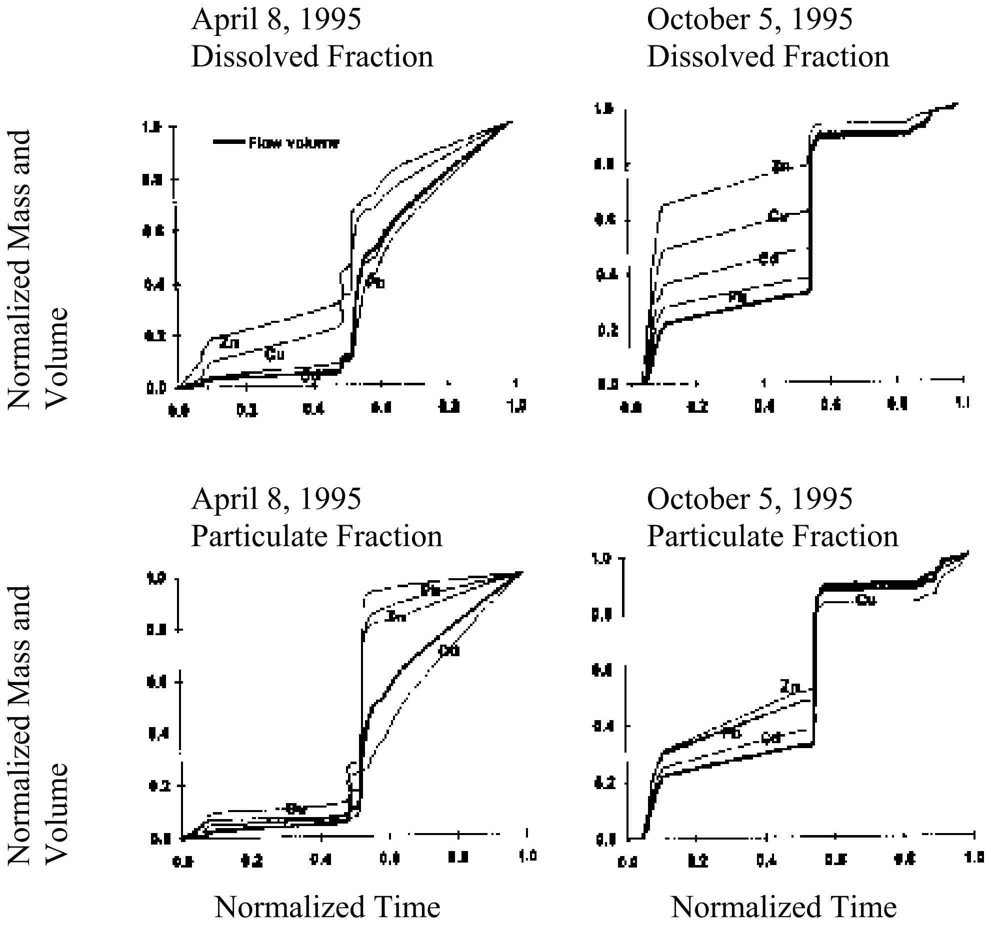


Figure 4.15. Cumulative curves of suspended solids for Miljakovac and Lund, Sweden (Deletic, 1997)



(a)

Figure 4.16. Mass and flow volume curves for (a) low intensity, low flow volume events and (b) high intensity, high volume events (Sansalone et al., 1997)


April 8, 1995
Dissolved Fraction

October 5, 1995
Dissolved Fraction

April 8, 1995
Particulate Fraction

October 5, 1995
Particulate Fraction

(b)

Figure 4.16. Continued

### 4.8 Bioretention Evaluation

A rough estimate of the filtration/bioretention facilities ability to improve the quality of the stormwater runoff from the Mt. Rainier, MD site can be based on its filtration capacity. An infiltration rate for stormwater runoff at the Mt. Rainier site was determined by multiplying the total filtration area of 40.2 $m^2$ (432 $ft^2$) at the site that includes the filter area of the two gutter filters and the bioretention chamber, by the infiltration rate that characterizes the filter media. Typically, bioretention soil media consists of 50% construction sand, 20-30% top soil, and 20-30% leaf compost that is a HSG Type A composite soil with an estimated infiltration rate of 6.12 cm/hr (2.41 in/hr) (Winogradoff, 2001). Since the infiltration rate is an estimated value, a more conservative value of 2.54 cm/hr (1 in/hr) was used in addition to the estimated value as the characteristic infiltration rate for the bioretention media. Using the conservative infiltration rate of 2.54 cm/hr, 1.02 $m^3$/hr (36 $ft^3$/hr) of stormwater runoff can filter through the gutter filters and bioretention chamber, whereas more than twice that amount, 2.46 $m^3$/hr (86.9 $ft^3$/hr), can be filtered when utilizing the estimated infiltration rate of 6.12 cm/hr. Both of the calculated infiltration volumes can differ from the actual amount of stormwater runoff produced as a result of the rainfall. Consequently, the rate of stormwater runoff delivered to the filter media was determined for the 17 storm events with complete hydrological data by multiplying the storm intensity for each event by the drainage area of the Mt. Rainier site (Table 4.21).

Table 4.21. Comparison of the stormwater runoff delivered to the filter media and the stormwater runoff that can infiltrate the media

| Date | Average Storm Intensity (cm/hr) | Delivered Runoff ($m^3$/hr) | Percent Delivered Runoff Infiltrated | |
|---|---|---|---|---|
| | | | Infiltration Rate = 1.02 $m^3$/hr | Infiltration Rate = 2.46 $m^3$/hr |
| 10/25/02 | 0.40 | 21 | 4.9 | 12 |
| 11/5/02 | 0.27 | 15 | 7.0 | 17 |
| 12/11/02 | 0.18 | 9.7 | 11 | 25 |
| 12/20/02 | 0.24 | 13 | 7.9 | 19 |
| 1/1/03 | 0.3 | 14 | 7.4 | 18 |
| 2/21/03 | 0.05 | 2.4 | 42 | 100 |
| 3/6/03 | 0.09 | 4.8 | 21 | 51 |
| 3/20/03 | 0.37 | 19 | 5.3 | 13 |
| 4/7/03 | 0.20 | 10 | 9.7 | 23 |
| 4/25/03 | 0.11 | 5.6 | 18 | 44 |
| 5/10/03 | 0.17 | 8.9 | 11 | 28 |
| 5/16/03 | 0.59 | 31 | 3.2 | 7.8 |
| 5/31/03 | 1.1 | 56 | 1.8 | 4.4 |
| 6/9/03 | 0.12 | 6.5 | 16 | 38 |
| 8/16/03 | 0.46 | 24 | 4.2 | 10 |
| 8/27/03 | 0.91 | 48 | 2.1 | 5.1 |
| 9/12/03 | 0.34 | 18 | 5.7 | 14 |

In all instances, the amount of stormwater runoff delivered to the filter media exceeded the amount of stormwater runoff that can infiltrate the media, using both the conservative and estimated infiltration rates for the soil media. When the infiltration rates were used, 25% of the delivered runoff was treated in one storm event (February 21, 2003) for the conservative value and 6 storm events for the estimated value.

In addition to the filter media, there are two collection chambers and one pretreatment chamber with a total volume of 1.91 $m^3$ that can contain an initial portion of the runoff volume for each event. In Table 4.22, the total runoff volume for each event was determined by multiplying the rainfall depth by the drainage area. For 16 of the 17 storm events, the percent of the total runoff volume that was collected was less than 12%. The exception was for the February 21, 2003 event in which 67% of the event volume was collected. In summary, 25% of the runoff volume was collected for recharge to ground water in 6% of the storm events and 25% of the delivered runoff was treated in 35% of the storm events when using the estimated infiltration rate, in contrast to 6% of the events when using the conservative infiltration rate. The infiltration rate of the treatment media affects the amount of runoff that can be treated.

Table 4.22. Percent of the runoff volume collected for each event by collection chambers at Mt. Rainier, MD

| Date | Rainfall (cm) | Runoff Volume ($m^3$) | Percent Runoff Volume Collected |
|---|---|---|---|
| 10/25/02 | 2.1 | 119 | 1.6 |
| 11/5/02 | 1.4 | 78 | 2.5 |
| 12/11/02 | 0.97 | 54 | 3.6 |
| 12/20/02 | 1.1 | 59 | 3.2 |
| 1/1/03 | 1.6 | 89 | 2.1 |
| 2/21/03 | 0.05 | 2.8 | 67 |
| 3/6/03 | 0.51 | 28 | 6.7 |
| 3/20/03 | 3.9 | 215 | 0.89 |
| 4/7/03 | 1.6 | 88 | 2.2 |
| 4/25/03 | 0.46 | 25 | 7.5 |
| 5/10/03 | 0.38 | 21 | 9.0 |
| 5/16/03 | 4.0 | 224 | 0.85 |
| 5/31/03 | 1.1 | 59 | 3.2 |
| 6/9/03 | 0.51 | 28 | 6.7 |
| 8/16/03 | 0.28 | 16 | 12 |
| 8/27/03 | 1.4 | 79 | 2.4 |
| 9/12/03 | 0.99 | 55 | 3.5 |

## Chapter 5

## CONCLUSIONS and RECOMMENDATIONS

Removal of pollutants from stormwater runoff has received particular attention locally because stormwater runoff contributes 75 to 90% of the pollution to the Anacostia River (EPA, 2003), which is the most populated subwatershed in the Chesapeake Bay watershed (Chesapeake, 2003). As result, evaluation of LID practices such as bioretention has received focus for the treatment of stormwater runoff because it employs natural mechanisms for pollutant removal, while striving to maintain the pre-development hydrology. As part of this research, the quality of stormwater runoff from a site in Mt. Rainier, MD, in which a bioretention facility is currently being retrofit, was characterized to meet in part the main goal of this project, that is to determine the ability of the retrofit to improve water quality. Stormwater characterization at Mt. Rainier, MD was achieved using the analyzed pollutant concentrations of discrete samples collected over the event duration for multiple storm events and the stormwater runoff flowrates calculated at two minute intervals for each storm event. In addition, flushing of pollutants was quantitatively analyzed throughout the storm event to determine if significant amounts of the pollutant load flushes in later portions of the event volume beyond the first 25% to support or refute the current first flush theory.

Water quality characterization resulted in EMC and pollutant loadings at the Mt. Rainier site greater in comparison to values determined for sites studied by other researchers. The mean EMC in mg/L and pollutant loadings in kg/ha/yr at the Mt. Rainier site were 0.035 and 0.24 for Cd, 0.11 and 0.84 for Cu, 0.22 and 1.7 for Pb, 1.18 and 8.5 for Zn, 420 and 3100 for TSS, 3.4 and 25 for TKN, 0.96 and 11.2 to 11.6 for

$NO_{2=3}^-$, and 0.56 and 3.9 to 4.6 for TP. The higher EMC and pollutant values appear to be mainly a result of the ultra-urban nature of the Mt. Rainier site, in contrast to the stormwater runoff at sites sampled in recent studies, which are located in rural areas. In addition, the annual rainfall at Mt. Rainier was higher than at any of the sites studied by other researchers, which also contributed to the higher annual loadings.

As part of the water quality characterization, concentration profiles were created to evaluate correlations between various stormwater pollutants. Cu, Pb, and Zn exhibited the highest number of incidences in which peaks in their concentrations occurred at the same point in time as peaks in TSS, corresponding to 58% of the storms for Cu, 55% for Zn, and 54% for Pb. However, $NO_2^-$, Cd, and TP demonstrated the fewest number of incidences in which their peaks in concentration corresponded with peaks in TSS concentration. Consequently, $NO_2^-$ peaks corresponded with TSS peaks in only 8% of the events, Cd in 17% of the events, and TP in 18% of the events. This supports the hypothesis that Cu, Pb, and Zn were predominantly associated with the particulate fractions of the stormwater runoff from Mt. Rainier, MD, yet $NO_2^-$ and TP were largely present in the dissolved phase.

First flush is defined as flushing of 50% of the total pollutant load in the first 25% of the event runoff volume. First flush occurred in 33% of the storm events for $NO_2^-$, 27% for TP, 22% for $NO_3^-$ and TKN, 21% for Cu, and 17% for TSS, 14% for Zn, and13% for Pb. On the other hand, second flush that is defined as flushing of 50% of the total pollutant load in 25% of the runoff volume beyond the first 25% transpired in 17% of the storm events for TSS, 11% of for $NO_3^-$, 5% for Zn, 4% for Pb and $NO_2^-$. No second flush was noted for for Cd, Cu, TKN, and TP. In addition, the median value for the percent of the total pollutant load flushed in the first 25% of the runoff volume was greater than the median value for the second flush for all pollutants, except TSS. Sometimes, the amount of the pollutant load contained in the first 25% of the runoff volume exceeds the pollutant load flushed in later portions of the runoff volume.

Despite the predominance of greater pollutant loading in the first flush, there were occasions in which the pollutant loading in a later 25% portion exceeded that in the first 25%. This occurred in 39% of the storm events for TSS, 33% for Cd, 28% for $NO_3^-$, 27% for Zn, 25% for $NO_2^-$ and Cu, 18% for TP, and 17% for Pb and TKN. As hypothesized, a significant amount of the pollutant load can be contained in portions of the runoff volume other than the first 25%. Furthermore, particulates exhibited the highest incidences in which the strength of the second flush exceeded the strength of the first flush. In contrast to predictions, however, particulate-bound constituents, Pb, Cu, and Zn did not display a greater tendency to flush a significant portion of their pollutant load in later portions of the runoff volume than dissolved constituents.

Most importantly, quantitative evaluation of flushing throughout the storm event makes it possible to determine the applicability of designing bioretention facilities to capture the first portion of an event's runoff volume. The overall higher pollutant loadings in the first 25% of the runoff volume and the higher median values for the percent of the pollutant load flushed in the first portion of the runoff volume, except TSS indicates that if only a certain portion of the runoff volume can be treated than higher pollutant removal rates could be achieved by treating the first 25%. The exception is the pollutant TSS which exhibited the same tendency to exhibit second flush as first flush and showed similar median values for its pollutant load in the first and second flush.

However, the median values for the percent of the pollutant load contained in the first flush are 39% or less for all pollutants. This indicates that greater than 50% of the total pollutant load can be flushed in portions of the runoff volume other than the first 25%. In addition, the second flush exceeds the first flush in at least 17% of the storms for all pollutants. Ideally, bioretention facilities should treat as much of the runoff volume as possible to improve the storm water runoff quality.

Evaluation of the amount of stormwater runoff that can be filtered, using a infiltration rate of 2.54 cm/hr or 6.12 cm/hr, resulted in infiltration of between 1.8 and 42% and 4.4 and 100% of the delivered runoff volume for the 17 storm events with complete hydrologic data. In addition, the two collection chambers and one pretreatment chamber that were part of the bioretention facility held 12% or less of the total runoff volume for 16 out 17 of the storm events. The exception was the February 21, 2003 event in which 67% of the total runoff volume was captured by the collection chambers. Therefore, the amount of the runoff volume that is captured by the infiltration/bioretention media is highly dependent on the infiltration rate of the system.

Areas in which information is lacking become apparent when attempting to explain the results of this research. For instance, the pollutant loadings at the ultra-urban Mt. Rainier site were consistently higher than at rural sites studied by other researchers. It would be interesting to determine if transboundary transport of pollutants outside the drainage area contributes to the higher loading, during high intensity storms, by completing tracer studies at rural and urban sites. In addition, research that analyzes the dependence of particulate size fractions in stormwater runoff on rainfall intensity could aid in predicting the types and amounts of particulate-bound pollutants present in the runoff. Furthermore, further research should determine if it is possible to create predictive models for pollutant loadings in the stormwater runoff at the Mt. Rainier site. Finally, studies that determine the infiltration rate of various media and the impact of the infiltration rate on biodegradation and evapotranspoiration of metal and nutrient removal in bioretention would contribute to understanding bioretention performance.

The ability of bioretention to remove at least 90% of the metals, Cu, Pb, and Zn has been documented for a retrofit facility in Greenbelt, MD (Davis et al., 2003). Ultimately, the goal of this research is to verify that bioretention is beneficial in removal of nutrients and heavy metals from stormwater runoff at Mt. Rainier, MD with performance data. Therefore, further research will involve characterizing stormwater runoff at the Mt. Rainier site after installation of the retrofit for future comparison of stormwater runoff quality before and after installation of the retrofit.

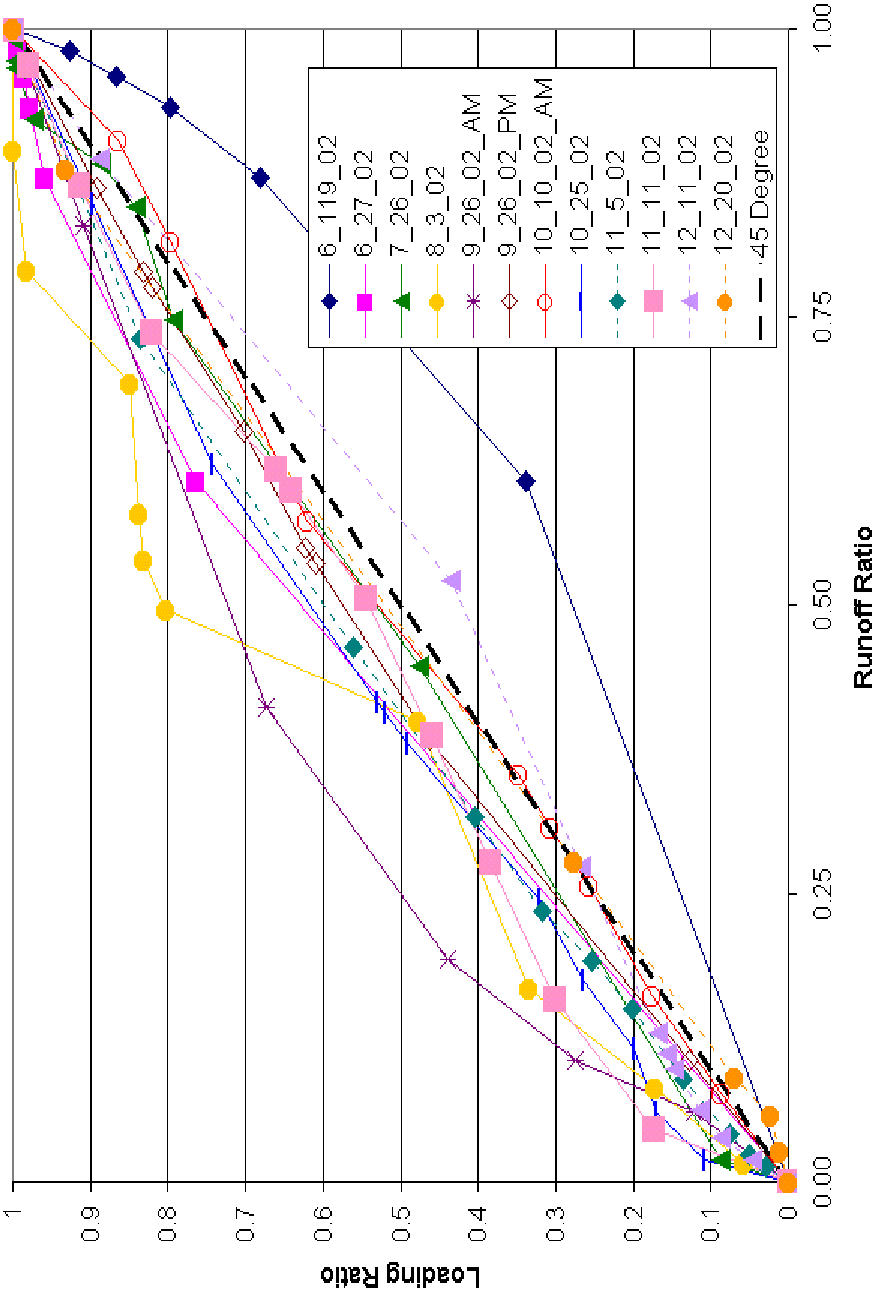


Figure A1. Flushing curves for TSS for 2002 storm events

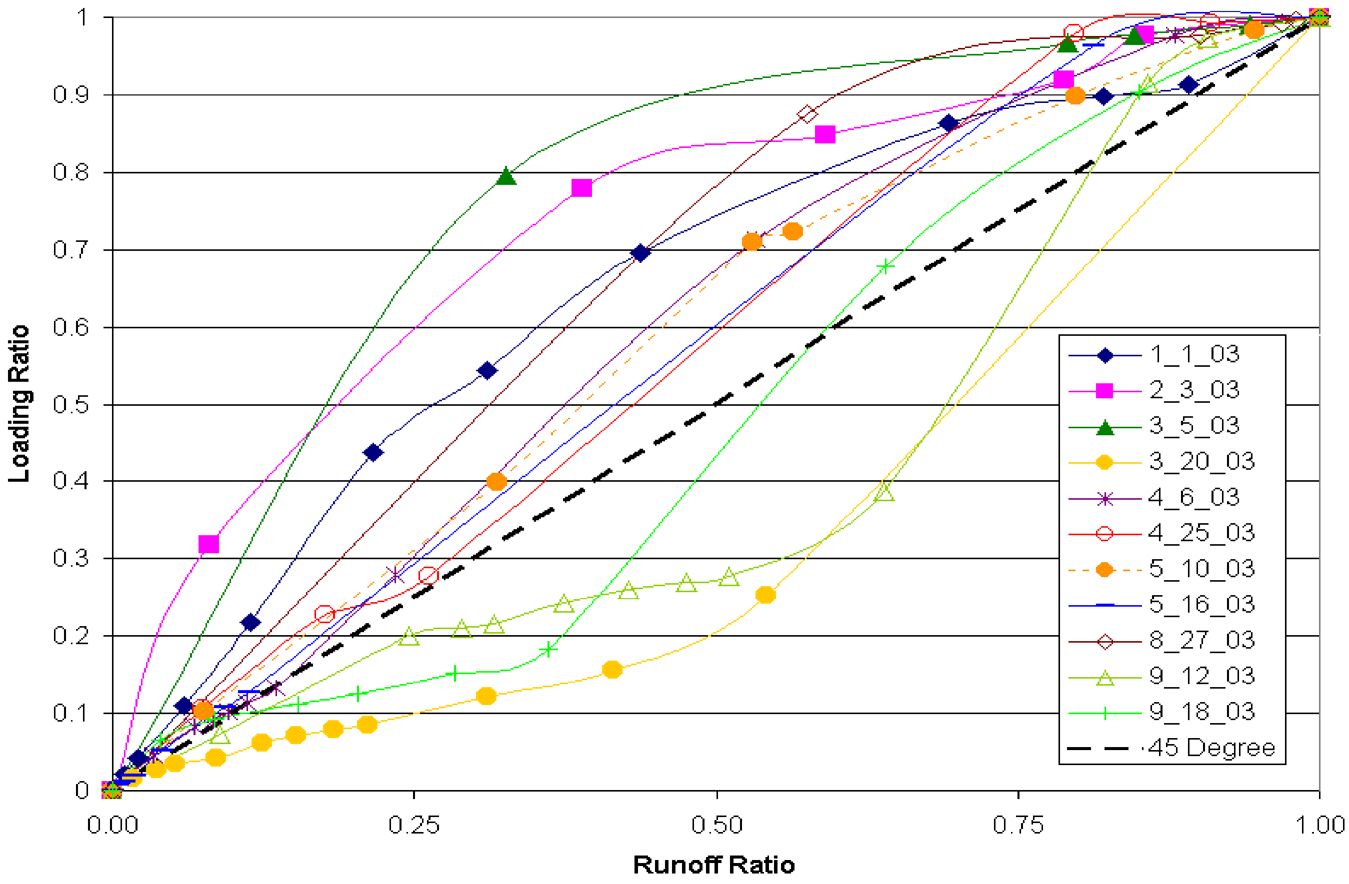


Figure A2. Flushing curves for TSS for 2003 storm events

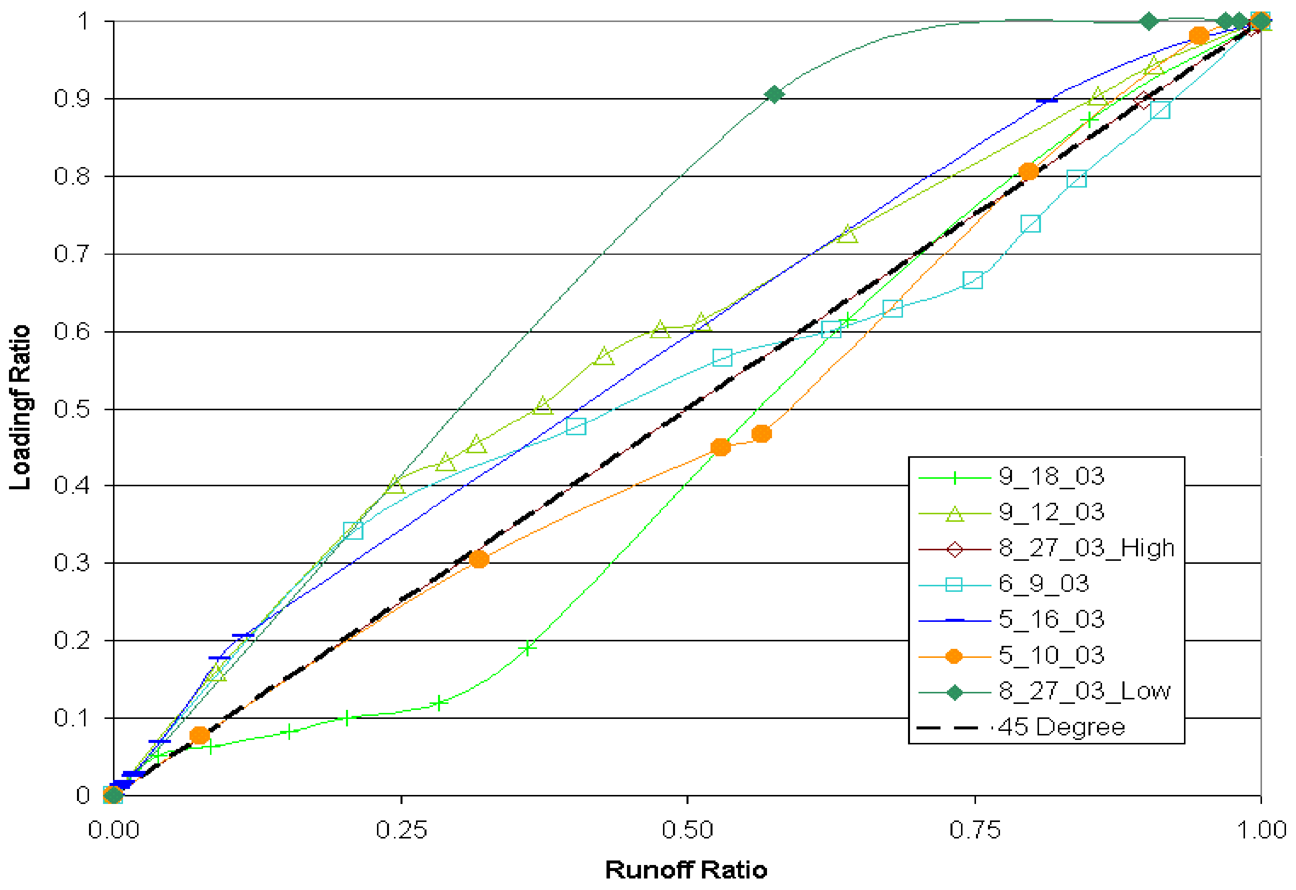


Figure A3. Flushing curves for Cd for 2002 storm events

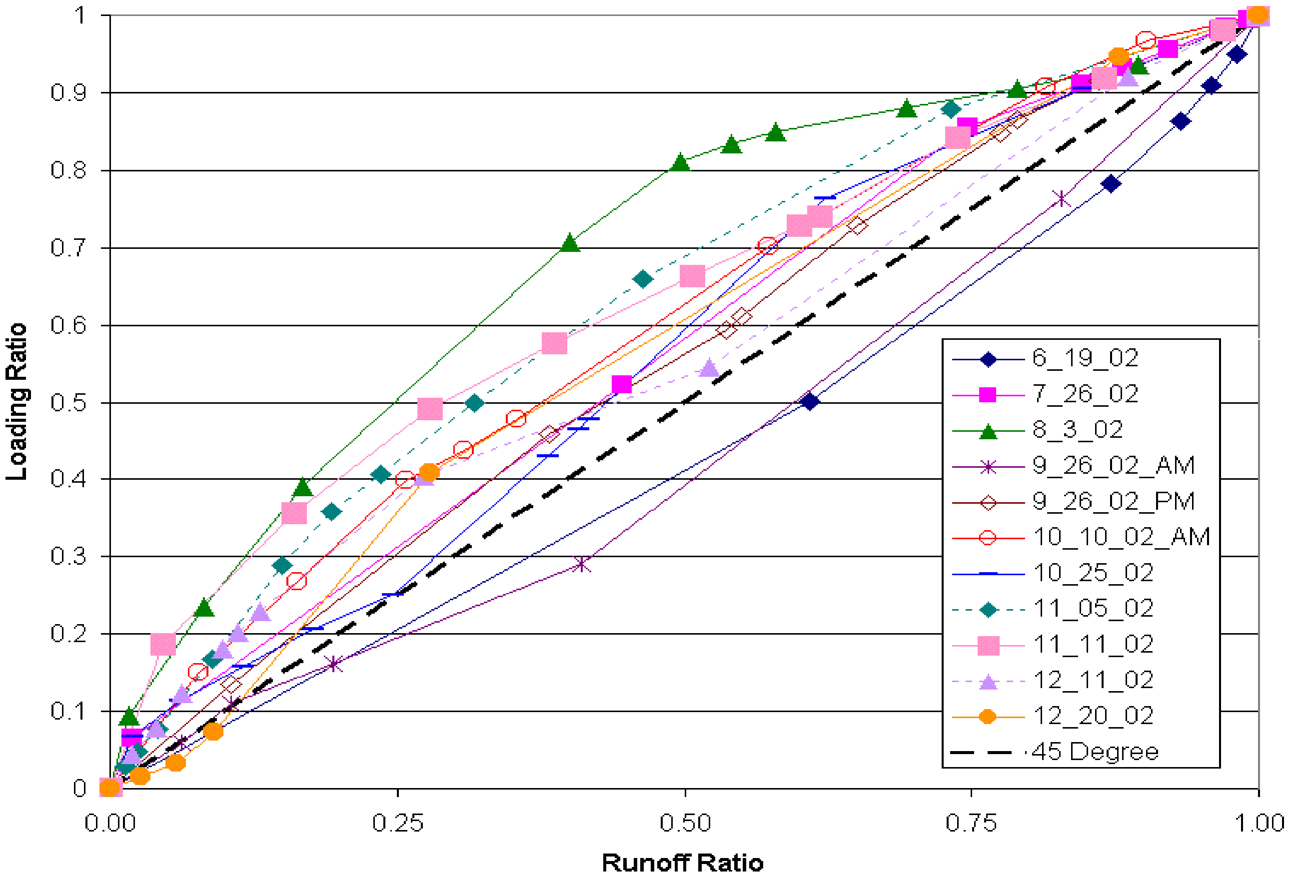


Figure A4. Flushing curves for Cu for 2002 storm events

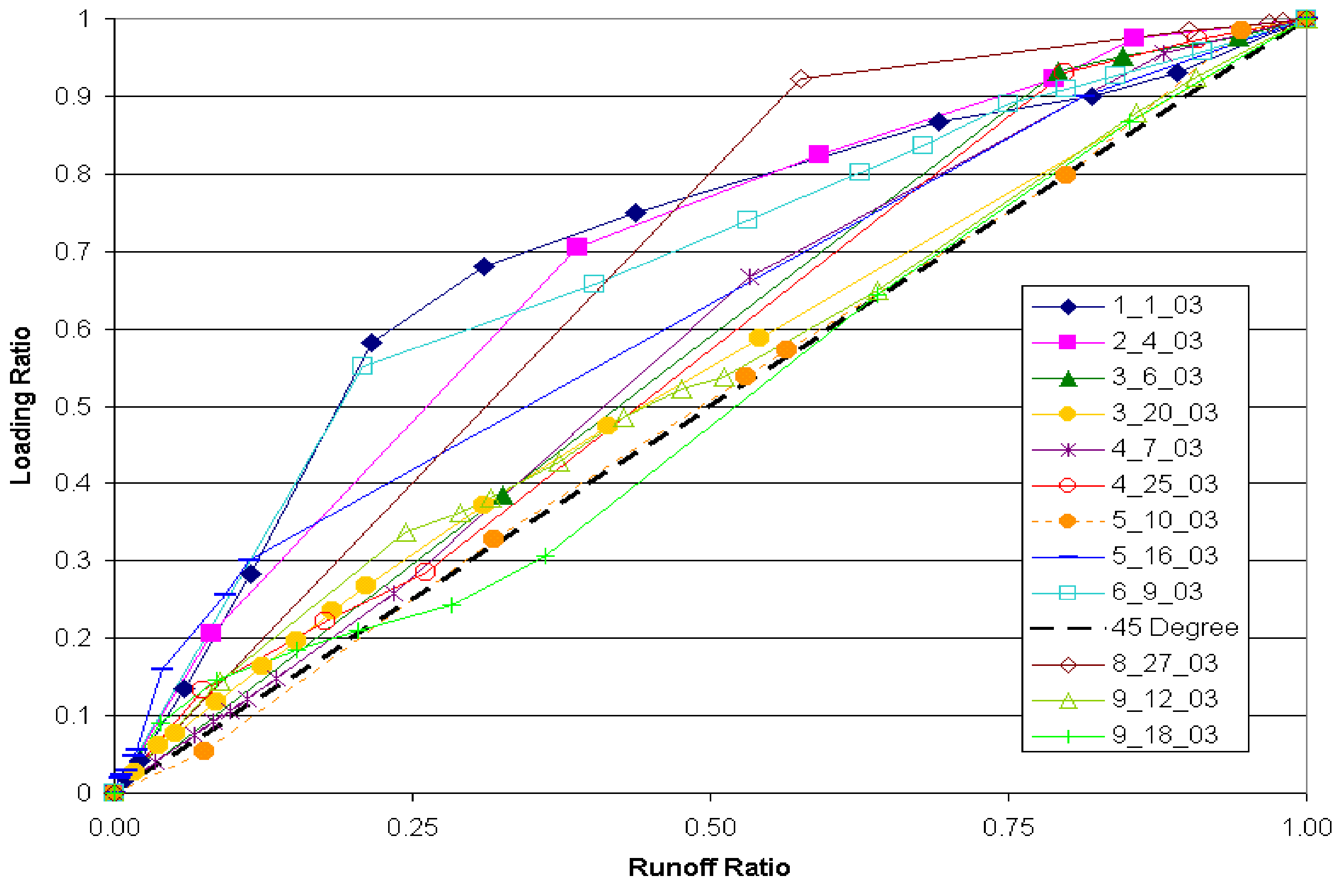


Figure A5. Flushing curves for Cu for 2003 storm events

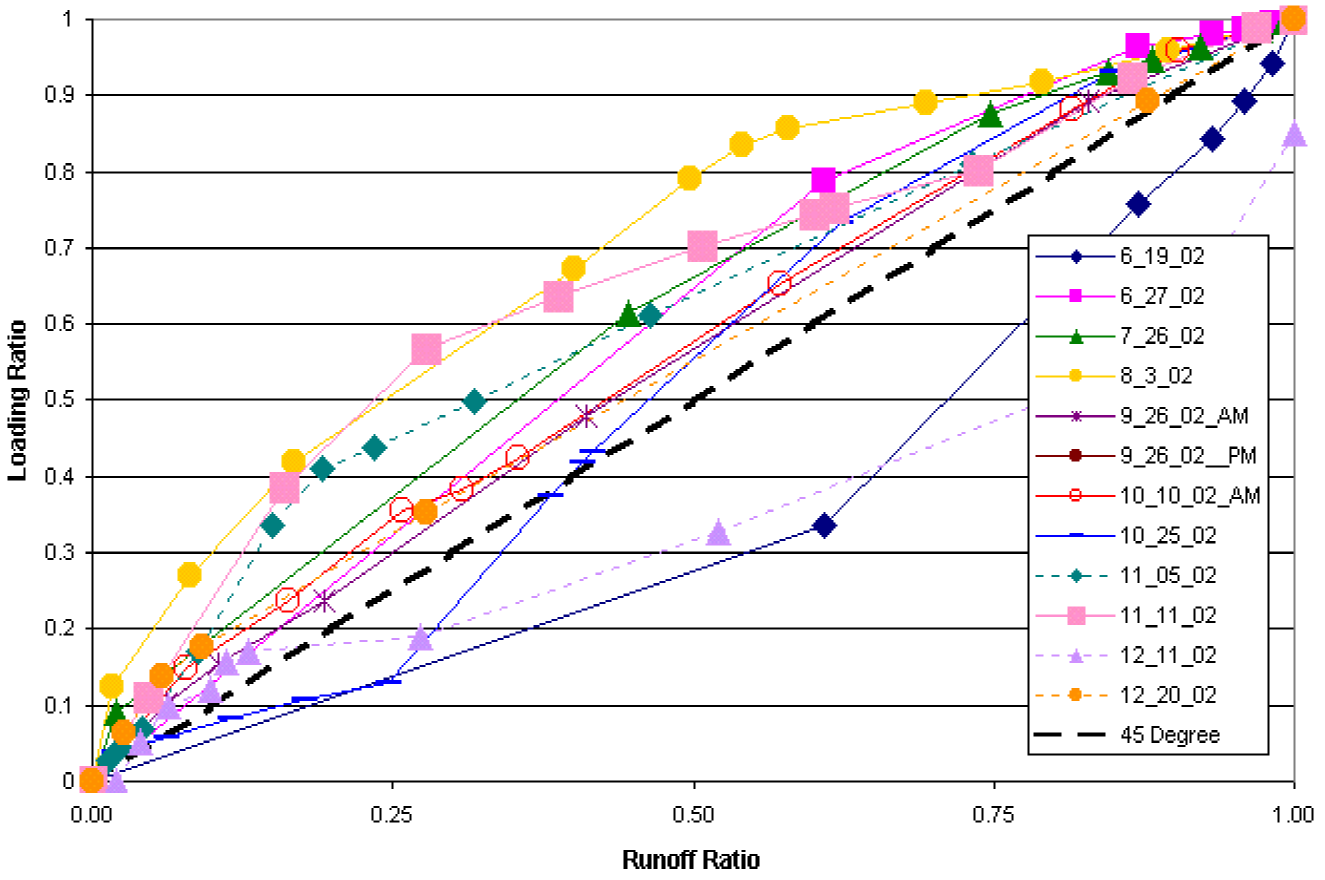


Figure A6. Flushing curves for Pb for 2002 storm events

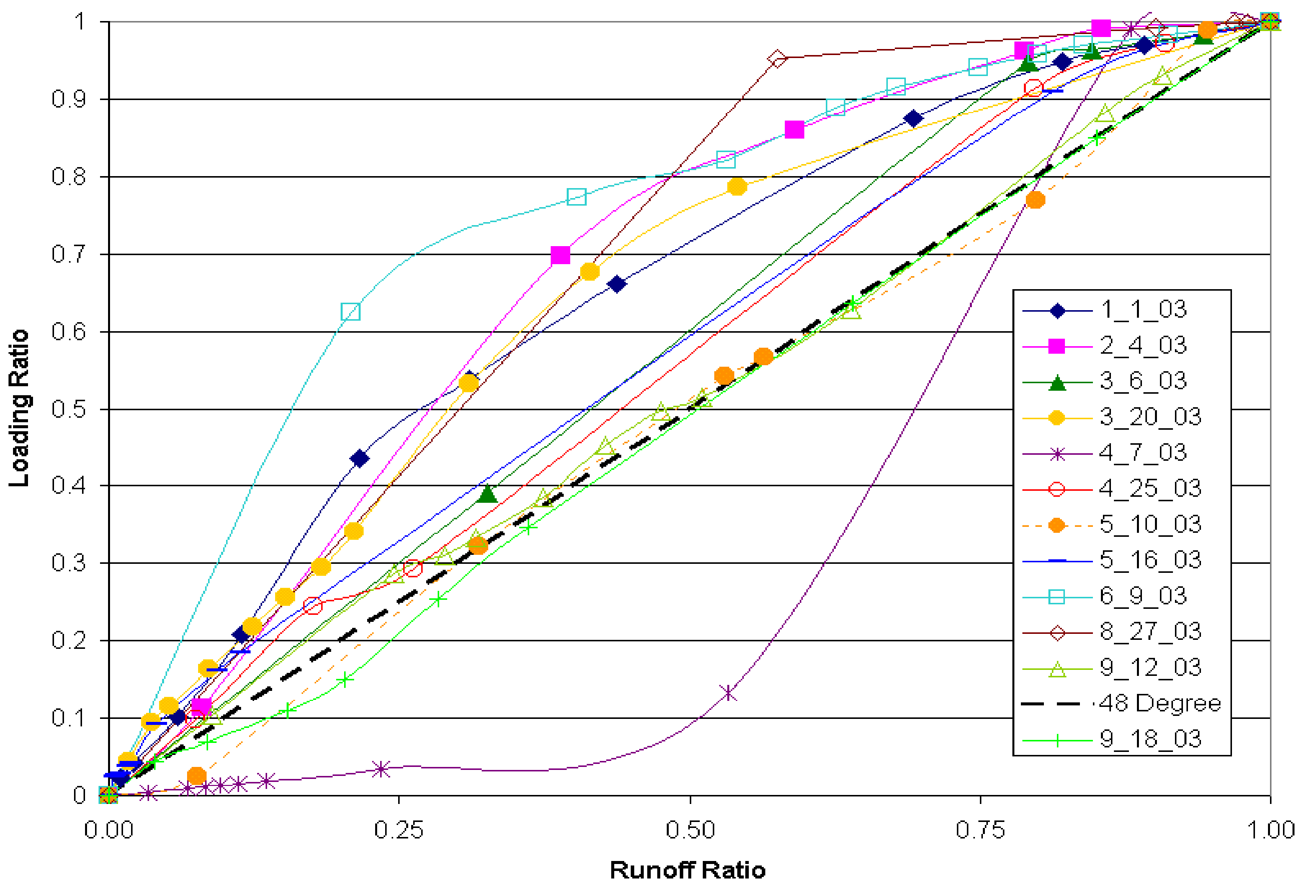


Figure A7. Flushing curves for Pb for 2003 storm events

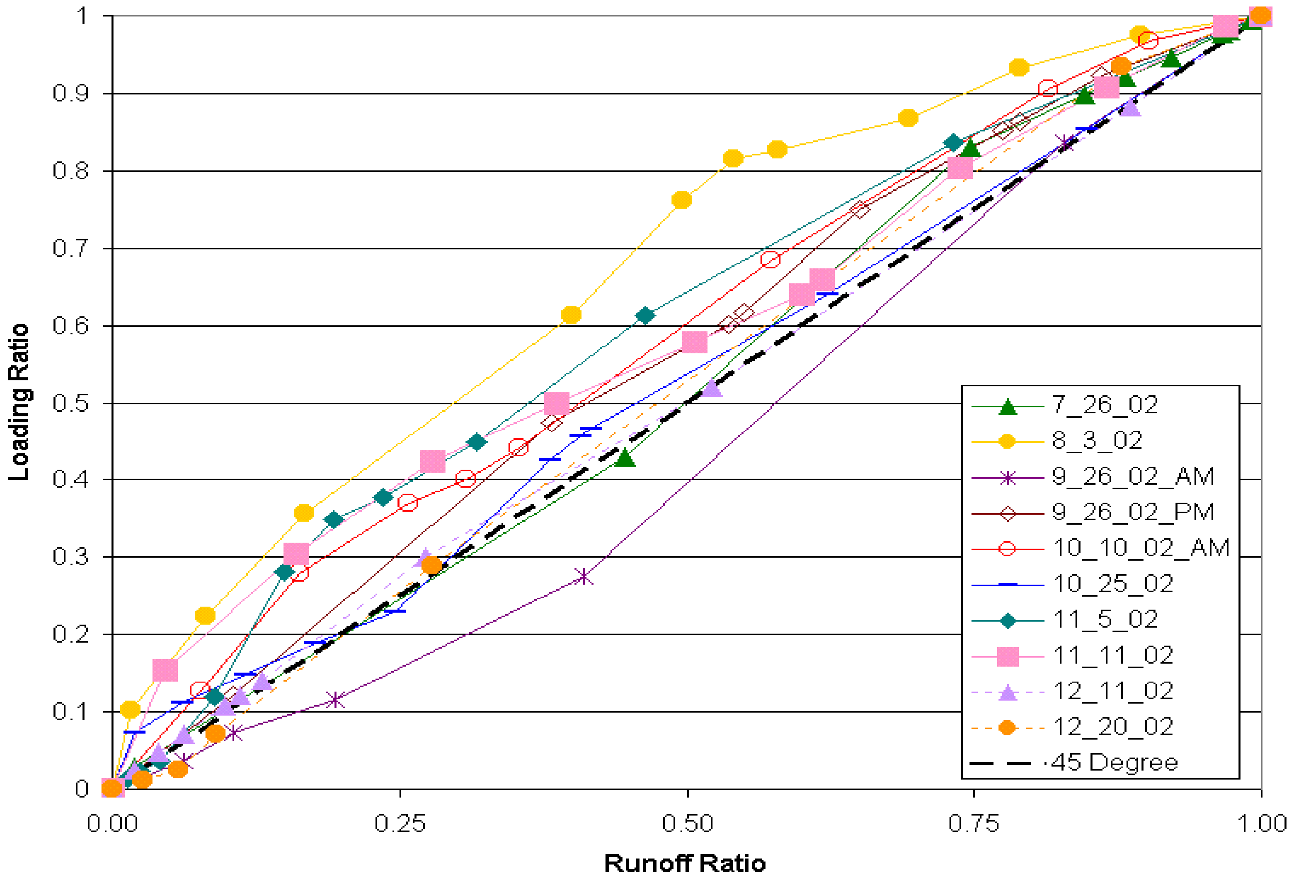


Figure A8. Flushing curves for Zn for 2002 storm events

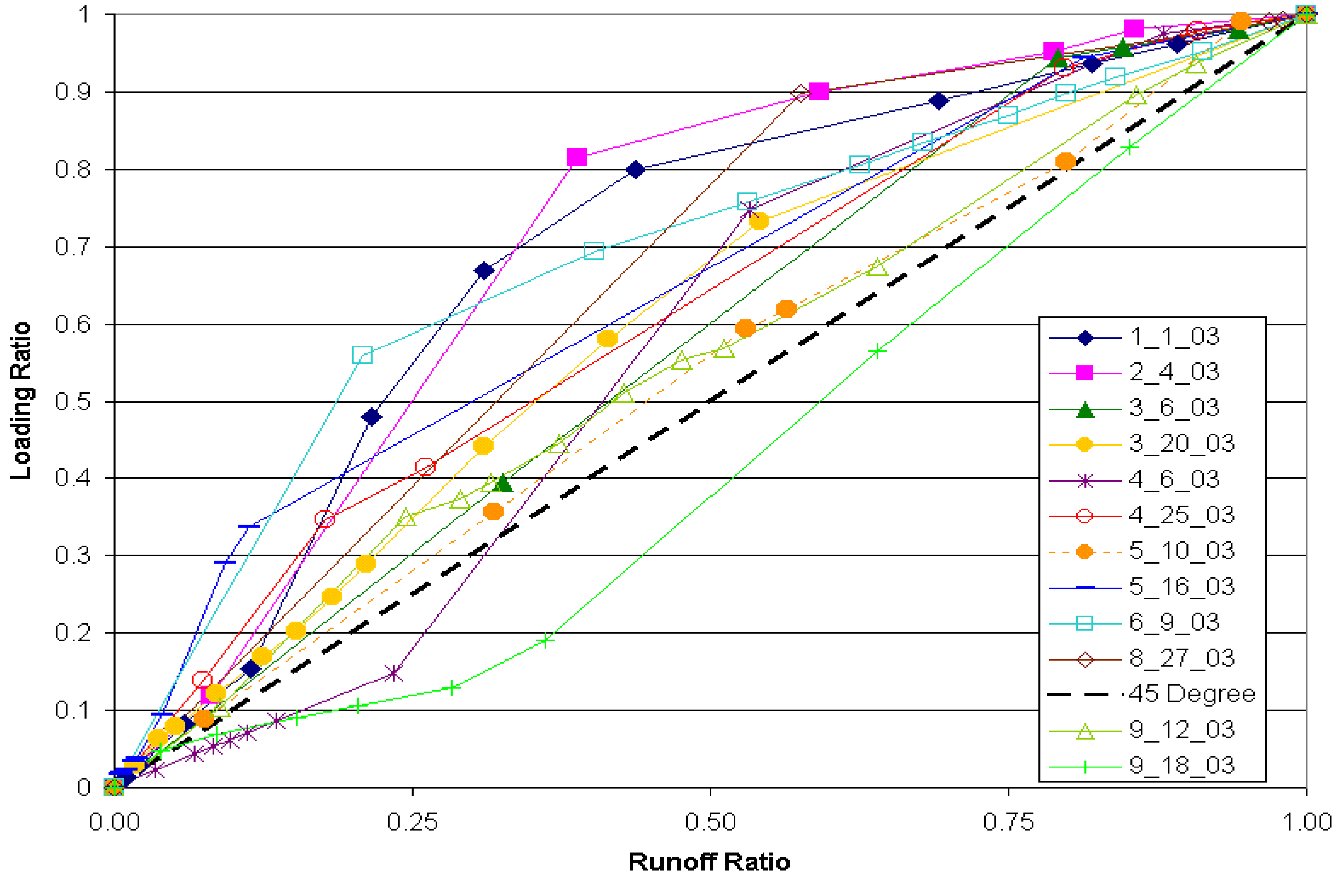


Figure A9. Flushing curves for Zn for 2003 storm events

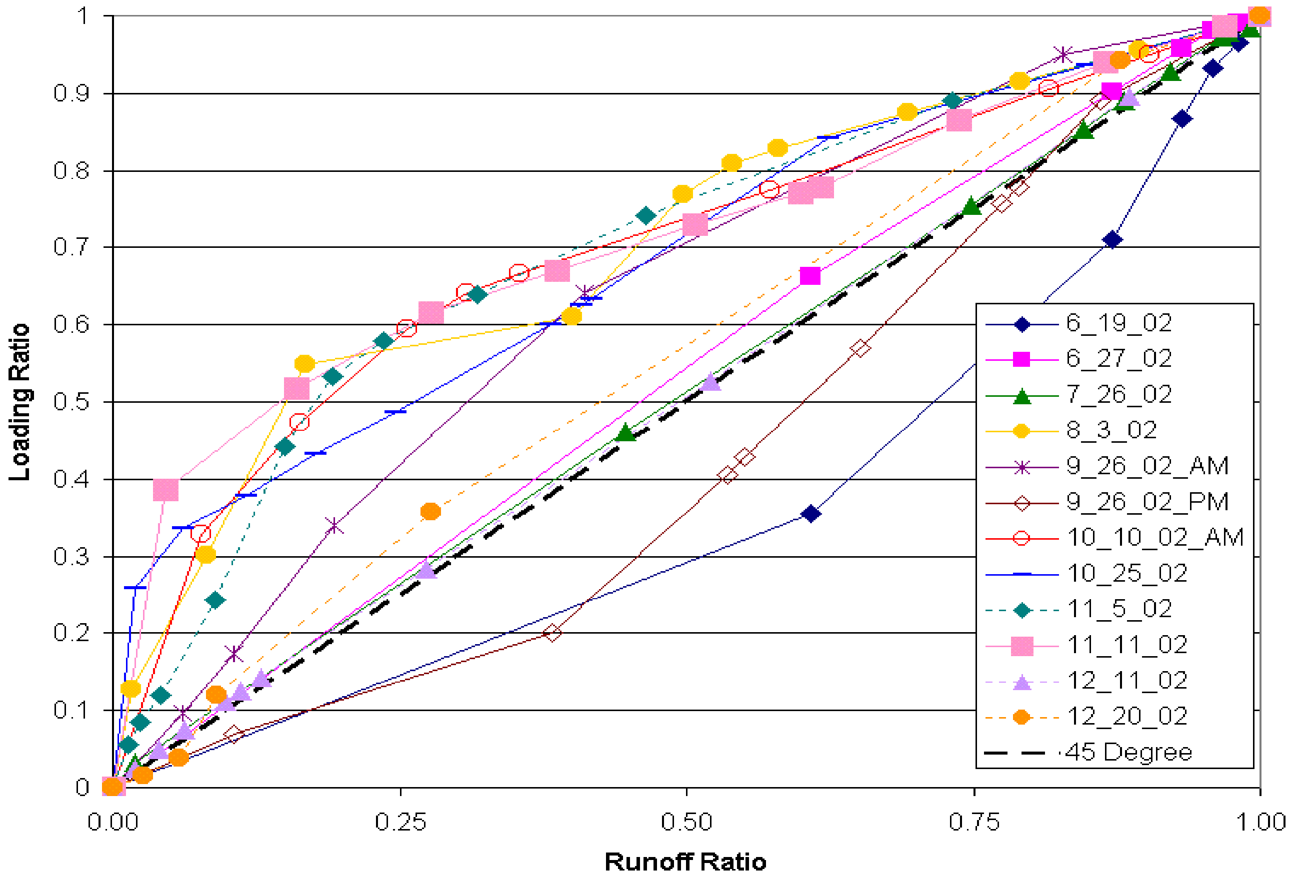


Figure A10. Flushing curves for TKN for 2002 storm events

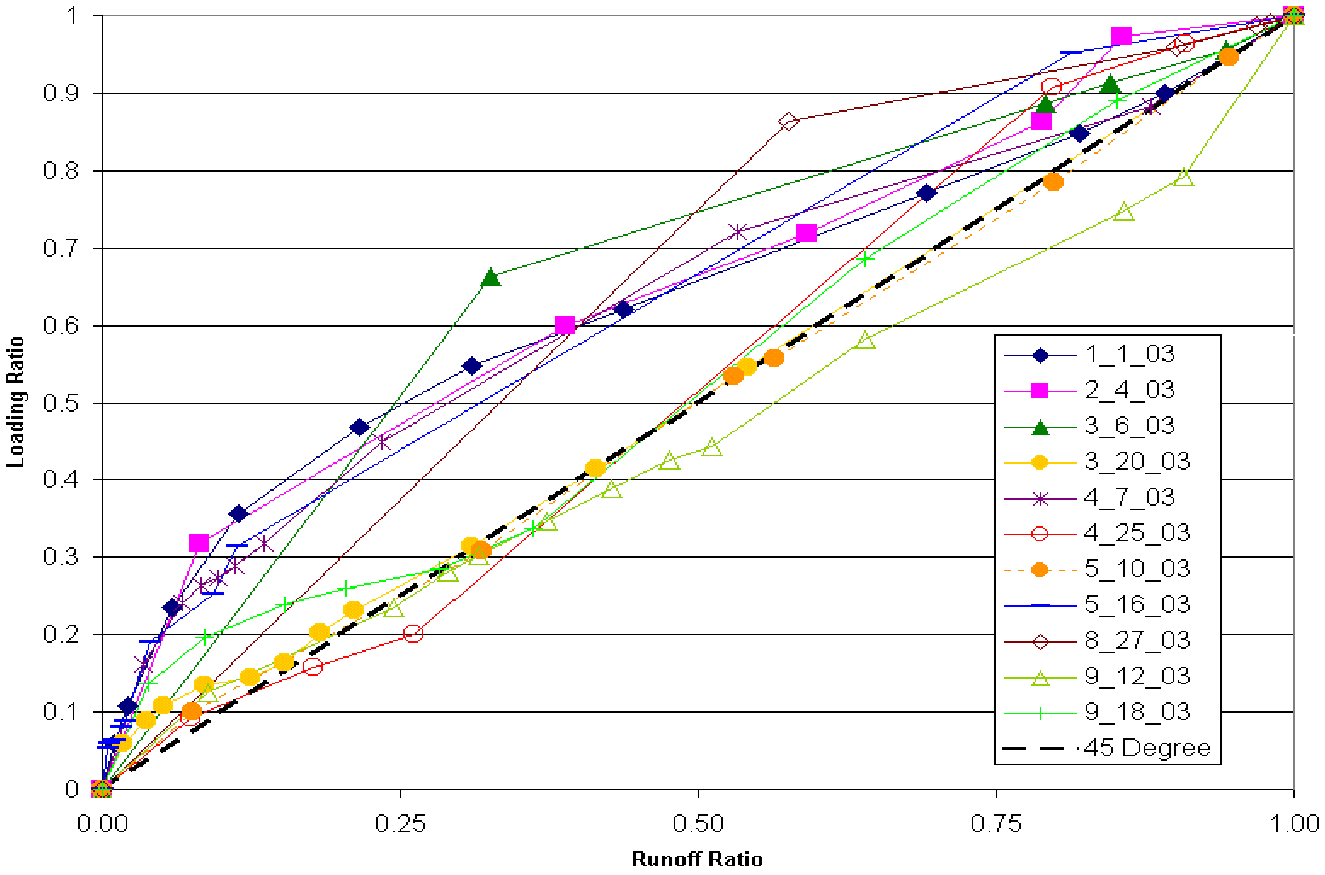


Figure A11. Flushing curves for TKN for 2003 storm events

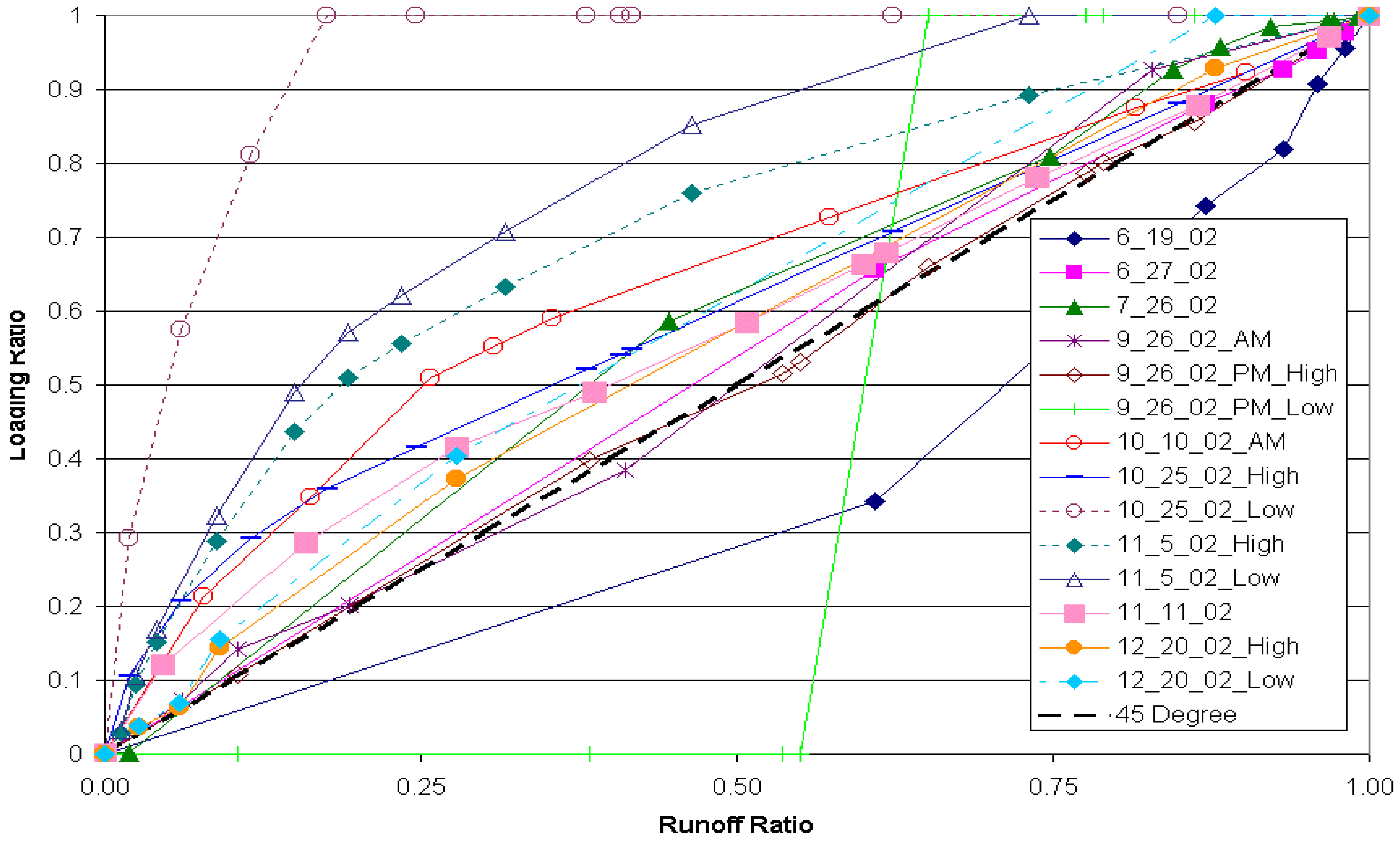


Figure A12. Flushing curves for TP for 2002 storm events

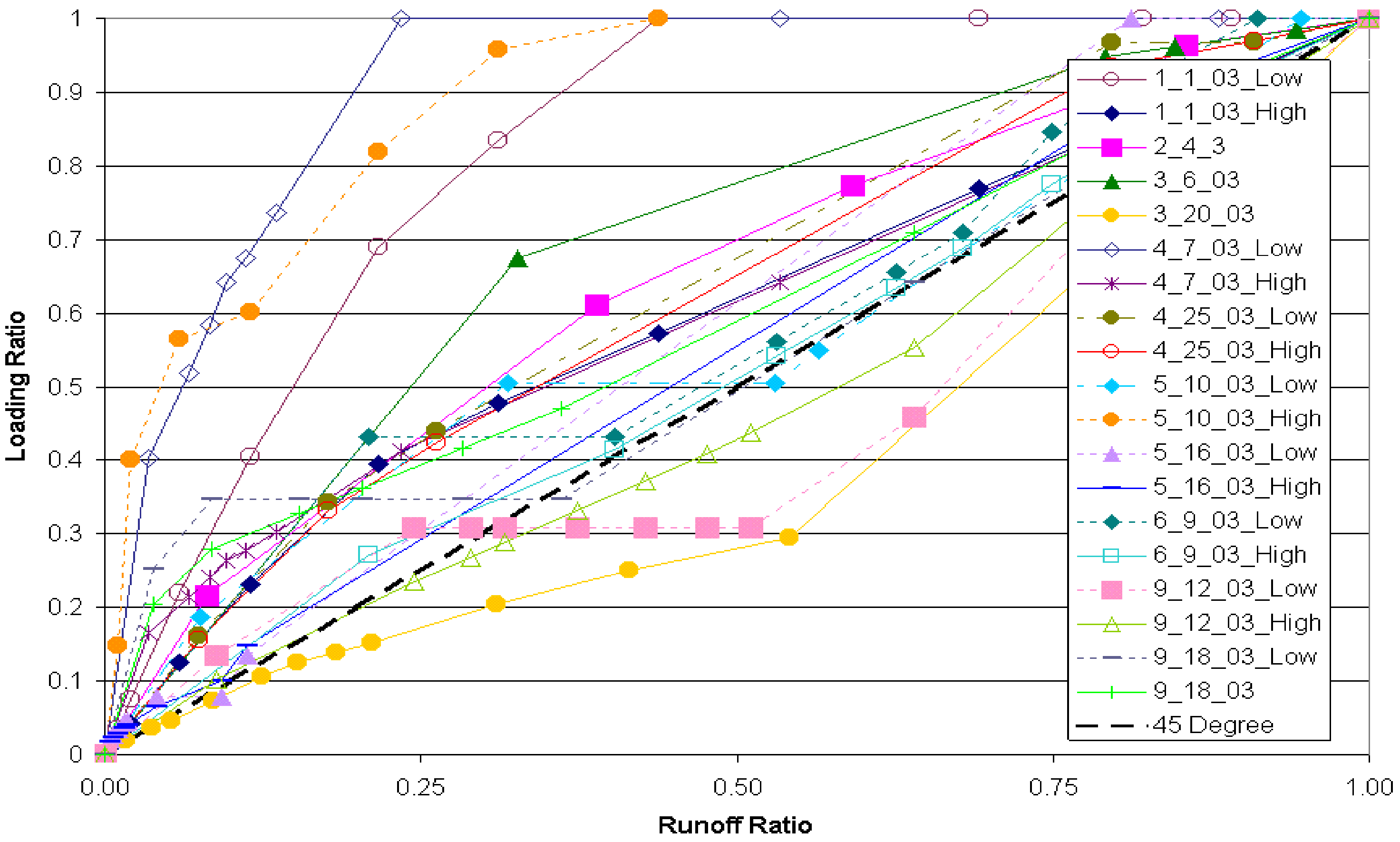


Figure A13. Flushing curves for TP for 2003 storm events

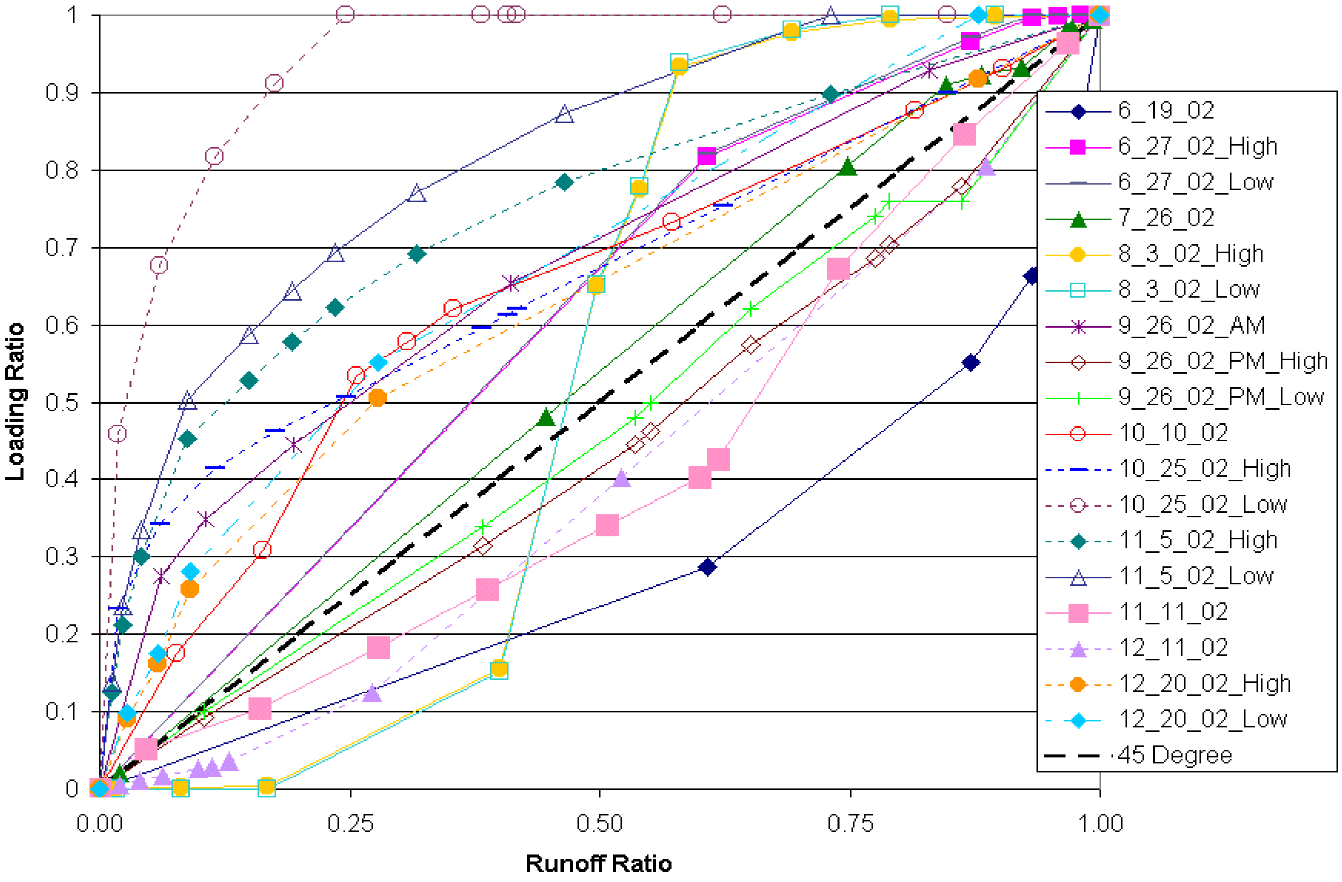


Figure A14.  Flushing curves for $NO_2^-$ for 2002 storm events

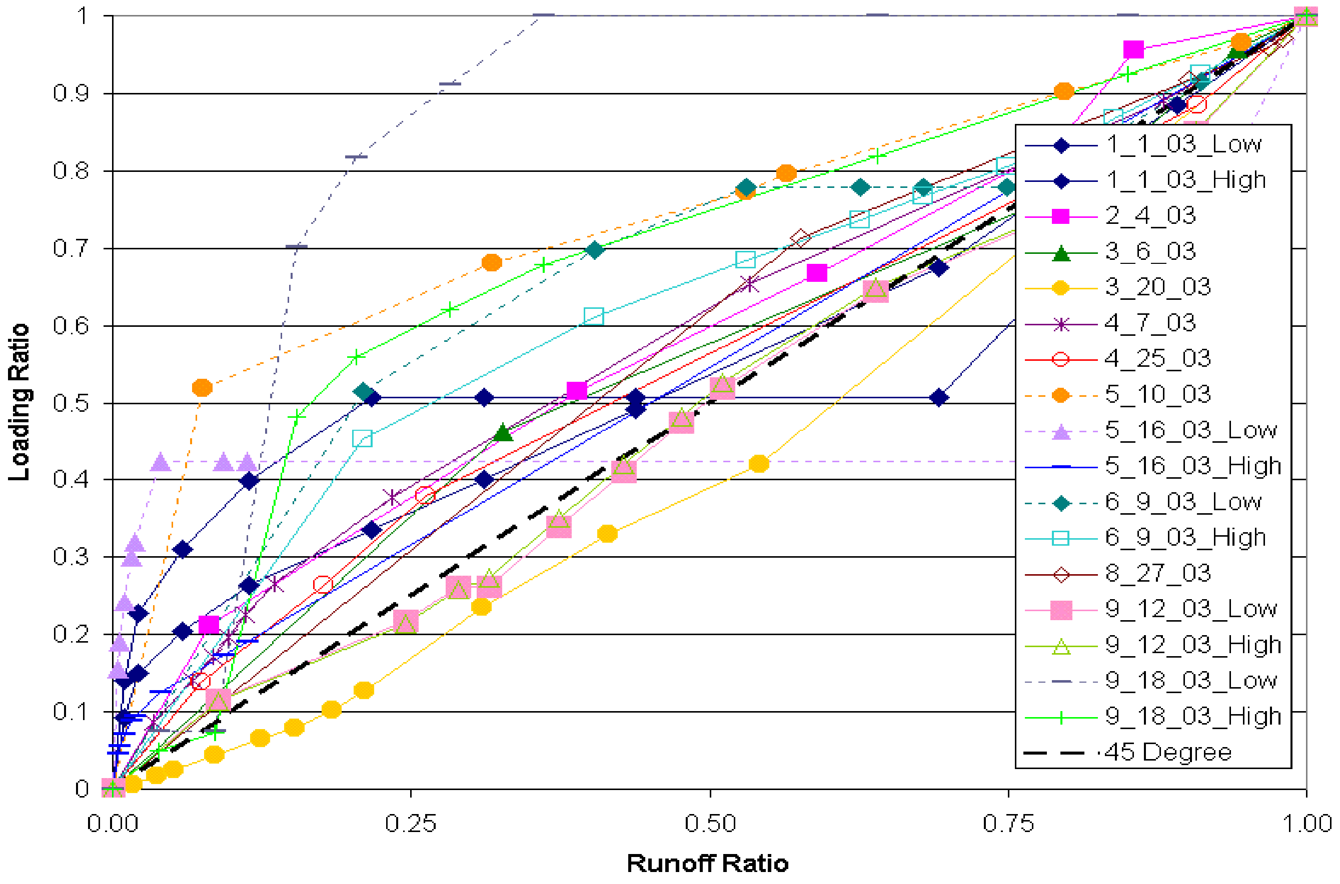
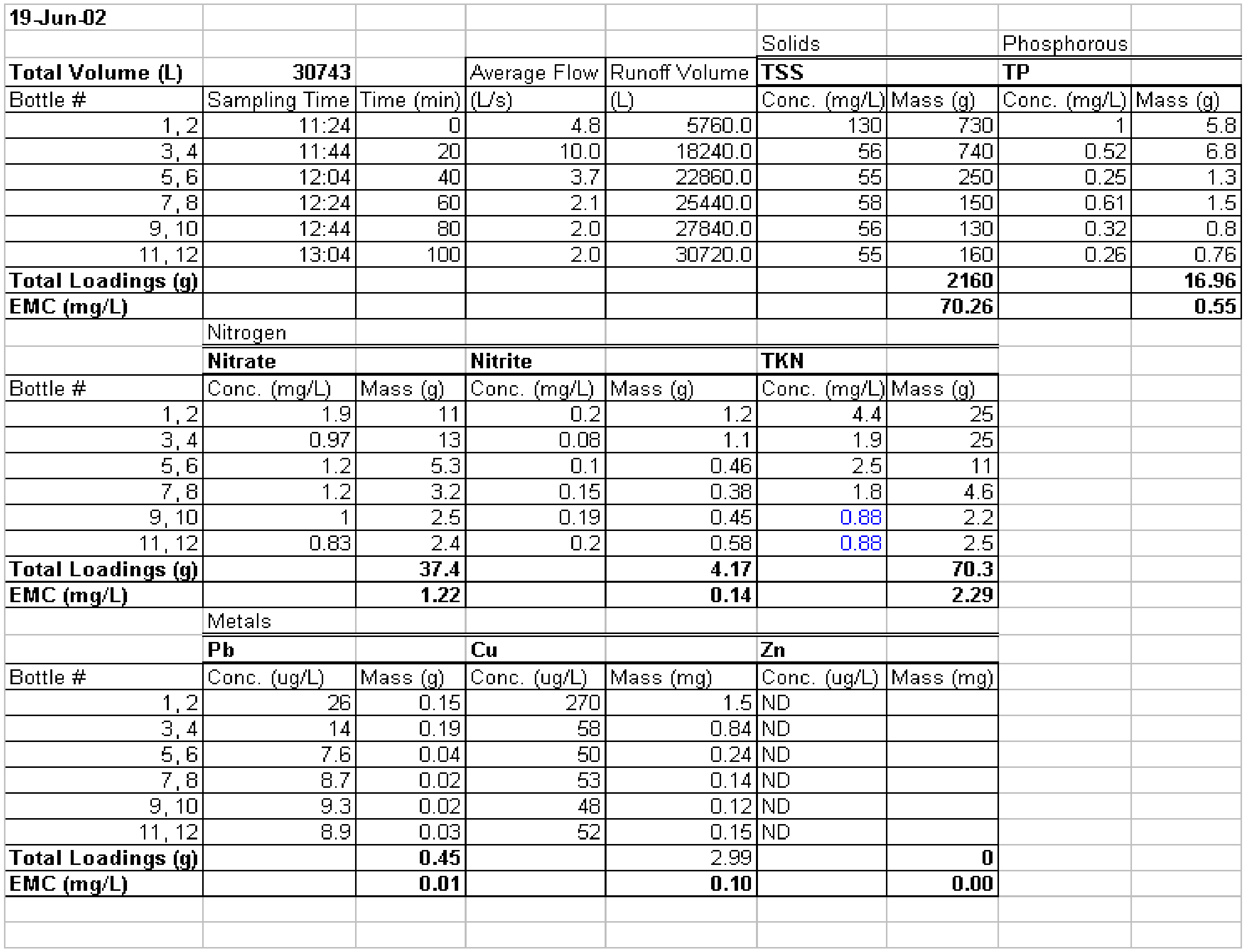


Figure A15. Flushing curves for $NO_2^-$ for 2003 storm events



| 19-Jun-02 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Solids | | Phosphorous | |
| **Total Volume (L)** | **30743** | | Average Flow | Runoff Volume | **TSS** | | **TP** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 11:24 | 0 | 4.8 | 5760.0 | 130 | 730 | 1 | 5.8 |
| 3, 4 | 11:44 | 20 | 10.0 | 18240.0 | 56 | 740 | 0.52 | 6.8 |
| 5, 6 | 12:04 | 40 | 3.7 | 22860.0 | 55 | 250 | 0.25 | 1.3 |
| 7, 8 | 12:24 | 60 | 2.1 | 25440.0 | 58 | 150 | 0.61 | 1.5 |
| 9, 10 | 12:44 | 80 | 2.0 | 27840.0 | 56 | 130 | 0.32 | 0.8 |
| 11, 12 | 13:04 | 100 | 2.0 | 30720.0 | 55 | 160 | 0.26 | 0.76 |
| **Total Loadings (g)** | | | | | | **2160** | | **16.96** |
| **EMC (mg/L)** | | | | | | **70.26** | | **0.55** |
| | Nitrogen | | | | | | | |
| | **Nitrate** | | **Nitrite** | | **TKN** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | |
| 1, 2 | 1.9 | 11 | 0.2 | 1.2 | 4.4 | 25 | | |
| 3, 4 | 0.97 | 13 | 0.08 | 1.1 | 1.9 | 25 | | |
| 5, 6 | 1.2 | 5.3 | 0.1 | 0.46 | 2.5 | 11 | | |
| 7, 8 | 1.2 | 3.2 | 0.15 | 0.38 | 1.8 | 4.6 | | |
| 9, 10 | 1 | 2.5 | 0.19 | 0.45 | 0.88 | 2.2 | | |
| 11, 12 | 0.83 | 2.4 | 0.2 | 0.58 | 0.88 | 2.5 | | |
| **Total Loadings (g)** | | **37.4** | | **4.17** | | **70.3** | | |
| **EMC (mg/L)** | | **1.22** | | **0.14** | | **2.29** | | |
| | Metals | | | | | | | |
| | **Pb** | | **Cu** | | **Zn** | | | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (mg) | Conc. (ug/L) | Mass (mg) | | |
| 1, 2 | 26 | 0.15 | 270 | 1.5 | ND | | | |
| 3, 4 | 14 | 0.19 | 58 | 0.84 | ND | | | |
| 5, 6 | 7.6 | 0.04 | 50 | 0.24 | ND | | | |
| 7, 8 | 8.7 | 0.02 | 53 | 0.14 | ND | | | |
| 9, 10 | 9.3 | 0.02 | 48 | 0.12 | ND | | | |
| 11, 12 | 8.9 | 0.03 | 52 | 0.15 | ND | | | |
| **Total Loadings (g)** | | **0.45** | | 2.99 | | **0** | | |
| **EMC (mg/L)** | | **0.01** | | **0.10** | | **0.00** | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 27-Jun-03 | | | | | | | | | | |
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **102000** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) |
| 1, 2 | 18:48 | 0 | 43.30 | 62280 | 38 | 2.1 | 86 | 4.9 | ND | |
| 3, 4 | 19:08 | 20 | 22.40 | 89160 | 9.4 | 0.47 | 31 | 1.3 | ND | |
| 5, 6 | 19:28 | 40 | 5.20 | 95400 | 6.4 | 0.04 | 32 | 0.21 | ND | |
| 7, 8 | 19:48 | 60 | 2.30 | 98160 | 7.1 | 0.02 | 37 | 0.1 | ND | |
| 9, 10 | 20:08 | 80 | 1.90 | 100440 | 7.5 | 0.02 | 37 | 0.08 | ND | |
| 11, 12 | 20:28 | 100 | 2.29 | 102360 | 7.9 | 0.02 | 37 | 0.08 | ND | |
| **Total Loadings (g)** | | | | | | **2.67** | | 6.67 | | **0** |
| **EMC (mg/L)** | | | | | | **0.03** | | **0.07** | | **0.00** |
| | Nitrogen | | | | | | | | Phosphorous | |
| | **Nitrate** | | **Nitrite** | | | | **TKN** | | **TP** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.09 | 5.1 | 0.63 | 36 | 0.63 | 36 | 3.2 | 180 | 0.57 | 32 |
| 3, 4 | 0.62 | 17 | 0.11 | 6.6 | 0.11 | 6.6 | 1.8 | 65 | 0.3 | 11 |
| 5, 6 | 0.2 | 1.6 | 0.21 | 1.3 | 0.21 | 1.3 | 2.2 | 15 | 0.34 | 2.2 |
| 7, 8 | 0.09 | 0.27 | 0.02 | 0.12 | 0 | 0 | 2.3 | 6.5 | 0.46 | 1.3 |
| 9, 10 | 0.1 | 0.22 | 0.02 | 0.04 | 0 | 0 | 1.2 | 2.7 | 0.55 | 1.2 |
| 11, 12 | 0.08 | 0.17 | 0.02 | 0.04 | 0 | 0 | 1.2 | 2.4 | 0.5 | 1.1 |
| **Total Loadings (g)** | | **24.36** | | **44.1** | | **43.9** | | **271.6** | | **48.8** |
| **EMC (mg/L)** | | **0.24** | | **0.43** | | | | **2.66** | | **0.48** |
| | Solids | | | | | | | | | |
| | **TSS** | | | | | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | | | | | | |
| 1, 2 | 230 | 13000 | | | | | | | | |
| 3, 4 | 72 | 3300 | | | | | | | | |
| 5, 6 | 49 | 340 | | | | | | | | |
| 7, 8 | 46 | 130 | | | | | | | | |
| 9, 10 | 54 | 120 | | | | | | | | |
| 11, 12 | 50 | 110 | | | | | | | | |
| **Total Loadings (g)** | | **17000** | | | | | | | | |
| **EMC (mg/L)** | | **166.67** | | | | | | | | |

| 26-Jul-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **43000** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 8:22 | 0 | 0.75 | 840.00 | 1050 | 0.9 | 440 | 0.37 | 1.4 | 1.2 |
| 5, 6 | 9:02 | 40 | 16.60 | 19080.00 | 200 | 5.2 | 140 | 2.6 | 0.94 | 17 |
| 7, 8 | 9:22 | 60 | 10.20 | 31920.00 | 200 | 2.6 | 150 | 1.9 | 1.3 | 17 |
| 9, 10 | 9:42 | 80 | 3.30 | 36120.00 | 100 | 0.543 | 75 | 0.32 | 0.66 | 2.8 |
| 11, 12 | 10:02 | 100 | 1.20 | 37680.00 | 100 | 0.16 | 75 | 0.12 | 0.66 | 1 |
| 13, 14 | 10:22 | 120 | 1.50 | 39360.00 | 100 | 0.17 | 75 | 0.13 | 0.66 | 1.1 |
| 15, 16 | 10:42 | 140 | 1.50 | 41280.00 | 100 | 0.2 | 75 | 0.14 | 0.66 | 1.3 |
| 17, 18 | 11:02 | 160 | 0.05 | 41520.00 | 100 | 0.02 | 75 | 0.02 | 0.66 | 0.16 |
| 21, 22 | 13:02 | 280 | 0.23 | 42360.00 | 100 | 0.09 | 75 | 0.06 | 0.66 | 0.56 |
| 23, 24 | 14:02 | 340 | 0.07 | 42720.00 | 100 | 0.04 | 75 | 0.03 | 0.66 | 0.24 |
| **Total Loadings (g)** | | | | | | **9.923** | | **5.69** | | **42.36** |
| **EMC (mg/L)** | | | | | | **0.23** | | **0.13** | | **0.99** |
| | Nitrogen | | | | | | Phosphorous | | Solids | |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | ND | | 4.6 | 3.9 | 3.1 | 2.6 | 0.84 | 0.68 | 7100 | 6000 |
| 3, 4 | ND | | | 0 | 3.1 | 0 | 0.84 | 0 | | 0 |
| 5, 6 | ND | | 4.6 | 84 | 1.9 | 35 | 2.3 | 1.9 | 1500 | 27000 |
| 7, 8 | ND | | 4.6 | 59 | 1.9 | 24 | 1.3 | 1 | 1700 | 22000 |
| 9, 10 | ND | | 4.6 | 19 | 1.9 | 7.9 | 2 | 1.7 | 790 | 3300 |
| 11, 12 | ND | | 1.5 | 2.3 | 1.9 | 3 | 1.3 | 1.1 | 2000 | 3100 |
| 13, 14 | ND | | 1.1 | 1.8 | 1.9 | 3.2 | 1.2 | 0.99 | 3700 | 6100 |
| 15, 16 | ND | | 4.3 | 8.3 | 1.9 | 3.6 | 0.25 | 0.19 | 760 | 1500 |
| 17, 18 | ND | | 3.2 | 0.11 | 1.9 | 0.45 | 0.3 | 0.22 | 430 | 100 |
| 21, 22 | ND | | 2.4 | 2 | 0.7 | 0.59 | 0.52 | 0.41 | 200 | 170 |
| 23, 24 | ND | | 3.2 | 1.2 | 0.28 | 1.2 | 0.26 | 0.21 | 170 | 62 |
| **Total Loadings (g)** | | | | **181.61** | | **81.54** | | **7.72** | | **69332** |
| **EMC (mg/L)** | | | | **4.22** | | **1.90** | | **0.18** | | **1.6E+03** |

| **3-Aug-03** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | |
| **Volume (L)** | **184300** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 14:46 | 0 | 1.8 | 3000 | 1400 | 4.2 | 1100 | 3.3 | 13 | 40 |
| 5, 6 | 15:26 | 40 | 9.6 | 14940 | 432 | 5 | 420 | 4.9 | 4 | 47 |
| 7, 8 | 15:46 | 60 | 13.0 | 30840 | 320 | 5.1 | 340 | 5.4 | 3.2 | 52 |
| 9, 10 | 16:06 | 80 | 34.3 | 73800 | 200 | 8.6 | 260 | 11 | 2.4 | 100 |
| 11, 12 | 16:26 | 100 | 16.5 | 94560 | 230 | 4.1 | 200 | 3.6 | 3.2 | 58 |
| 13, 14 | 16:46 | 120 | 6.6 | 99540 | 190 | 1.5 | 100 | 0.8 | 2.6 | 21 |
| 15, 16 | 17:06 | 140 | 6.1 | 106860 | 98 | 0.72 | 76 | 0.56 | 0.57 | 4.2 |
| 17, 18 | 17:26 | 160 | 5.8 | 127740 | 52 | 1.1 | 52 | 1.1 | 0.78 | 16 |
| 19, 20 | 18:26 | 220 | 5.0 | 145680 | 58 | 1 | 46 | 0.83 | 1.5 | 26 |
| 21, 22 | 19:26 | 280 | 5.4 | 165000 | 71 | 1.4 | 58 | 1.1 | 0.84 | 16 |
| 23, 24 | 20:26 | 340 | 5.2 | 184320 | 73 | 1.4 | 120 | 2.2 | 0.54 | 10 |
| **Loadings (g)** | | | | | | **34.12** | | **34.79** | | **390.2** |
| **EMC (mg/L)** | | | | | | **0.185** | | **0.189** | | **2.117** |
| Phosphorous | Solids | | Nitrogen | | | | | | | |
| **TP** | **TSS** | | **Nitrate DL** | | **Nitrite DL** | | **No Nitrite** | | **TKN** | |
| Conc. (mg/L) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| ND | 2700 | 8200 | 0.14 | 0.42 | 0.02 | 0.06 | 0 | 0 | 29 | 88 |
| ND | 2700 | 16000 | 0.14 | 9.2 | 0.02 | 0.23 | 0 | 0 | 21 | 120 |
| ND | 1600 | 23000 | 0.14 | 26 | 0.02 | 0.32 | 0 | 0 | 11 | 170 |
| ND | 1000 | 20000 | 0.14 | 9.8 | 1.2 | 24 | 1.2 | 24 | 2.1 | 42 |
| ND | 1100 | 46000 | 0.14 | 6 | 1.8 | 78 | 1.8 | 78 | 2.6 | 110 |
| ND | 460 | 4100 | 0.14 | 1.2 | 2.3 | 20 | 2.3 | 20 | 3.1 | 27 |
| ND | 110 | 860 | 0.14 | 1.1 | 3.1 | 25 | 3.1 | 25 | 1.5 | 13 |
| ND | 66 | 1400 | 0.14 | 2.9 | 0.33 | 6.9 | 0.33 | 6.9 | 1.5 | 32 |
| ND | 10000 | 19000 | 0.14 | 2.5 | 0.16 | 2.9 | 0.16 | 2.9 | 1.5 | 28 |
| ND | 120 | 2300 | 0.14 | 2.7 | 0.02 | 0.38 | 0 | 0 | 1.5 | 29 |
| ND | 130 | 69 | 0.14 | 8.3 | 0.02 | 0.39 | 0 | 0 | 1.5 | 30 |
| | | **140929** | | **59.3** | | **158.18** | | **156.8** | | **689** |
| | | **7.6E+02** | | **0.321758003** | | **0.858** | | **0.851** | | **3.738** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **14-Sep-03** | | | | | | | | |
| | | | Metals | | | | | |
| **Total Volume (L)** | **7800** | Average Flow | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | (L/s) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 20:05 | 6.4 | 120 | 0.97 | 96 | 0.75 | 1.1 | 8.5 |
| **Total Loadings (g)** | | | | **0.97** | | **0.75** | | **8.5** |
| **EMC (mg/L)** | | | | **0.124** | | **0.096** | | **1.090** |
| | | | | | | | | |
| | Nitrogen | | | | | | | |
| | **Nitrate** | | | | **Nitrite** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) | | |
| 1, 2 | 0.14 | 1.1 | 0 | 0 | 0.02 | 0.16 | 0 | 0 |
| **Total Loadings (g)** | | **1.1** | | **0** | | **0.16** | | **0** |
| **EMC (mg/L)** | | **0.141025641** | | | | **0.021** | | |
| | | | Phosphorous | | Solids | | | |
| | **TKN** | | **TP** | | **TSS** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | |
| 1, 2 | 10 | 80 | 1.9 | 15 | 390 | 3200 | | |
| **Total Loadings (g)** | | **80** | | **15** | | **3200** | | |
| **EMC (mg/L)** | | **10.256** | | **1.923** | | **410.256** | | |

| 15-Sep-03 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Metals | | | | | | Solids | |
| **Total Volume (L)** | **16100** | Average Flow | **Pb** | | **Cu** | | **Zn** | | **TSS** | |
| Bottle # | Sampling Time | (L/s) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 18:38 | 8.9 | 100 | 1.6 | 96 | 1.5 | 0.76 | 12 | 530 | 8600 |
| **Total Loadings (g)** | | | | **1.6** | | 1.5 | | **12** | | **8600** |
| **EMC (mg/L)** | | | | **0.099** | | **0.093** | | **0.745** | | **534.161** |
| | | | | | | | | | | |
| | Nitrogen | | | | | | | | Phosphorous | |
| | **Nitrate** | | | | **Nitrite** | | **TKN** | | **TP** | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.14 | 2.3 | 0 | 0 | 0.03 | 0.48 | 7.7 | 120 | 0.82 | 13 |
| **Total Loadings (g)** | | **2.3** | | **0** | | **0.48** | | **120** | | **13** |
| **EMC (mg/L)** | | **0.142857143** | | | | **0.030** | | **7.453** | | **0.807** |

| 26-Sep-02 | **Morning** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **54600** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 11, 12 | 13:26 | 100 | 2.6 | 3360 | 160 | 0.54 | 83 | 0.28 | 0.58 | 1.9 |
| 13, 14 | 13:46 | 120 | 2.0 | 5760 | 120 | 0.29 | 95 | 0.23 | 0.78 | 1.9 |
| 15, 16 | 14:06 | 140 | 2.0 | 10560 | 91 | 0.44 | 51 | 0.24 | 0.45 | 2.2 |
| 17, 18 | 14:26 | 160 | 3.3 | 22440 | 110 | 1.3 | 51 | 0.61 | 0.69 | 8.2 |
| 19, 20 | 15:26 | 220 | 6.3 | 45240 | 98 | 2.2 | 97 | 2.2 | 1.3 | 29 |
| 21, 22 | 16:26 | 280 | 2.6 | 54600 | 62 | 0.58 | 120 | 1.1 | 0.91 | 8.5 |
| **Total Loadings (g)** | | | | | | **5.35** | | **4.66** | | **51.7** |
| **EMC (mg/L)** | | | | | | **0.098** | | **0.085** | | **0.947** |
| | Nitrogen | | | | | | Phosphorous | | Solids | |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 11, 12 | 1.3 | 4.5 | 0.34 | 1.1 | 4.5 | 15 | 0.72 | 2.4 | 170 | 570 |
| 13, 14 | 0.75 | 1.8 | 0.12 | 0.9 | 5 | 12 | 0.94 | 2.3 | 300 | 720 |
| 15, 16 | 0.64 | 3.1 | 0.08 | 0.38 | 5.5 | 26 | 0.41 | 2 | 160 | 770 |
| 17, 18 | 0.51 | 6.1 | 0.07 | 0.83 | 4 | 47 | 0.51 | 6.1 | 92 | 1100 |
| 19, 20 | 0.42 | 9.6 | 0.05 | 1.1 | 2.1 | 48 | 0.79 | 18 | 46 | 1100 |
| 21, 22 | 0.32 | 3 | 0.03 | 0.28 | 0.84 | 7.9 | 0.26 | 2.4 | 46 | 430 |
| **Total Loadings (g)** | | **28.1** | | **4.59** | | **155.9** | | **33.2** | | **4690** |
| **EMC (mg/L)** | | **0.514652** | | **0.084** | | **2.855** | | **0.608** | | **85.897** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **26-Sep-02** | **Evening** | | | | | | | | | |
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **25000** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 19:46 | 0 | 2.0 | 2640 | 62 | 0.16 | 32 | 0.08 | 0.21 | 0.55 |
| 3, 4 | 20:06 | 20 | 5.8 | 9600 | 76 | 0.53 | 27 | 0.19 | 0.23 | 1.6 |
| 5, 6 | 20:26 | 40 | 3.2 | 13440 | 34 | 0.12 | 20 | 0.08 | 0.15 | 0.58 |
| 7, 8 | 20:46 | 60 | 0.3 | 13800 | 37 | 0.01 | 23 | 0.01 | 0.2 | 0.07 |
| 9, 10 | 21:06 | 80 | 2.1 | 16320 | 37 | 0.09 | 26 | 0.07 | 0.24 | 0.6 |
| 11, 12 | 21:26 | 100 | 2.6 | 19440 | 39 | 0.12 | 21 | 0.07 | 0.15 | 0.47 |
| 13, 14 | 21:46 | 120 | 0.3 | 19800 | 29 | 0.01 | 19 | 0.01 | 0.15 | 0.05 |
| 15, 16 | 22:06 | 140 | 1.5 | 21600 | 19 | 0.03 | 17 | 0.03 | 0.15 | 0.27 |
| 17, 18 | 22:26 | 160 | 1.5 | 25080 | 12 | 0.04 | 14 | 0.05 | 0.08 | 0.35 |
| **Total Loadings (g)** | | | | | | **1.11** | | **0.59** | | **4.54** |
| **EMC (mg/L)** | | | | | | **0.044** | | **0.024** | | **0.182** |
| | Nitrogen | | | | | | | | | |
| | **Nitrate** | | | | **Nitrite** | | | | **TKN** | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.33 | 0.87 | 0.33 | 0.87 | 0.02 | 0.05 | 0.02 | 0.05 | 0.71 | 1.9 |
| 3, 4 | 0.14 | 0.97 | 0 | 0 | 0.02 | 0.12 | 0.02 | 0.12 | 0.58 | 3.6 |
| 5, 6 | 0.42 | 1.2 | 0.42 | 1.2 | 0.02 | 0.07 | 0.02 | 0.07 | 2 | 5.6 |
| 7, 8 | 0.42 | 0.15 | 0.42 | 0.15 | 0.02 | 0.01 | 0.02 | 0.01 | 1.8 | 0.63 |
| 9, 10 | 0.41 | 0.98 | 0.41 | 0.98 | 0.02 | 0.06 | 0.02 | 0.06 | 1.6 | 3.9 |
| 11, 12 | 0.36 | 1.1 | 0.36 | 1.1 | 0.02 | 0.06 | 0.02 | 0.06 | 1.6 | 5.1 |
| 13, 14 | 0.37 | 0.13 | 0.37 | 0.13 | 0.02 | 0.01 | 0.02 | 0.01 | 1.6 | 0.59 |
| 15, 16 | 0.38 | 0.5 | 0.38 | 0.5 | 0.02 | 0.04 | 0 | 0 | 1.7 | 3.1 |
| 17, 18 | 0.43 | 1.5 | 0.43 | 1.5 | 0.03 | 0.12 | 0.02 | 0.12 | 0.86 | 3 |
| **Total Loadings (g)** | | **7.4** | | **6.43** | | **0.54** | | **0.5** | | **27.42** |
| **EMC (mg/L)** | | **0.296** | | **0.2572** | | **0.0216** | | **0.02** | | **1.0968** |
| | Phosphorous | | | | Solids | | | | | |
| | **TP** | | | | **TSS** | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) | | | | |
| 1, 2 | 0.24 | 0.63 | 0 | 0 | 50 | 130 | | | | |
| 3, 4 | 0.24 | 1.7 | 0 | 0 | 49 | 340 | | | | |
| 5, 6 | 0.24 | 0.69 | 0 | 0 | 40 | 150 | | | | |
| 7, 8 | 0.28 | 0.1 | 0.16 | 0.06 | 34 | 12 | | | | |
| 9, 10 | 0.31 | 0.75 | 0.31 | 0.75 | 32 | 81 | | | | |
| 11, 12 | 0.24 | 0.75 | 0 | 0 | 40 | 120 | | | | |
| 13, 14 | 0.24 | 0.09 | 0 | 0 | 37 | 13 | | | | |
| 15, 16 | 0.24 | 0.32 | 0 | 0 | 34 | 60 | | | | |
| 17, 18 | 0.24 | 0.84 | 0 | 0 | 32 | 110 | | | | |
| **Total Loadings (g)** | | **5.87** | | **0.81** | | **1016** | | | | |
| **EMC (mg/L)** | | **0.2348** | | **0.0324** | | **40.64** | | | | |

| 10-Oct-02 | Morning | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **49500** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 4:12 | 0 | 2.91 | 3840 | 170 | 0.65 | 210 | 0.81 | 1.1 | 4.2 |
| 3, 4 | 4:32 | 20 | 2.92 | 8040 | 90 | 0.38 | 150 | 0.63 | 1.2 | 5 |
| 11, 12 | 5:52 | 100 | 3.55 | 12720 | 110 | 0.51 | 150 | 0.7 | 0.64 | 3 |
| 13, 14 | 6:12 | 120 | 2.10 | 15240 | 53 | 0.13 | 84 | 0.21 | 0.39 | 1 |
| 15, 16 | 6:32 | 140 | 1.90 | 17520 | 75 | 0.17 | 97 | 0.22 | 0.57 | 1.3 |
| 17, 18 | 6:52 | 160 | 4.50 | 28320 | 97 | 1 | 110 | 1.2 | 0.74 | 8 |
| 19, 20 | 7:52 | 220 | 3.33 | 40320 | 87 | 1 | 92 | 1.1 | 0.61 | 7.3 |
| 21, 22 | 8:52 | 280 | 1.20 | 44640 | 76 | 0.33 | 73 | 0.32 | 0.47 | 2 |
| 23, 24 | 9:52 | 340 | 1.33 | 49440 | 38 | 0.18 | 37 | 0.18 | 0.23 | 1.1 |
| **Total Loadings (g)** | | | | | | **4.35** | | **5.37** | | **32.9** |
| **EMC (mg/L)** | | | | | | **0.088** | | **0.108** | | **0.665** |
| | Nitrogen | | | | | | | | Phosphorous | |
| | **Nitrate** | | | | **Nitrite** | | **TKN** | | **TP** | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.14 | 0.54 | 0 | 0 | 0.45 | 1.7 | 27 | 100 | 1.9 | 7.2 |
| 3, 4 | 3.8 | 16 | 3.8 | 16 | 0.3 | 1.3 | 10 | 44 | 1.1 | 4.5 |
| 11, 12 | 1.9 | 8.7 | 1.9 | 8.7 | 0.47 | 2.2 | 7.9 | 37 | 1.2 | 5.5 |
| 13, 14 | 1.3 | 3.3 | 1.3 | 3.3 | 0.17 | 0.43 | 5.6 | 14 | 0.55 | 1.4 |
| 15, 16 | 1.4 | 3.1 | 1.4 | 3.1 | 0.17 | 0.4 | 3.4 | 7.7 | 0.59 | 1.3 |
| 17, 18 | 1.2 | 13 | 1.2 | 13 | 0.1 | 1.1 | 3.1 | 33 | 0.42 | 4.6 |
| 19, 20 | 0.85 | 10 | 0.85 | 10 | 0.12 | 1.4 | 3.4 | 40 | 0.42 | 5 |
| 21, 22 | 0.69 | 3 | 0.69 | 3 | 0.12 | 0.52 | 3.2 | 14 | 0.37 | 1.6 |
| 23, 24 | 0.71 | 3.4 | 0.71 | 3.4 | 0.14 | 0.68 | 3.1 | 15 | 0.55 | 2.6 |
| **Total Loadings (g)** | | **61.04** | | **60.5** | | **9.73** | | **304.7** | | **33.7** |
| **EMC (mg/L)** | | **1.233131** | | **1.222222222** | | **0.19657** | | **6.15556** | | **0.68081** |
| | Solids | | | | | | | | | |
| | **TSS** | | | | | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | | | | | | |
| 1, 2 | 230 | 900 | | | | | | | | |
| 3, 4 | 220 | 900 | | | | | | | | |
| 11, 12 | 180 | 840 | | | | | | | | |
| 13, 14 | 210 | 520 | | | | | | | | |
| 15, 16 | 180 | 420 | | | | | | | | |
| 17, 18 | 260 | 2800 | | | | | | | | |
| 19, 20 | 150 | 1800 | | | | | | | | |
| 21, 22 | 160 | 690 | | | | | | | | |
| 23, 24 | 280 | 1400 | | | | | | | | |
| **Total Loadings (g)** | | **10270** | | | | | | | | |
| **EMC (mg/L)** | | **207.4747** | | | | | | | | |

| **10-Oct-02** | **Evening** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **2800** | | 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) |
| 3, 4 | 21:10 | 20 | 0.36 | | 100 | 0.04 | 120 | 0.06 | 1.2 | 0.58 |
| 19, 20 | 0:30 | 220 | 0.66 | | 36 | 0.08 | 36 | 0.08 | 0.19 | 0.43 |
| **Total Loadings (g)** | | | | | | **0.12** | | **0.14** | | **1.01** |
| **EMC (mg/L)** | | | | | | **0.04** | | **0.05** | | **0.36** |
| | Nitrogen | | | | | | Phosphorous | | Solids | |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 3, 4 | 0.31 | 0.15 | 0.05 | 0.02 | 3.2 | 1.54 | 0.39 | 0.19 | 440 | 210 |
| 19, 20 | 0.35 | 1.3 | 0.07 | 0.26 | 1.8 | 6.5 | 0.27 | 1 | 270 | 1000 |
| **Total Loadings (g)** | | **1.45** | | **0.28** | | **8.04** | | **1.19** | | **1210** |
| **EMC (mg/L)** | | **0.52** | | **0.10** | | **2.87** | | **0.43** | | **432.14** |

| 25-Oct-02 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **94800** | | Average Flow | Runoff Volume | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 21:15 | 0 | 1.5 | | 190 | 0.34 | 210 | 0.38 | 1.6 | 2.9 |
| 3, 4 | 21:35 | 20 | 3.3 | | 47 | 0.19 | 65 | 0.26 | 0.38 | 1.5 |
| 5, 6 | 21:55 | 40 | 4.3 | | 40 | 0.21 | 47 | 0.24 | 0.29 | 1.5 |
| 9, 10 | 22:35 | 80 | 4.8 | | 38 | 0.22 | 47 | 0.27 | 0.27 | 1.6 |
| 11, 12 | 22:55 | 100 | 5.5 | | 34 | 0.22 | 38 | 0.25 | 0.24 | 1.6 |
| 13, 14 | 23:15 | 120 | 10.7 | | 170 | 2.2 | 78 | 1 | 0.61 | 7.8 |
| 15, 16 | 23:35 | 140 | 1.4 | | 160 | 0.4 | 80 | 0.2 | 0.48 | 1.2 |
| 17, 18 | 23:55 | 160 | 0.5 | | 160 | 0.13 | 80 | 0.07 | 0.48 | 0.4 |
| 19, 20 | 0:55 | 220 | 5.4 | | 140 | 2.7 | 82 | 1.6 | 0.35 | 6.8 |
| 21, 22 | 1:55 | 280 | 5.9 | | 85 | 1.8 | 37 | 0.79 | 0.4 | 8.5 |
| 23, 24 | 2:55 | 340 | 3.9 | | 43 | 0.62 | 37 | 0.53 | 0.4 | 5.8 |
| **Total Loadings (g)** | | | | | | **9.03** | | **5.59** | | **39.6** |
| **EMC (mg/L)** | | | | | | **0.095** | | **0.059** | | **0.418** |
| | Nitrogen | | | | | | Phosphorous | | | |
| | **Nitrate** | | **Nitrite** | | | | **TP** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | | | Mass (g) | Conc. (mg/L) | Mass (g) | | |
| 1, 2 | 3.3 | 5.9 | 0.38 | 0.68 | 0.38 | 0.68 | 1.7 | 3.1 | 1.7 | 3.1 |
| 3, 4 | 0.95 | 3.8 | 0.08 | 0.32 | 0.08 | 0.32 | 0.76 | 3 | 0.76 | 3 |
| 5, 6 | 0.5 | 2.6 | 0.04 | 0.21 | 0.04 | 0.21 | 0.49 | 2.5 | 0.49 | 2.5 |
| 9, 10 | 0.35 | 2 | 0.02 | 0.14 | 0.02 | 0.14 | 0.34 | 2 | 0.34 | 2 |
| 11, 12 | 0.4 | 2.6 | 0.02 | 0.13 | 0.02 | 0.13 | 0.24 | 1.6 | 0 | 0 |
| 13, 14 | 0.17 | 2.2 | 0.02 | 0.26 | 0 | 0 | 0.24 | 3.1 | 0 | 0 |
| 15, 16 | 0.17 | 0.42 | 0.02 | 0.05 | 0 | 0 | 0.24 | 0.6 | 0 | 0 |
| 17, 18 | 0.17 | 0.14 | 0.02 | 0.02 | 0 | 0 | 0.24 | 0.2 | 0 | 0 |
| 19, 20 | 0.16 | 3.1 | 0.02 | 0.39 | 0 | 0 | 0.24 | 4.7 | 0 | 0 |
| 21, 22 | 0.21 | 4.5 | 0.02 | 0.43 | 0 | 0 | 0.24 | 5.1 | 0 | 0 |
| 23, 24 | 0.21 | 3 | 0.02 | 0.29 | 0 | 0 | 0.24 | 3.5 | 0 | 0 |
| **Total Loadings (g)** | | **30.26** | | **2.92** | | **1.48** | | **29.4** | | **10.6** |
| **EMC (mg/L)** | | **0.319198** | | **0.030801688** | | **0.016** | | **0.310** | | **0.112** |
| | | | Solids | | | | | | | |
| | **TKN** | | **TSS** | | | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | | | | | |
| 1, 2 | 17 | 30 | 420 | 760 | | | | | | |
| 3, 4 | 2.2 | 8.9 | 110 | 450 | | | | | | |
| 5, 6 | 0.93 | 4.8 | 38 | 200 | | | | | | |
| 9, 10 | 1.1 | 6.2 | 82 | 470 | | | | | | |
| 11, 12 | 0.97 | 6.4 | 59 | 390 | | | | | | |
| 13, 14 | 1 | 13 | 93 | 1200 | | | | | | |
| 15, 16 | 1.1 | 2.9 | 84 | 210 | | | | | | |
| 17, 18 | 1.1 | 0.96 | 84 | 70 | | | | | | |
| 19, 20 | 1.3 | 24 | 75 | 1500 | | | | | | |
| 21, 22 | 0.52 | 11 | 50 | 1100 | | | | | | |
| 23, 24 | 0.52 | 7.4 | 50 | 720 | | | | | | |
| **Total Loadings (g)** | | **115.56** | | **7070** | | | | | | |
| **EMC (mg/L)** | | **1.219** | | **74.578** | | | | | | |

| 5-Nov-02 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Solids | | | | | | Phosphorous | | | |
| **Total Volume (L)** | **111000** | | Average Flo (L/s) | Cumulative Volume (L) | **TSS** | | **Nitrite** | | | | **TP** | | | |
| Bottle # | Sampling Time | Time (min) | | | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 3, 4 | 18:19 | 20 | 1.2 | 1440 | 270 | 380 | 0.51 | 0.74 | 0.51 | 0.74 | 1.4 | 2 | 1.4 | 2 |
| 5, 6 | 18:39 | 40 | 1.0 | 2640 | 210 | 260 | 0.43 | 0.52 | 0.43 | 0.52 | 3.6 | 4.3 | 3.6 | 4.3 |
| 7, 8 | 18:59 | 60 | 1.6 | 4560 | 170 | 320 | 0.27 | 0.52 | 0.27 | 0.52 | 2 | 3.9 | 2 | 3.9 |
| 9, 10 | 19:19 | 80 | 4.4 | 9840 | 150 | 770 | 0.17 | 0.9 | 0.17 | 0.9 | 1.8 | 9.2 | 1.8 | 9.2 |
| 11, 12 | 19:39 | 100 | 5.7 | 16680 | 120 | 830 | 0.07 | 0.45 | 0.07 | 0.45 | 1.5 | 10 | 1.5 | 10 |
| 13, 14 | 19:59 | 120 | 3.9 | 21360 | 150 | 680 | 0.06 | 0.29 | 0.06 | 0.29 | 1 | 4.9 | 1 | 4.9 |
| 15, 16 | 20:19 | 140 | 4.0 | 26160 | 170 | 810 | 0.06 | 0.27 | 0.06 | 0.27 | 0.62 | 3 | 0.62 | 3 |
| 17, 18 | 20:39 | 160 | 3.8 | 35280 | 120 | 1100 | 0.05 | 0.41 | 0.05 | 0.41 | 0.57 | 5.2 | 0.57 | 5.2 |
| 19, 20 | 21:39 | 220 | 4.5 | 51600 | 120 | 2000 | 0.03 | 0.54 | 0.03 | 0.54 | 0.53 | 8.6 | 0.53 | 8.6 |
| 21, 22 | 22:39 | 280 | 8.3 | 81360 | 120 | 3500 | 0.02 | 0.68 | 0.02 | 0.68 | 0.3 | 8.9 | 0.3 | 8.9 |
| 23, 24 | 23:39 | 340 | 8.0 | 111240 | 69 | 2100 | 0 | 0 | 0.02 | 0.6 | 0 | 0 | 0.24 | 7.2 |
| **Total Loadings (g)** | | | | | | **12750** | | **5.32** | | **5.92** | | **60** | | **67.2** |
| **EMC (mg/L)** | | | | | | **114.86** | | **0.05** | | **0.05** | | **0.54** | | **0.61** |

| | **Pb** | | **Cu** | | **Zn** | | **TKN** | | **Nitrate** | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 3, 4 | 180 | 0.26 | 170 | 0.24 | 0.88 | 1.3 | 11 | 16 | 2.1 | 3 |
| 5, 6 | 120 | 0.14 | 130 | 0.16 | 0.77 | 0.92 | 6.7 | 8.1 | 1.7 | 2.1 |
| 7, 8 | 120 | 0.23 | 120 | 0.23 | 0.74 | 1.4 | 5 | 9.7 | 1.4 | 2.7 |
| 9, 10 | 170 | 0.9 | 140 | 0.74 | 1.5 | 8 | 6.6 | 35 | 1 | 5.5 |
| 11, 12 | 220 | 1.5 | 150 | 1 | 2.3 | 16 | 8.2 | 56 | 0.67 | 4.6 |
| 13, 14 | 138 | 0.65 | 120 | 0.56 | 1.4 | 6.6 | 5.5 | 24 | 0.65 | 3 |
| 15, 16 | 55 | 0.26 | 83 | 0.4 | 0.57 | 2.7 | 2.8 | 13 | 0.62 | 3 |
| 17, 18 | 60 | 0.55 | 83 | 0.76 | 0.77 | 7 | 2.3 | 17 | 0.51 | 4.7 |
| 19, 20 | 64 | 1 | 82 | 1.3 | 0.96 | 16 | 1.8 | 29 | 0.4 | 6.5 |
| 21, 22 | 61 | 1.8 | 59 | 1.8 | 0.75 | 22 | 1.4 | 42 | 0.29 | 8.5 |
| 23, 24 | 57 | 1.7 | 35 | 1 | 0.53 | 16 | 1 | 31 | 0.17 | 5.1 |
| **Total Loadings (g)** | | **8.99** | | **8.19** | | **97.92** | | **280.8** | | **48.7** |
| **EMC (mg/L)** | | **0.08** | | **0.07** | | **0.88** | | **2.53** | | **0.44** |

| 11-Nov-02 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| **Total Volume (L)** | **88000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 7:32 | 0 | 3.4 | 4080.0 | 140 | 0.57 | 230 | 0.94 | 1.2 | 4.9 |
| 3, 4 | 7:52 | 20 | 8.3 | 14040.0 | 140 | 1.4 | 86 | 0.86 | 0.47 | 4.7 |
| 5, 6 | 8:12 | 40 | 8.7 | 24480.0 | 89 | 0.93 | 65 | 0.68 | 0.36 | 3.8 |
| 7, 8 | 8:32 | 60 | 8.0 | 34080.0 | 38 | 0.36 | 44 | 0.42 | 0.25 | 2.4 |
| 9, 10 | 8:52 | 80 | 8.8 | 44640.0 | 32 | 0.34 | 42 | 0.44 | 0.24 | 2.5 |
| 11, 12 | 9:12 | 100 | 6.8 | 52800.0 | 26 | 0.21 | 40 | 0.33 | 0.23 | 1.9 |
| 13, 14 | 9:32 | 120 | 1.3 | 54360.0 | 25 | 0.04 | 38 | 0.06 | 0.39 | 0.61 |
| 17, 18 | 10:12 | 160 | 5.9 | 64920.0 | 25 | 0.26 | 48 | 0.51 | 0.44 | 4.6 |
| 19, 20 | 11:12 | 220 | 3.1 | 76080.0 | 55 | 0.61 | 35 | 0.39 | 0.3 | 3.3 |
| 21, 22 | 12:12 | 280 | 2.5 | 85200.0 | 38 | 0.35 | 34 | 0.31 | 0.27 | 2.5 |
| 23, 24 | 13:12 | 340 | 0.7 | 88000.0 | 19 | 0.05 | 34 | 0.1 | 0.14 | 0.4 |
| **Total Loadings (g)** | | | | | | **5.12** | | **5.04** | | **31.61** |
| **EMC (mg/L)** | | | | | | **0.058** | | **0.057** | | **0.359** |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 1.8 | 7.2 | 0.05 | 0.2 | 21 | 86 | 1.2 | 4.9 | 320 | 1300 |
| 3, 4 | 0.71 | 7.1 | 0.02 | 0.2 | 2.9 | 29 | 0.68 | 6.8 | 96 | 960 |
| 5, 6 | 0.48 | 5 | 0.03 | 0.31 | 2.1 | 22 | 0.5 | 5.2 | 58 | 610 |
| 7, 8 | 0.25 | 2.4 | 0.03 | 0.29 | 1.3 | 12 | 0.32 | 3.1 | 59 | 570 |
| 9, 10 | 0.25 | 2.6 | 0.03 | 0.32 | 1.2 | 13 | 0.36 | 3.8 | 60 | 630 |
| 11, 12 | 0.24 | 2 | 0.03 | 0.24 | 1.1 | 9 | 0.39 | 3.2 | 89 | 730 |
| 13, 14 | 0.29 | 0.45 | 0.06 | 0.09 | 1.3 | 2 | 0.41 | 0.64 | 89 | 140 |
| 17, 18 | 0.32 | 3.4 | 0.09 | 0.95 | 1.8 | 19 | 0.4 | 4.2 | 117 | 1200 |
| 19, 20 | 0.24 | 2.7 | 0.06 | 0.67 | 1.5 | 17 | 0.36 | 4 | 76 | 700 |
| 21, 22 | 0.24 | 2.2 | 0.05 | 0.46 | 1.1 | 10 | 0.41 | 3.7 | 53 | 480 |
| 23, 24 | 0.24 | 0.69 | 0.05 | 0.14 | 1.1 | 3.2 | 0.41 | 1.2 | 53 | 150 |
| **Total Loadings (g)** | | **35.74** | | **3.87** | | **222.2** | | **40.74** | | **7470** |
| **EMC (mg/L)** | | **0.406** | | **0.044** | | **2.525** | | **0.463** | | **84.886** |

| 11-Dec-02 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **134000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 5:01 | 0 | 2.0 | 2640.0 | 77 | 0.2 | 71 | 0.19 | 1.1 | 2.9 |
| 3, 4 | 5:21 | 20 | 2.2 | 5280.0 | 63 | 0.17 | 57 | 0.15 | 1.1 | 2.9 |
| 5, 6 | 5:41 | 40 | 2.6 | 8400.0 | 29 | 0.09 | 60 | 0.19 | 0.84 | 2.6 |
| 7, 8 | 6:01 | 60 | 4.0 | 13200.0 | 28 | 0.13 | 50 | 0.24 | 0.91 | 4.4 |
| 9, 10 | 6:21 | 80 | 1.5 | 15000.0 | 28 | 0.05 | 50 | 0.09 | 0.91 | 1.6 |
| 15, 16 | 7:21 | 140 | 1.3 | 17400.0 | 28 | 0.07 | 50 | 0.12 | 0.91 | 2.2 |
| 17, 18 | 7:41 | 160 | 8.0 | 36600.0 | 27 | 0.52 | 39 | 0.75 | 0.98 | 19 |
| 19, 20 | 8:41 | 220 | 9.3 | 69960.0 | 26 | 0.87 | 18 | 0.6 | 0.79 | 26 |
| 21, 22 | 9:41 | 280 | 14.0 | 118920.0 | 22 | 1.1 | 33 | 1.6 | 0.87 | 43 |
| 23, 24 | 10:41 | 340 | 4.2 | 134160.0 | 37 | 0.56 | 22 | 0.34 | 0.93 | 14 |
| **Total Loadings (g)** | | | | | | **3.76** | | **4.27** | | **118.6** |
| **EMC (mg/L)** | | | | | | **0.028** | | **0.032** | | **0.885** |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | ND | | 0.11 | 0.29 | 2.8 | 7.4 | ND | | 280 | 740 |
| 3, 4 | ND | | 0.09 | 0.24 | 2.8 | 7.4 | ND | | 250 | 660 |
| 5, 6 | ND | | 0.09 | 0.28 | 2.4 | 7.5 | ND | | 140 | 440 |
| 7, 8 | ND | | 0.09 | 0.43 | 2.3 | 11 | ND | | 110 | 530 |
| 9, 10 | ND | | 0.08 | 0.14 | 2.2 | 4 | ND | | 80 | 140 |
| 15, 16 | ND | | 0.15 | 0.36 | 2.2 | 5.3 | ND | | 83 | 200 |
| 17, 18 | ND | | 0.22 | 4.2 | 2.2 | 42 | ND | | 85 | 1600 |
| 19, 20 | ND | | 0.38 | 13 | 2.2 | 73 | ND | | 80 | 2700 |
| 21, 22 | ND | | 0.39 | 19 | 2.2 | 110 | ND | | 150 | 7300 |
| 23, 24 | ND | | 0.66 | 9.2 | 2.2 | 31 | ND | | 130 | 1800 |
| **Total Loadings (g)** | | **0** | | **47.14** | | **298.6** | | **0** | | **16110** |
| **EMC (mg/L)** | | **0.000** | | **0.352** | | **2.228** | | **0.000** | | **120.224** |

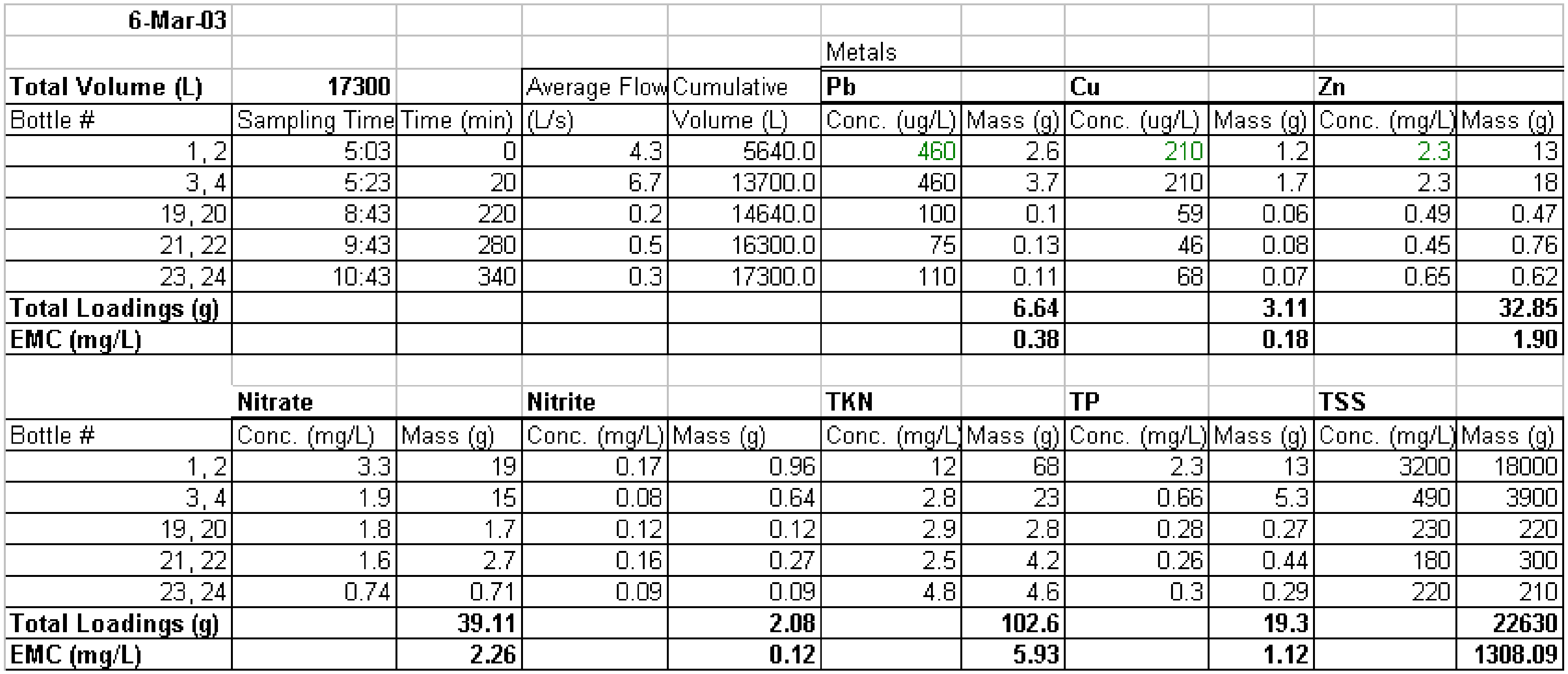
| 20-Dec-02 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **89000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 6:55 | 0 | 1.8 | 2400.0 | 80 | 0.19 | 80 | 0.19 | 0.6 | 1.4 |
| 3, 4 | 7:15 | 20 | 2.3 | 5160.0 | 78 | 0.22 | 79 | 0.22 | 0.53 | 1.5 |
| 11, 12 | 8:35 | 100 | 2.0 | 8040.0 | 39 | 0.11 | 180 | 0.52 | 1.8 | 5.2 |
| 15, 16 | 9:15 | 140 | 13.0 | 24600.0 | 32 | 0.53 | 260 | 4.3 | 1.5 | 25 |
| 17, 18 | 9:35 | 160 | 22.0 | 77640.0 | 30 | 1.6 | 130 | 6.9 | 1.4 | 74 |
| 19, 20 | 10:35 | 220 | 3.0 | 88440.0 | 30 | 0.32 | 65 | 0.7 | 0.7 | 7.6 |
| **Total Loadings (g)** | | | | | | **2.97** | | **12.83** | | **114.7** |
| **EMC (mg/L)** | | | | | | **0.033** | | **0.144** | | **1.289** |
| | **Nitrate** | | **Nitrite** | | | | **TKN** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L | Mass (g) | | |
| 1, 2 | ND | | 0.1 | 0.24 | 0.1 | 0.24 | 1.5 | 3.6 | | |
| 3, 4 | ND | | 0.07 | 0.19 | 0.07 | 0.19 | 1.8 | 5 | | |
| 11, 12 | ND | | 0.09 | 0.26 | 0.09 | 0.26 | 6.2 | 18 | | |
| 15, 16 | ND | | 0.04 | 0.66 | 0.04 | 0.66 | 3.2 | 53 | | |
| 17, 18 | ND | | 0.02 | 1.1 | 0.02 | 1.1 | 2.4 | 130 | | |
| 19, 20 | ND | | 0 | 0 | 0.02 | 0.22 | 1.2 | 13 | | |
| **Total Loadings (g)** | | **0** | | **2.45** | | **2.67** | | **222.6** | | |
| **EMC (mg/L)** | | **0.000** | | **0.028** | | **0.030** | | **2.501** | | |
| | **TP** | | | | **TSS** | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | | | | |
| 1, 2 | 0.53 | 1.3 | 0.53 | 1.3 | 280 | 670 | | | | |
| 3, 4 | 0.38 | 1 | 0.38 | 1 | 200 | 550 | | | | |
| 11, 12 | 1 | 2.9 | 1 | 2.9 | 870 | 2500 | | | | |
| 15, 16 | 0.5 | 8.3 | 0.5 | 8.3 | 650 | 11000 | | | | |
| 17, 18 | 0.37 | 20 | 0.37 | 20 | 660 | 35000 | | | | |
| 19, 20 | 0 | 0 | 0.24 | 2.6 | 330 | 3600 | | | | |
| **Total Loadings (g)** | | **33.5** | | **36.1** | | **53320** | | | | |
| **EMC (mg/L)** | | **0.376** | | **0.406** | | **599.101** | | | | |

| 1-Jan-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **287000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 5:56 | 0 | 2.2 | 0.0 | 170 | 0.49 | 140 | 0.4 | 0.85 | 2.4 |
| 5, 6 | 6:36 | 40 | 2.4 | 2800.0 | 145 | 0.45 | 160 | 0.5 | 0.84 | 2.6 |
| 7, 8 | 6:56 | 60 | 9.1 | 6000.0 | 120 | 1.3 | 180 | 2 | 0.82 | 9 |
| 9, 10 | 7:16 | 80 | 13.0 | 16920.0 | 145 | 2.3 | 200 | 3.2 | 0.78 | 12 |
| 11, 12 | 7:36 | 100 | 24.0 | 32880.0 | 170 | 5 | 220 | 6.4 | 1.9 | 55 |
| 13, 14 | 7:56 | 120 | 23.0 | 62040.0 | 83 | 2.2 | 79 | 2.1 | 1.2 | 32 |
| 15, 16 | 8:16 | 140 | 30.0 | 89040.0 | 73 | 2.7 | 42 | 1.5 | 0.61 | 22 |
| 17, 18 | 8:36 | 160 | 30.0 | 125400.0 | 64 | 4.7 | 34 | 2.5 | 0.2 | 15 |
| 19, 20 | 9:36 | 220 | 10.0 | 198360.0 | 43 | 1.6 | 19 | 0.7 | 0.22 | 8.1 |
| 21, 22 | 10:36 | 280 | 5.6 | 235230.0 | 22 | 0.44 | 33 | 0.67 | 0.21 | 4.2 |
| 23, 24 | 11:36 | 340 | 8.7 | 255480.0 | 22 | 0.69 | 47 | 1.5 | 0.21 | 6.6 |
| **Total Loadings (g)** | | | | 286680.0 | | **21.87** | | **21.47** | | **168.9** |
| **EMC (mg/L)** | | | | | | **0.076** | | **0.075** | | **0.589** |
| | **Nitrate** | | **Nitrite** | | | | **TKN** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 4.3 | 12 | 0.26 | 0.75 | 0.26 | 0.75 | 6.9 | 20 | 270 | 780 |
| 5, 6 | 4.3 | 13 | 0.15 | 0.47 | 0.15 | 0.47 | 5.4 | 17 | 245 | 760 |
| 7, 8 | 4.3 | 47 | 0.04 | 0.44 | 0.04 | 0.44 | 3.9 | 43 | 220 | 2400 |
| 9, 10 | 4.3 | 69 | 0.03 | 0.48 | 0.03 | 0.48 | 2.6 | 41 | 245 | 3900 |
| 11, 12 | 4.3 | 130 | 0.02 | 0.58 | 0.02 | 0.58 | 1.3 | 38 | 270 | 7900 |
| 13, 14 | 4.3 | 120 | 0 | 0 | 0.02 | 0.54 | 1 | 27 | 140 | 3800 |
| 15, 16 | 4.2 | 150 | 0 | 0 | 0.02 | 0.73 | 0.7 | 25 | 150 | 5500 |
| 17, 18 | 4.2 | 310 | 0 | 0 | 0.02 | 1.5 | 0.7 | 51 | 82 | 6000 |
| 19, 20 | 4.2 | 160 | 0.03 | 1.1 | 0.03 | 1.1 | 0.7 | 26 | 34 | 1300 |
| 21, 22 | 4.2 | 85 | 0.03 | 0.6 | 0.03 | 0.6 | 0.9 | 18 | 27 | 540 |
| 23, 24 | 4.2 | 130 | 0.03 | 0.94 | 0.03 | 0.94 | 1.1 | 34 | 100 | 3100 |
| **Total Loadings (g)** | | **1226** | | **5.36** | | **8.13** | | **340** | | **35980** |
| **EMC (mg/L)** | | **4.272** | | **0.019** | | **0.028** | | **1.185** | | **125.366** |
| | | | | | | | **TP** | | | |
| | | | | | | | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| | | | | | | | 0.64 | 1.8 | 0.64 | 1.8 |
| | | | | | | | 0.67 | 2.1 | 0.67 | 2.1 |
| | | | | | | | 0.7 | 7.6 | 0.7 | 7.6 |
| | | | | | | | 0.61 | 9.7 | 0.61 | 9.7 |
| | | | | | | | 0.52 | 15 | 0.52 | 15 |
| | | | | | | | 0.28 | 7.6 | 0.28 | 7.6 |
| | | | | | | | 0.24 | 8.7 | 0.24 | 8.7 |
| | | | | | | | 0 | 0 | 0.24 | 18 |
| | | | | | | | 0 | 0 | 0.24 | 8.9 |
| | | | | | | | 0 | 0 | 0.24 | 4.8 |
| | | | | | | | 0 | 0 | 0.24 | 7.5 |
| | | | | | | | | **52.5** | | **91.7** |
| | | | | | | | | **0.183** | | **0.320** |

| **4-Feb-03** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **23800** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 8:32 | 0 | 1.6 | 1920.0 | 1700 | 3.3 | 740 | 1.4 | 9.1 | 17 |
| 3, 4 | 8:52 | 20 | 6.1 | 9240.0 | 2300 | 17 | 470 | 3.4 | 14 | 100 |
| 5, 6 | 9:12 | 40 | 4.0 | 14040.0 | 970 | 4.7 | 170 | 0.82 | 2.6 | 12 |
| 7, 8 | 9:32 | 60 | 3.9 | 18720.0 | 650 | 3 | 140 | 0.66 | 1.6 | 7.5 |
| 9, 10 | 9:52 | 80 | 3.0 | 22320.0 | 240 | 0.86 | 99 | 0.36 | 1.1 | 4 |
| 11, 12 | 10:12 | 100 | 1.0 | 23760.0 | 180 | 0.26 | 120 | 0.17 | 2 | 2.9 |
| **Total Loadings (g)** | | | | | | **29.12** | | **6.81** | | **143.4** |
| **EMC (mg/L)** | | | | | | **1.22** | | **0.29** | | **6.03** |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 1.5 | 2.9 | 0.35 | 0.67 | 18 | 35 | 2.3 | 4.4 | 3200 | 6100 |
| 3, 4 | 0.85 | 6.2 | 0.13 | 0.95 | 4.2 | 31 | 1.1 | 8.1 | 1200 | 8800 |
| 5, 6 | 0.68 | 3.3 | 0.1 | 0.48 | 2.8 | 13 | 0.68 | 3.3 | 280 | 1300 |
| 7, 8 | 0.66 | 3.1 | 0.11 | 0.51 | 3.5 | 16 | 0.54 | 2.5 | 290 | 1400 |
| 9, 10 | 0.64 | 2.3 | 0.11 | 0.4 | 3.2 | 12 | 0.4 | 1.4 | 300 | 1100 |
| 11, 12 | 0.67 | 0.96 | 0.1 | 0.14 | 2.1 | 3 | 0.52 | 0.75 | 300 | 430 |
| **Total Loadings (g)** | | **18.76** | | **3.15** | | **110** | | **20.45** | | **19130** |
| **EMC (mg/L)** | | **0.79** | | **0.13** | | **4.62** | | **0.86** | | **803.78** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **21-Feb-03** | | | | | | | | | |
| | | | | Metals | | | | | |
| **Total Volume (L)** | **4440** | | 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 | 20:14 | 0 | 1.4 | 430 | 0.72 | 300 | 0.5 | 3.7 | 6.2 |
| 3, 4 | 20:34 | 20 | 1.8 | 240 | 0.52 | 110 | 0.24 | 1.1 | 2.4 |
| 5, 6 | 20:54 | 40 | 0.5 | 170 | 0.1 | 78 | 0.05 | 0.53 | 0.32 |
| **Total Loadings (g)** | | | | | **1.34** | | **0.79** | | **8.92** |
| **EMC (mg/L)** | | | | | **0.30** | | **0.18** | | **2.01** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) |
| 1, 2 | 0.71 | 1.2 | 0.06 | 0.1 | 3.6 | 6 | 0.27 | 0.45 | 1500 | 2500 |
| 3, 4 | 0.77 | 1.7 | 0.05 | 0.11 | 1.5 | 3.2 | 0.42 | 0.91 | 500 | 1100 |
| 5, 6 | 0.83 | 0.5 | 0.06 | 0.04 | 0.75 | 0.45 | 1.1 | 0.66 | 230 | 140 |
| **Total Loadings (g)** | | **3.4** | | **0.25** | | **9.65** | | **2.02** | | **3740** |
| **EMC (mg/L)** | | **0.77** | | **0.06** | | **2.17** | | **0.45** | | **842.34** |



| 6-Mar-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **17300** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 5:03 | 0 | 4.3 | 5640.0 | 460 | 2.6 | 210 | 1.2 | 2.3 | 13 |
| 3, 4 | 5:23 | 20 | 6.7 | 13700.0 | 460 | 3.7 | 210 | 1.7 | 2.3 | 18 |
| 19, 20 | 8:43 | 220 | 0.2 | 14640.0 | 100 | 0.1 | 59 | 0.06 | 0.49 | 0.47 |
| 21, 22 | 9:43 | 280 | 0.5 | 16300.0 | 75 | 0.13 | 46 | 0.08 | 0.45 | 0.76 |
| 23, 24 | 10:43 | 340 | 0.3 | 17300.0 | 110 | 0.11 | 68 | 0.07 | 0.65 | 0.62 |
| **Total Loadings (g)** | | | | | | **6.64** | | **3.11** | | **32.85** |
| **EMC (mg/L)** | | | | | | **0.38** | | **0.18** | | **1.90** |

| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 3.3 | 19 | 0.17 | 0.96 | 12 | 68 | 2.3 | 13 | 3200 | 18000 |
| 3, 4 | 1.9 | 15 | 0.08 | 0.64 | 2.8 | 23 | 0.66 | 5.3 | 490 | 3900 |
| 19, 20 | 1.8 | 1.7 | 0.12 | 0.12 | 2.9 | 2.8 | 0.28 | 0.27 | 230 | 220 |
| 21, 22 | 1.6 | 2.7 | 0.16 | 0.27 | 2.5 | 4.2 | 0.26 | 0.44 | 180 | 300 |
| 23, 24 | 0.74 | 0.71 | 0.09 | 0.09 | 4.8 | 4.6 | 0.3 | 0.29 | 220 | 210 |
| **Total Loadings (g)** | | **39.11** | | **2.08** | | **102.6** | | **19.3** | | **22630** |
| **EMC (mg/L)** | | **2.26** | | **0.12** | | **5.93** | | **1.12** | | **1308.09** |

| 20-Mar-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **134040** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 8:54 | 0 | 1.9 | 2280.0 | 330 | 0.75 | 120 | 0.27 | 1.1 | 2.5 |
| 3, 4 | 9:14 | 20 | 2.2 | 4920.0 | 330 | 0.87 | 120 | 0.32 | 1.1 | 2.9 |
| 5, 6 | 9:34 | 40 | 1.7 | 6960.0 | 190 | 0.39 | 78 | 0.16 | 0.67 | 1.4 |
| 7, 8 | 9:54 | 60 | 3.8 | 11520.0 | 180 | 0.82 | 85 | 0.39 | 0.79 | 3.6 |
| 9, 10 | 10:14 | 80 | 4.3 | 16680.0 | 180 | 0.93 | 85 | 0.44 | 0.79 | 4.1 |
| 11, 12 | 10:34 | 100 | 3.1 | 20400.0 | 180 | 0.67 | 85 | 0.32 | 0.79 | 2.9 |
| 13, 14 | 10:54 | 120 | 3.5 | 24600.0 | 160 | 0.67 | 91 | 0.38 | 0.91 | 3.8 |
| 15, 16 | 11:14 | 140 | 3.1 | 28320.0 | 210 | 0.78 | 85 | 0.32 | 0.96 | 3.6 |
| 17, 18 | 11:34 | 160 | 5.5 | 41520.0 | 250 | 3.3 | 78 | 1 | 1 | 13 |
| 19, 20 | 12:34 | 220 | 3.9 | 55560.0 | 180 | 2.5 | 72 | 1 | 0.88 | 12 |
| 21, 22 | 13:34 | 280 | 4.7 | 72600.0 | 110 | 1.9 | 65 | 1.1 | 0.76 | 13 |
| 23, 24 | 14:34 | 340 | 16.0 | 134040.0 | 60 | 3.7 | 65 | 4 | 0.38 | 23 |
| **Total Loadings (g)** | | | | | | **17.28** | | **9.7** | | **85.8** |
| **EMC (mg/L)** | | | | | | **0.129** | | **0.072** | | **0.640** |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | **TSS** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.9 | 2.1 | 0.02 | 0.05 | 5.7 | 13 | 0.94 | 2.1 | 640 | 1500 |
| 3, 4 | 0.56 | 1.5 | 0.03 | 0.08 | 2.4 | 6.3 | 0.78 | 2.1 | 400 | 1100 |
| 5, 6 | 1.2 | 2.4 | 0.03 | 0.06 | 2.1 | 4.3 | 0.55 | 1.1 | 440 | 900 |
| 7, 8 | 0.85 | 3.9 | 0.03 | 0.14 | 1.3 | 5.9 | 0.64 | 2.9 | 160 | 730 |
| 9, 10 | 0.49 | 2.5 | 0.03 | 0.15 | 0.42 | 2.2 | 0.73 | 3.8 | 360 | 1900 |
| 11, 12 | 0.39 | 1.5 | 0.03 | 0.11 | 1.2 | 4.5 | 0.56 | 2.1 | 240 | 900 |
| 13, 14 | 0.28 | 1.2 | 0.04 | 0.17 | 2 | 8.4 | 0.38 | 1.6 | 190 | 800 |
| 15, 16 | 0.28 | 1 | 0.05 | 0.19 | 1.7 | 6.3 | 0.42 | 1.6 | 160 | 600 |
| 17, 18 | 0.28 | 3.7 | 0.06 | 0.79 | 1.4 | 18 | 0.45 | 5.9 | 270 | 3600 |
| 19, 20 | 0.37 | 5.2 | 0.05 | 0.7 | 1.6 | 22 | 0.37 | 5.2 | 250 | 3500 |
| 21, 22 | 0.45 | 7.7 | 0.04 | 0.68 | 1.7 | 29 | 0.29 | 4.9 | 550 | 9400 |
| 23, 24 | 0.33 | 20 | 0.07 | 4.3 | 1.7 | 100 | 1.3 | 80 | 1200 | 74000 |
| **Total Loadings (g)** | | **52.7** | | **7.42** | | **219.9** | | **113.3** | | **98930** |
| **EMC (mg/L)** | | **0.393** | | **0.055** | | **1.641** | | **0.845** | | **738.063** |

| 7-Apr-03 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | | | |
| **Total Volume (L)** | **73320** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | | **TSS** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 5:56 | 0 | 1.9 | 2520.0 | 100 | 0.25 | 97 | 0.24 | 1 | 2.5 | 370 | 930 |
| 5, 6 | 6:36 | 40 | 1.8 | 4920.0 | 100 | 0.24 | 83 | 0.2 | 0.94 | 2.3 | 300 | 720 |
| 7, 8 | 6:56 | 60 | 1.0 | 6120.0 | 110 | 0.13 | 87 | 0.1 | 0.95 | 1.1 | 130 | 160 |
| 9, 10 | 7:16 | 80 | 0.8 | 7080.0 | 110 | 0.11 | 87 | 0.08 | 0.95 | 0.91 | 230 | 220 |
| 13, 14 | 7:56 | 120 | 0.8 | 8160.0 | 110 | 0.12 | 87 | 0.09 | 0.95 | 1 | 210 | 230 |
| 15, 16 | 8:16 | 140 | 1.5 | 9960.0 | 110 | 0.2 | 87 | 0.16 | 0.95 | 1.7 | 200 | 360 |
| 17, 18 | 8:36 | 160 | 3.0 | 17160.0 | 110 | 0.79 | 90 | 0.65 | 0.96 | 6.9 | 400 | 2900 |
| 19, 20 | 9:36 | 220 | 6.1 | 39120.0 | 240 | 5.3 | 110 | 2.4 | 3 | 66 | 390 | 8600 |
| 21, 22 | 10:36 | 280 | 7.1 | 64560.0 | 1800 | 46 | 66 | 1.7 | 1 | 25 | 200 | 5200 |
| 23, 24 | 11:36 | 340 | 2.4 | 73320.0 | 60 | 0.53 | 30 | 0.26 | 0.32 | 2.8 | 54 | 470 |
| **Total Loadings (g)** | | | | | | **53.67** | | **5.88** | | **110.21** | | **19790** |
| **EMC (mg/L)** | | | | | | **0.732** | | **0.080** | | **1.503** | | **269.913** |

| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 1.5 | 3.8 | 0.11 | 0.28 | 10 | 25 | 1.5 | 3.8 | 1.5 | 3.8 |
| 5, 6 | 0.71 | 1.7 | 0.07 | 0.17 | 4.8 | 12 | 0.45 | 1.1 | 0.45 | 1.1 |
| 7, 8 | 0.72 | 0.86 | 0.08 | 0.1 | 3.2 | 3.8 | 0.51 | 0.61 | 0.51 | 0.61 |
| 9, 10 | 0.73 | 0.7 | 0.08 | 0.08 | 1.5 | 1.4 | 0.56 | 0.54 | 0.56 | 0.54 |
| 13, 14 | 0.64 | 0.69 | 0.08 | 0.09 | 2.2 | 2.4 | 0.29 | 0.31 | 0.29 | 0.31 |
| 15, 16 | 0.53 | 0.95 | 0.07 | 0.13 | 2.5 | 4.5 | 0.32 | 0.58 | 0.32 | 0.58 |
| 17, 18 | 0.42 | 3 | 0.05 | 0.36 | 2.8 | 20 | 0.35 | 2.5 | 0.35 | 2.5 |
| 19, 20 | 0.35 | 7.7 | 0.04 | 0.88 | 1.9 | 42 | 0 | 0 | 0.24 | 5.3 |
| 21, 22 | 0.27 | 6.9 | 0.03 | 0.76 | 0.98 | 25 | 0 | 0 | 0.24 | 6.1 |
| 23, 24 | 0.36 | 3.2 | 0.04 | 0.35 | 2.1 | 18 | 0 | 0 | 0.24 | 2.1 |
| **Total Loadings (g)** | | **29.5** | | **3.2** | | **154.1** | | **9.44** | | **22.94** |
| **EMC (mg/L)** | | **0.402** | | **0.044** | | **2.102** | | **0.129** | | **0.313** |

| **25-Apr-03** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **22440** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 20:40 | 0 | 1.4 | 1680.0 | 210 | 0.35 | 170 | 0.29 | 2.1 | 3.5 |
| 3, 4 | 21:00 | 20 | 1.9 | 3960.0 | 230 | 0.52 | 84 | 0.19 | 2.3 | 5.2 |
| 5, 6 | 21:20 | 40 | 1.5 | 5880.0 | 91 | 0.17 | 75 | 0.14 | 0.88 | 1.7 |
| 13, 14 | 22:40 | 120 | 10.0 | 17880.0 | 180 | 2.2 | 120 | 1.4 | 1.1 | 13 |
| 15, 16 | 23:00 | 140 | 1.9 | 20400.0 | 83 | 0.21 | 35 | 0.09 | 0.47 | 1.2 |
| 19, 20 | 0:20 | 220 | 0.6 | 22440.0 | 51 | 0.1 | 28 | 0.06 | 0.27 | 0.55 |
| **Total Loadings (g)** | | | | | | **3.55** | | **2.17** | | **25.15** |
| **EMC (mg/L)** | | | | | | **0.158** | | **0.097** | | **1.121** |
| | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 0.82 | 1.4 | 0.07 | 0.12 | 7.8 | 13 | 1.6 | 2.7 | 1.6 | 2.7 |
| 3, 4 | 0.76 | 1.7 | 0.05 | 0.11 | 4.1 | 9.3 | 1.3 | 3 | 1.3 | 3 |
| 5, 6 | 0.8 | 1.5 | 0.05 | 0.1 | 3.1 | 6 | 0.85 | 1.6 | 0.85 | 1.6 |
| 13, 14 | 0.59 | 7.1 | 0.03 | 0.36 | 8.3 | 100 | 0.73 | 8.8 | 0.73 | 8.8 |
| 15, 16 | 0.46 | 1.2 | 0.03 | 0.08 | 3.2 | 8 | 0 | 0 | 0.24 | 0.6 |
| 19, 20 | 0.98 | 2 | 0.05 | 0.1 | 2.5 | 5.1 | 0.26 | 0.53 | 0.26 | 0.53 |
| **Total Loadings (g)** | | **14.9** | | **0.87** | | **141.4** | | **16.63** | | **17.23** |
| **EMC (mg/L)** | | **0.664** | | **0.039** | | **6.301** | | **0.741** | | **0.768** |
| | **TSS** | | | | | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | | | | | | | | |
| 1, 2 | 1200 | 2000 | | | | | | | | |
| 3, 4 | 1000 | 2300 | | | | | | | | |
| 5, 6 | 490 | 940 | | | | | | | | |
| 13, 14 | 1100 | 13200 | | | | | | | | |
| 15, 16 | 100 | 250 | | | | | | | | |
| 19, 20 | 75 | 150 | | | | | | | | |
| **Total Loadings (g)** | | **18840** | | | | | | | | |
| **EMC (mg/L)** | | **839.572** | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **10-May-03** | | | | | | | | | | |
| | | | | | Metals | | | | | |
| **Total Volume (L)** | **38040** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 9:06 | 0 | 2.4 | 2880.0 | 37 | 0.11 | 69 | 0.2 | 0.84 | 2.4 |
| 3, 4 | 9:26 | 20 | 7.7 | 12120.0 | 140 | 1.3 | 110 | 1 | 0.79 | 7.3 |
| 5, 6 | 9:46 | 40 | 6.7 | 20160.0 | 120 | 0.96 | 96 | 0.77 | 0.79 | 6.4 |
| 7, 8 | 10:06 | 60 | 1.1 | 21480.0 | 81 | 0.11 | 95 | 0.13 | 0.51 | 0.67 |
| 9, 10 | 10:26 | 80 | 7.4 | 30360.0 | 100 | 0.89 | 93 | 0.83 | 0.59 | 5.2 |
| 11, 12 | 10:46 | 100 | 4.7 | 36000.0 | 170 | 0.96 | 120 | 0.68 | 0.86 | 4.9 |
| 13, 14 | 11:06 | 120 | 1.5 | 38040.0 | 26 | 0.05 | 28 | 0.06 | 0.13 | 0.27 |
| **Total Loadings (g)** | | | | | | **4.38** | | **3.67** | | **27.14** |
| **EMC (mg/L)** | | | | | | **0.115** | | **0.096** | | **0.713** |
| | **Cd** | | **Nitrate** | | **Nitrite** | | **TKN** | | | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L | Mass (g) | | |
| 1, 2 | 95 | 0.27 | 0.85 | 2.4 | 0.31 | 0.89 | 3.9 | 11 | | |
| 3, 4 | 88 | 0.81 | 0.59 | 5.5 | 0.03 | 0.28 | 2.5 | 23 | | |
| 5, 6 | 64 | 0.51 | 0.48 | 3.9 | 0.02 | 0.16 | 3.1 | 25 | | |
| 7, 8 | 46 | 0.06 | 0.39 | 0.51 | 0.03 | 0.04 | 2 | 2.6 | | |
| 9, 10 | 130 | 1.2 | 0.84 | 7.5 | 0.02 | 0.18 | 2.8 | 25 | | |
| 11, 12 | 110 | 0.62 | 0.36 | 2 | 0.02 | 0.11 | 3.2 | 18 | | |
| 13, 14 | 36 | 0.07 | 1.33 | 2.7 | 0.03 | 0.06 | 2.9 | 5.9 | | |
| **Total Loadings (g)** | | **3.54** | | **24.51** | | **1.72** | | **110.5** | | |
| **EMC (mg/L)** | | **0.093** | | **0.644** | | **0.045** | | **2.905** | | |
| | | | | | | | | | | |
| Bottle # | **TP** | | | | **TSS** | | | | | |
| 1, 2 | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | | | | |
| 3, 4 | 0.58 | 1.7 | 0.58 | 1.7 | 260 | 750 | | | | |
| 5, 6 | 0.31 | 2.9 | 0.31 | 2.9 | 240 | 2200 | | | | |
| 7, 8 | 0 | 0 | 0.24 | 1.9 | 280 | 2300 | | | | |
| 9, 10 | 0.31 | 0.41 | 0.31 | 0.41 | 79 | 100 | | | | |
| 11, 12 | 0.28 | 2.5 | 0.28 | 2.5 | 150 | 1300 | | | | |
| 13, 14 | 0.28 | 1.6 | 0.28 | 1.6 | 110 | 620 | | | | |
| **Total Loadings (g)** | 0 | 0 | 0.24 | 0.49 | 64 | 130 | | | | |
| **EMC (mg/L)** | | **9.11** | | **11.5** | | **7400** | | | | |
| | | **0.239** | | **0.302** | | **194.532** | | | | |

| 16-May-03 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | | | | | |
| **Total Volume (L)** | **537120** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | | **TP** | | | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 1:22 | 0 | 1.6 | 2160.0 | 370 | 0.8 | 230 | 0.5 | 1.6 | 3.5 | 1.7 | 3.7 | 1.7 | 3.7 |
| 5, 6 | 2:02 | 40 | 0.7 | 3120.0 | 57 | 0.05 | 66 | 0.06 | 0.32 | 0.31 | 1 | 0.96 | 1 | 0.96 |
| 7, 8 | 2:22 | 60 | 1.7 | 5160.0 | 44 | 0.09 | 79 | 0.16 | 0.43 | 0.88 | 0.57 | 1.2 | 0.57 | 1.2 |
| 9, 10 | 2:42 | 80 | 2.5 | 8520.0 | 87 | 0.29 | 150 | 0.5 | 0.66 | 2.2 | 0.51 | 1.7 | 0.51 | 1.7 |
| 11, 12 | 3:02 | 100 | 1.1 | 9720.0 | 87 | 0.1 | 150 | 0.18 | 0.66 | 0.79 | 0.51 | 0.61 | 0.51 | 0.61 |
| 13, 14 | 3:22 | 120 | 10.0 | 21720.0 | 130 | 1.6 | 220 | 2.6 | 0.89 | 11 | 0.45 | 5.4 | 0.45 | 5.4 |
| 15, 16 | 3:42 | 140 | 23.0 | 49800.0 | 77 | 2.2 | 85 | 2.4 | 1.4 | 39 | 0 | 0 | 0.24 | 6.7 |
| 17, 18 | 4:02 | 160 | 4.6 | 60840.0 | 69 | 0.76 | 100 | 1.1 | 0.82 | 9.1 | 0.9 | 9.9 | 0.9 | 9.9 |
| 21, 22 | 6:02 | 280 | 100.0 | 436320.0 | 61 | 23 | 41 | 15 | 0.33 | 120 | 0.4 | 150 | 0.4 | 150 |
| 23, 24 | 7:02 | 340 | 28.0 | 537120.0 | 29 | 2.9 | 25 | 2.5 | 0.11 | 11 | 0 | 0 | 0.24 | 24 |
| **Total Loadings (g)** | | | | | | **31.79** | | **25** | | **197.78** | | **173.47** | | **204.17** |
| **EMC (mg/L)** | | | | | | **0.059** | | **0.047** | | **0.368** | | **0.323** | | **0.380** |
| | **Cd** | | **Nitrate** | | | | **Nitrite** | | | | **TKN** | | **TSS** | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 42 | 0.09 | 3.5 | 7.6 | 3.5 | 7.6 | 0.25 | 0.54 | 0.25 | 0.54 | 29 | 63 | 390 | 840 |
| 5, 6 | 31 | 0.03 | 1.4 | 1.3 | 1.4 | 1.3 | 0.12 | 0.12 | 0.12 | 0.12 | 6.9 | 6.6 | 100 | 96 |
| 7, 8 | 20 | 0.04 | 1.2 | 2.4 | 1.2 | 2.4 | 0.09 | 0.18 | 0.09 | 0.18 | 2.7 | 5.5 | 82 | 170 |
| 9, 10 | 26 | 0.08 | 1 | 3.4 | 1 | 3.4 | 0.06 | 0.2 | 0.06 | 0.2 | 6.3 | 21 | 220 | 740 |
| 11, 12 | 26 | 0.03 | 1 | 1.2 | 1 | 1.2 | 0.06 | 0.07 | 0.06 | 0.07 | 6.3 | 7.6 | 19 | 23 |
| 13, 14 | 32 | 0.38 | 0 | 0 | 0.14 | 0.96 | 0.03 | 0.36 | 0.03 | 0.36 | 9.9 | 120 | 270 | 3200 |
| 15, 16 | 36 | 1 | 0.62 | 17 | 0.62 | 17 | 0 | 0 | 0.02 | 0.56 | 2.6 | 73 | 200 | 5600 |
| 17, 18 | 24 | 0.26 | 0.29 | 3.2 | 0.29 | 3.2 | 0 | 0 | 0.02 | 0.22 | 6.6 | 73 | 180 | 2000 |
| 21, 22 | 17 | 6.4 | 0.24 | 90 | 0.24 | 90 | 0 | 0 | 0.02 | 7.5 | 2 | 750 | 220 | 83000 |
| 23, 24 | 9.6 | 0.97 | 1.2 | 120 | 1.2 | 120 | 0.02 | 2 | 0.02 | 2 | 0.56 | 56 | 36 | 3600 |
| **Total Loadings (g)** | | **9.28** | | **246.1** | | **247.06** | | **3.47** | | **11.75** | | **1175.7** | | **99269** |
| **EMC (mg/L)** | | **0.017** | | **0.458** | | **0.460** | | **0.006** | | **0.022** | | **2.189** | | **184.817** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **31-May-03** | | | | | | | | | |
| | | | | Metals | | | | | |
| **Total Volume (L)** | **79400** | | 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 | 19:01 | 0 | 4.40 | 140 | 0.81 | 150 | 0.86 | 2 | 12 |
| 3, 4 | 19:21 | 20 | 57.00 | 63 | 4.3 | 47 | 3.2 | 0.44 | 30 |
| 5, 6 | 19:41 | 40 | 4.70 | 38 | 0.21 | 40 | 0.23 | 0.27 | 1.5 |
| **Total Loadings (g)** | | | | | **5.32** | | **4.29** | | **43.5** |
| **EMC (mg/L)** | | | | | **0.07** | | **0.05** | | **0.55** |
| | **Cd** | | **Nitrate** | | **Nitrite** | | **TKN** | | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) | |
| 1, 2 | 38 | 0.21 | 0.05 | 0.29 | 0.11 | 0.63 | 0.78 | 4.5 | |
| 3, 4 | 14 | 0.95 | 1.5 | 100 | 0.02 | 1.4 | 0.78 | 53 | |
| 5, 6 | 15 | 0.08 | 0.55 | 3.1 | 0.03 | 0.17 | 1.3 | 7.3 | |
| **Total Loadings (g)** | | **1.24** | | **103.39** | | **2.2** | | **64.8** | |
| **EMC (mg/L)** | | **0.016** | | **1.30** | | **0.03** | | **0.82** | |
| | **TP** | | | | **TSS** | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | | | |
| 1, 2 | 1.2 | 6.9 | 1.2 | 6.9 | 600 | 3500 | | | |
| 3, 4 | 0.27 | 18 | 0.27 | 18 | 200 | 14000 | | | |
| 5, 6 | 0 | 0 | 0.24 | 1.4 | 100 | 600 | | | |
| **Total Loadings (g)** | | **24.9** | | **26.3** | | **18100** | | | |
| **EMC (mg/L)** | | **0.31** | | **0.33** | | **227.96** | | | |

| 9-Jun-03 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | | | | | |
| **Total Volume (L)** | **104000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | | **TKN** | | **TSS** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 1:12 | 0 | 18.0 | 21720.0 | 120 | 2.6 | 160 | 3.5 | 1.1 | 24 | ND | | ND | |
| 3, 4 | 1:32 | 20 | 17.0 | 41880.0 | 31 | 0.62 | 33 | 0.67 | 0.29 | 5.8 | ND | | ND | |
| 5, 6 | 1:52 | 40 | 11.0 | 55200.0 | 15 | 0.2 | 40 | 0.53 | 0.2 | 2.7 | ND | | ND | |
| 7, 8 | 2:12 | 60 | 8.2 | 65040.0 | 28 | 0.28 | 40 | 0.39 | 0.21 | 2.1 | ND | | ND | |
| 9, 10 | 2:32 | 80 | 4.6 | 70560.0 | 22 | 0.12 | 40 | 0.22 | 0.21 | 1.2 | ND | | ND | |
| 11, 12 | 2:52 | 100 | 6.1 | 77880.0 | 13 | 0.1 | 47 | 0.34 | 0.2 | 1.5 | ND | | ND | |
| 13, 14 | 3:12 | 120 | 4.3 | 83040.0 | 14 | 0.07 | 23 | 0.12 | 0.23 | 1.2 | ND | | ND | |
| 15, 16 | 3:32 | 140 | 3.5 | 87240.0 | 11 | 0.05 | 26 | 0.11 | 0.22 | 0.92 | ND | | ND | |
| 17, 18 | 3:52 | 160 | 3.0 | 94800.0 | 8 | 0.06 | 28 | 0.2 | 0.2 | 1.4 | ND | | ND | |
| 19, 20 | 4:52 | 220 | 2.1 | 103920.0 | 7 | 0.07 | 28 | 0.27 | 0.22 | 2.1 | ND | | ND | |
| **Total Loadings (g)** | | | | | | **4.17** | | **6.35** | | **42.92** | | **0** | | **0** |
| **EMC (mg/L)** | | | | | | **0.040** | | **0.061** | | **0.413** | | **0.000** | | **0.000** |
| | **Cd** | | **Nitrate** | | | | **TP** | | | | **Nitrite** | | | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 30 | 0.65 | 0.23 | 5 | 0.23 | 5 | 0.42 | 9.1 | 0.42 | 9.1 | 0.08 | 1.7 | 0.08 | 1.7 |
| 3, 4 | 13 | 0.26 | 0.26 | 5.2 | 0.26 | 5.2 | 0 | 0 | 0.24 | 4.8 | 0.03 | 0.6 | 0.03 | 0.6 |
| 5, 6 | 13 | 0.17 | 0 | 0 | 0.14 | 1.9 | 0.2 | 2.7 | 0.32 | 4.3 | 0.02 | **0.27** | 0.02 | **0.27** |
| 7, 8 | 7.3 | 0.07 | 0.17 | 1.7 | 0.17 | 1.7 | 0.2 | 2 | 0.32 | 3.1 | 0 | 0 | 0.02 | 0.2 |
| 9, 10 | 8.2 | 0.05 | 0.29 | 1.6 | 0.29 | 1.6 | 0.2 | 1.1 | 0.32 | 1.8 | 0 | 0 | 0.02 | 0.11 |
| 11, 12 | 9 | 0.07 | 0.4 | 2.9 | 0.4 | 2.9 | 0.4 | 2.9 | 0.4 | 2.9 | 0 | 0 | 0.02 | 0.15 |
| 13, 14 | 27 | 0.14 | 0.23 | 1.2 | 0.23 | 1.2 | 0.2 | 1 | 0.32 | 1.7 | 0.02 | 0.1 | 0.02 | 0.1 |
| 15, 16 | 25 | 0.11 | 0.12 | 0.5 | 0.19 | 0.8 | 0.2 | 0.84 | 0.32 | 1.3 | 0.03 | 0.13 | 0.03 | 0.13 |
| 17, 18 | 23 | 0.17 | 0 | 0 | 0.14 | 1 | 0.2 | 1.4 | 0.32 | 2.3 | 0.03 | 0.22 | 0.03 | 0.22 |
| 19, 20 | 23 | 0.22 | 0.2 | 1.9 | 0.2 | 1.9 | 0 | 0 | 0.24 | 2.3 | 0.03 | 0.28 | 0.03 | 0.28 |
| **Total Loadings (g)** | | **1.91** | | **20** | | **23.2** | | **21.04** | | **33.6** | | **3.3** | | **3.76** |
| **EMC (mg/L)** | | **0.018** | | **0.192** | | **0.223** | | **0.202** | | **0.323** | | **0.032** | | **0.036** |

| 1-Aug-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Metals | | | | | | |
| **Total Volume (L)** | **27400** | | 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 | 15:57 | 0 | 10.0 | 200 | 2.4 | 230 | 2.8 | 50 | 0.61 | |
| 3, 4 | 16:17 | 20 | 10.0 | 310 | 3.7 | 230 | 2.8 | 48 | 0.58 | |
| 5, 6 | 16:37 | 40 | 2.6 | 210 | 0.66 | 150 | 0.47 | 31 | 0.1 | |
| **Total Loadings (g)** | | | | | **6.76** | | **6.07** | | **1.29** | |
| **EMC (mg/L)** | | | | | **0.25** | | **0.22** | | **0.05** | |
| | **Zn** | | **Nitrate** | | **Nitrite** | | **Nitrite** | | **TKN** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) |
| 1, 2 | 2.2 | 27 | 0.98 | 12 | 0 | 0 | 0.02 | 0.24 | 5.7 | 70 |
| 3, 4 | 2.2 | 26 | 0.57 | 6.8 | 0.03 | 0.36 | 0.03 | 0.36 | 1.7 | 20 |
| 5, 6 | 1.2 | 3.7 | 0.73 | 2.3 | 0.03 | 0.09 | 0.03 | 0.09 | 1.1 | 3.4 |
| **Total Loadings (g)** | | **56.7** | | **21.1** | | **0.45** | | **0.69** | | **93.4** |
| **EMC (mg/L)** | | **2.07** | | **0.77** | | **0.02** | | **0.03** | | **3.41** |
| | **TP** | | **TSS** | | **Cl** | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | | | | |
| 1, 2 | 1.9 | 23 | 530 | 6500 | 13 | 160 | | | | |
| 3, 4 | 0.84 | 10 | 340 | 4100 | 2 | 24 | | | | |
| 5, 6 | 0.47 | 1.5 | 170 | 530 | 2 | 6.2 | | | | |
| **Total Loadings (g)** | | **34.5** | | **11130** | | **190.2** | | | | |
| **EMC (mg/L)** | | **1.26** | | **406.20** | | **6.94** | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **5-Aug-03** | | | | | | | | | | |
| | | | | Metals | | | | | | |
| **Total Volume (L)** | **4680** | | 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 | 5:26 | 0 | 2.0 | 54 | 0.13 | 110 | 0.26 | 16 | 0.04 | |
| 3, 4 | 5:46 | 20 | 1.9 | 40 | 0.09 | 100 | 0.23 | 8.2 | 0.02 | |
| **Total Loadings (g)** | | | | | **0.22** | | **0.49** | | **0.06** | |
| **EMC (mg/L)** | | | | | **0.05** | | **0.10** | | **0.01** | |
| | **Zn** | | **Nitrate** | | **Nitrite** | | **TKN** | | **TP** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) |
| 1, 2 | 0.64 | 1.5 | 3.1 | 7.4 | 0.23 | 0.55 | 0.28 | 0.67 | 0.64 | 1.5 |
| 3, 4 | 0.39 | 0.89 | 2.6 | 5 | 0.14 | 0.32 | 3.5 | 8 | 0.51 | 1.2 |
| **Total Loadings (g)** | | **2.39** | | **12.4** | | **0.87** | | **8.67** | | **2.7** |
| **EMC (mg/L)** | | **0.51** | | **2.65** | | **0.19** | | **1.85** | | **0.58** |
| | **TSS** | | **Cl** | | | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | | | | | |
| 1, 2 | ND | | 18 | 43 | | | | | | |
| 3, 4 | ND | | 12 | 23 | | | | | | |
| **Total Loadings (g)** | | **0** | | **66** | | | | | | |
| **EMC (mg/L)** | | **0.00** | | **14.10** | | | | | | |

| 16-Aug-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| **Total Volume (L)** | **23800** | | 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 | 15:55 | 0 | 15.0 | 950 | 17 | 360 | 6.3 | 52 | 0.91 | |
| 3, 4 | 16:15 | 20 | 4.8 | 130 | 0.83 | 61 | 0.39 | 8.4 | 0.05 | |
| **Total Loadings (g)** | | | | | **17.83** | | **6.69** | | **0.96** | |
| **EMC (mg/L)** | | | | | **0.75** | | **0.28** | | **0.04** | |
| | **Zn** | | **Nitrate** | | **Nitrite** | | **Nitrite** | | **TKN** | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) | Conc. (m | Mass (g) |
| 1, 2 | 3.4 | 59 | ND | | 0 | 0.000 | 0.02 | 0.350 | 9.9 | 170 |
| 3, 4 | 0.43 | 2.7 | ND | | 0.33 | 2.100 | 0.33 | 2.100 | 5.7 | 36 |
| **Total Loadings (g)** | | **61.7** | | **0** | | **2.100** | | **2.450** | | **206** |
| **EMC (mg/L)** | | **2.59** | | **0.00** | | **0.088** | | **0.103** | | **8.66** |
| | **TP** | | **TSS** | | **Cl** | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (m | Mass (g) | | | | |
| 1, 2 | 0.92 | 16 | 550 | 9600 | TBD | | | | | |
| 3, 4 | 0.35 | 2.2 | 95 | 600 | TBD | | | | | |
| **Total Loadings (g)** | | **18.2** | | **10200** | | **0** | | | | |
| **EMC (mg/L)** | | **0.76** | | **428.57** | | **0.00** | | | | |

| 27-Aug-03 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| **Total Volume (L)** | **161800** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Cd** | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) |
| 1, 2 | 18:23 | 0 | 78.0 | 93120.0 | 1100 | 100 | 240 | 22 | 40 | 3.7 |
| 3, 4 | 18:43 | 20 | 44.0 | 145800.0 | 84 | 4.4 | 28 | 1.5 | 7.3 | 0.39 |
| 5, 6 | 19:03 | 40 | 9.1 | 156720.0 | 47 | 0.51 | 19 | 0.21 | 2 | 0.02 |
| 7, 8 | 19:23 | 60 | 1.6 | 158640.0 | 38 | 0.07 | 37 | 0.07 | 2 | 0.04 |
| 9, 10 | 19:43 | 80 | 2.4 | 161760.0 | 51 | 0.16 | 21 | 0.07 | 2 | 0.01 |
| **Total Loadings (g)** | | | | | | **105.14** | | **23.85** | | 4.16 |
| **EMC (mg/L)** | | | | | | **0.65** | | **0.15** | | **0.03** |
| | **Zn** | | **Nitrate** | | **Nitrite** | | **TKN** | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L | Mass (g) | | |
| 1, 2 | 1.1 | 100 | ND | | 0.06 | 5.6 | 5.5 | 510 | | |
| 3, 4 | 0.16 | 8.4 | ND | | 0.03 | 1.6 | 1.1 | 58 | | |
| 5, 6 | 0.18 | 2 | ND | | 0.03 | 0.33 | 1.4 | 15 | | |
| 7, 8 | 0.12 | 0.23 | ND | | 0.05 | 0.1 | 1.6 | 3.1 | | |
| 9, 10 | 0.25 | 0.78 | ND | | 0.07 | 0.22 | 1.7 | 5.3 | | |
| **Total Loadings (g)** | | **111.41** | | **0** | | **7.85** | | **591.4** | | |
| **EMC (mg/L)** | | **0.69** | | **0.00** | | **0.05** | | **3.66** | | |
| | **TP** | | | | **TSS** | | | | | |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | | | |
| 1, 2 | 1.3 | 120 | 1.3 | 120 | 640 | 60000 | | | | |
| 3, 4 | 0 | 0 | 0.24 | 13 | 130 | 6900 | | | | |
| 5, 6 | 0 | 0 | 0.24 | 2.6 | 99 | 1100 | | | | |
| 7, 8 | 0 | 0 | 0.24 | 0.46 | 110 | 210 | | | | |
| 9, 10 | 0.26 | 0.81 | 0.26 | 0.81 | 100 | 310 | | | | |
| **Total Loadings (g)** | | **120.81** | | **136.87** | | **68520** | | | | |
| **EMC (mg/L)** | | **0.75** | | **0.85** | | **423.49** | | | | |

| **12-Sep-03** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Metals | | | | | | | | Nitrogen | |
| **Total Volume (L)** | **102000** | | Average Flow | Cumulative | **Pb** | | **Cu** | | **Zn** | | **TP** | | | |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 13:40 | 0 | 15.0 | 9000.0 | 200 | 1.8 | 131 | 1.2 | 0.83 | 7.5 | 0.37 | 3.3 | 0.37 | 3.3 |
| 3, 4 | 14:00 | 20 | 13.0 | 24960.0 | 200 | 3.2 | 100 | 1.6 | 1.1 | 18 | 0.27 | 4.3 | 0.27 | 4.3 |
| 5, 6 | 14:20 | 40 | 3.8 | 29520.0 | 91 | 0.41 | 43 | 0.2 | 30.35 | 1.6 | 0.24 | 1.1 | 0 | 0 |
| 7, 8 | 14:40 | 60 | 2.2 | 32160.0 | 150 | 0.4 | 65 | 0.17 | 0.61 | 1.6 | 0.24 | 0.63 | 0 | 0 |
| 9, 10 | 15:00 | 80 | 4.9 | 38040.0 | 150 | 0.88 | 65 | 0.38 | 0.61 | 3.6 | 0.24 | 1.4 | 0 | 0 |
| 11, 12 | 15:20 | 100 | 4.6 | 43560.0 | 210 | 1.2 | 87 | 0.48 | 0.87 | 4.8 | 0.24 | 1.3 | 0 | 0 |
| 13, 14 | 15:40 | 120 | 4.6 | 48480.0 | 150 | 0.74 | 60 | 0.3 | 0.6 | 3 | 0.24 | 1.2 | 0 | 0 |
| 15, 16 | 16:00 | 140 | 2.7 | 52080.0 | 82 | 0.3 | 32 | 0.12 | 0.33 | 1.2 | 0.26 | 0.94 | 0 | 0 |
| 17, 18 | 16:20 | 160 | 5.5 | 65160.0 | 150 | 2 | 72 | 0.94 | 0.59 | 7.7 | 0.28 | 3.7 | 0.28 | 3.7 |
| 19, 20 | 17:20 | 220 | 6.2 | 87360.0 | 200 | 4.4 | 84 | 1.9 | 0.7 | 16 | 0.45 | 10 | 0.45 | 10 |
| 21, 22 | 18:20 | 280 | 1.4 | 92400.0 | 170 | 0.86 | 75 | 0.38 | 0.59 | 3 | 0.24 | 1.2 | 0 | 0 |
| 23, 24 | 19:20 | 340 | 2.6 | 101880.0 | 130 | 1.2 | 65 | 0.62 | 0.48 | 4.6 | 0.35 | 3.3 | 0.35 | 3.3 |
| **Total Loadings (g)** | | | | | | **17.39** | | **8.29** | | **72.6** | | **32.37** | | **24.6** |
| **EMC (mg/L)** | | | | | | **0.17** | | **0.08** | | **0.71** | | **0.32** | | **0.24** |
| | **Cd** | | **Nitrate** | | **Nitrite** | | | | **TKN** | | **TSS** | | | |
| Bottle # | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | | |
| 1, 2 | 31 | 0.28 | ND | | 0.04 | 0.36 | 0.04 | 0.36 | 2 | 18 | 290 | 2600 | | |
| 3, 4 | 27 | 0.43 | ND | | 0.02 | 0.32 | 0.02 | 0.32 | 0.98 | 16 | 290 | 4600 | | |
| 5, 6 | 10 | 0.05 | ND | | 0.03 | 0.14 | 0.03 | 0.14 | 1.5 | 6.8 | 80 | 360 | | |
| 7, 8 | 15 | 0.04 | ND | | 0.02 | 0.05 | 0 | 0 | 1.1 | 2.9 | 76 | 200 | | |
| 9, 10 | 15 | 0.09 | ND | | 0.04 | 0.24 | 0.04 | 0.24 | 1.1 | 6.5 | 160 | 940 | | |
| 11, 12 | 20 | 0.11 | ND | | 0.04 | 0.22 | 0.04 | 0.22 | 1.1 | 6.1 | 120 | 660 | | |
| 13, 14 | 13 | 0.06 | ND | | 0.04 | 0.2 | 0.04 | 0.2 | 1.1 | 5.4 | 61 | 300 | | |
| 15, 16 | 6.6 | 0.02 | ND | | 0.04 | 0.14 | 0.04 | 0.14 | 0.7 | 2.5 | 88 | 320 | | |
| 17, 18 | 15 | 0.2 | ND | | 0.03 | 0.39 | 0.03 | 0.39 | 1.5 | 20 | 300 | 3900 | | |
| 19, 20 | 14 | 0.31 | ND | | 0.02 | 0.44 | 0.02 | 0.44 | 1.1 | 24 | 850 | 19000 | | |
| 21, 22 | 13 | 0.07 | ND | | 0.04 | 0.2 | 0.04 | 0.2 | 1.3 | 6.6 | 410 | 2100 | | |
| 23, 24 | 11 | 0.1 | ND | | 0.05 | 0.47 | 0.05 | 0.47 | 3.2 | 30 | 99 | 940 | | |
| **Total Loadings (g)** | | **1.76** | | **0** | | **3.17** | | **3.12** | | **144.8** | | **35920** | | |
| **EMC (mg/L)** | | **0.02** | | **0.00** | | **0.03** | | **0.03** | | **1.42** | | **352.16** | | |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **18-Sep-03** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | Metals |  |  |  |  |  |  |  | Nitrogen |  |
| **Total Volume (L)** | **86000** |  | Average Flow | Cumulative | **Pb** |  | **Cu** |  | **Zn** |  | **Cd** |  | **TSS** |  |
| Bottle # | Sampling Time | Time (min) | (L/s) | Volume (L) | Conc. (ug/L) | Mass (g) | Conc. (ug/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |
| 1, 2 | 11:49 | 0 | 2.8 | 3360.0 | 870 | 2.9 | 190 | 0.64 | 2.8 | 9.4 | 83 | 0.28 | 700 | 2400 |
| 3, 4 | 12:09 | 20 | 3.3 | 7320.0 | 430 | 1.7 | 100 | 0.4 | 1 | 4 | 16 | 0.06 | 250 | 990 |
| 5, 6 | 12:29 | 40 | 4.9 | 13200.0 | 440 | 2.6 | 47 | 0.28 | 0.68 | 4 | 19 | 0.11 | 110 | 650 |
| 7, 8 | 12:49 | 60 | 3.6 | 17520.0 | 620 | 2.7 | 39 | 0.17 | 0.74 | 3.2 | 20 | 0.09 | 110 | 480 |
| 9, 10 | 13:09 | 80 | 5.7 | 24360.0 | 1000 | 6.8 | 35 | 0.24 | 0.62 | 4.2 | 16 | 0.11 | 150 | 1000 |
| 11, 12 | 13:29 | 100 | 5.6 | 31080.0 | 900 | 6 | 67 | 0.45 | 1.8 | 12 | 56 | 0.38 | 160 | 1100 |
| 13, 14 | 13:49 | 120 | 20.0 | 55080.0 | 790 | 19 | 99 | 2.4 | 3 | 72 | 96 | 2.3 | 760 | 18000 |
| 15, 16 | 14:09 | 140 | 15.0 | 73200.0 | 780 | 14 | 86 | 1.6 | 2.8 | 51 | 75 | 1.4 | 450 | 8200 |
| 17, 18 | 14:29 | 160 | 5.4 | 86040.0 | 770 | 9.9 | 73 | 0.94 | 2.6 | 33 | 54 | 0.69 | 270 | 3500 |
| **Total Loadings (g)** |  |  |  |  |  | **62.7** |  | **6.48** |  | **183.4** |  | **5.42** |  | **33920** |
| **EMC (mg/L)** |  |  |  |  |  | **0.73** |  | **0.08** |  | **2.13** |  | **0.06** |  | **394.42** |
|  | **Nitrate** |  | **Nitrite** |  |  |  | **TKN** |  | **TP** |  |  |  |  |  |
| Bottle # | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) | Conc. (mg/L) | Mass (g) |  |  |
| 1, 2 | ND |  | 0.05 | 0.170 | 0.05 | 0.170 | 20 | 67 | 1.8 | 6 | 1.8 | 6 |  |  |
| 3, 4 | ND |  | 0.02 | 0.080 | 0 | 0.000 | 7.4 | 29 | 0.55 | 2.2 | 0.55 | 2.2 |  |  |
| 5, 6 | ND |  | 0.23 | 1.400 | 0.23 | 1.400 | 3.5 | 21 | 0.24 | 1.4 | 0 | 0 |  |  |
| 7, 8 | ND |  | 0.06 | 0.260 | 0.06 | 0.260 | 2.4 | 10 | 0.24 | 1 | 0 | 0 |  |  |
| 9, 10 | ND |  | 0.03 | 0.210 | 0.03 | 0.210 | 1.7 | 12 | 0.24 | 1.6 | 0 | 0 |  |  |
| 11, 12 | ND |  | 0.03 | 0.200 | 0.03 | 0.200 | 3.8 | 26 | 0.24 | 1.6 | 0 | 0 |  |  |
| 13, 14 | ND |  | 0.02 | 0.480 | 0 | 0.000 | 7 | 170 | 0.29 | 7 | 0.29 | 7 |  |  |
| 15, 16 | ND |  | 0.02 | 0.360 | 0 | 0.000 | 5.6 | 100 | 0.3 | 5.4 | 0.3 | 5.4 |  |  |
| 17, 18 | ND |  | 0.02 | 0.260 | 0 | 0.000 | 4.2 | 54 | 0.24 | 3.1 | 0.24 | 3.1 |  |  |
| **Total Loadings (g)** |  | **0** |  | **3.250** |  | **2.070** |  | **422** |  | **23.3** |  | **17.7** |  |  |
| **EMC (mg/L)** |  | **0.00** |  | **0.038** |  | **0.024** |  | **4.91** |  | **0.27** |  | **0.21** |  |  |

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