Abstract

TUCKER, ROBERT S. Urban Stormwater: First Flush Analysis and Treatment by an Undersized Constructed Wetland. (Under the direction of Jean Spooner and William F. Hunt.)

Nonpoint stormwater runoff remains a leading threat to surface water quality in the U.S. Increased impervious surfaces, climate change, and increasing water demands put even more pressure on stormwater managers to improve stormwater management practices with regards to cost effectiveness, removal performance, and ecological sustainability. More effective BMPs can be designed by understanding the nature of pollutant runoff loads with respect to the hydrograph. Many studies have been performed on the first flush (FF) phenomenon (the assumption that the initial portion of a rainfall-runoff event is more polluted than the later portions). However, controversy remains on whether or not the first flush truly exists, which environmental factors influence a first flush, and how best to define the first flush phenomenon. The objective of this study as to evaluate the first flush occurrence in two small urban watersheds (differing in extent of impervious area) using multiple analytical methods and definitions previously published in the literature. The first watershed is 4.8 acres with 67% impervious roadway and the second watershed is 5.6 acres with 87% wooded land cover. Statistical tests were performed to analyze for site-specific correlations between first flush strength and rainfall characteristics (e.g. rainfall depth, peak flow rate, runoff volume, peak rainfall intensity, and antecedent dry period) and determine differences in FF strength between different land uses and pollutants. Furthermore, the FF study was utilized to perform an annual treatable load analysis in order to evaluate the effectiveness of four hypothetical BMPs sized to treat stormwater from the highly impervious watershed based on the 1.3 cm, 1.9 cm, 2.6 cm and 3.2 cm of rainfall water quality volumes.

A year-long study captured stormwater samples from over 33 storm events and analyzed for TSS, turbidity, nutrients and heavy metals. Samples were collected using flow-based sampling frequencies that yield a more accurate quantification of pollutant mass transport throughout the storm event than time-paced sampling used in most of the previous first flush studies. For each collected storm, normalized cumulative pollutant load (L') and runoff volume curves (V') were generated for each pollutant with a minimum of seven discrete

curve points to quantify the first flush effect and evaluate for first flush occurrence based on several published methods and definitions (e.g., max L'>V', max L'-V' > 0.2, and 80% of total load runoff in first 30% of total runoff volume). Linear regression analyses were performed to determine the first flush coefficient (*b*) for the power function $L' = V'^{b}$ to quantify the FF strength. Relationships between the first flush strength and rainfall characteristics were examined. Analysis of covariance (ANCOVA) was utilized to determine if FF strength (i.e. *b*-value) significantly differed between wooded and impervious watersheds, and a nonparametric ANOVA (Kruskal-Wallis test) was used to evaluate differences in FF strength among the pollutants within each watershed.

As indicated by all the methods utilized in this study, most pollutants exhibit a slight FF effect on average but substantial pollutant loading still occurred in the latter portion of the storm's total runoff volume. Thus, to treat the majority of a storm's total pollutant load requires capturing almost the same fraction of runoff volume. Although the FF phenomenon was not dominant, this study did define a "most efficient" design volume (first 40% of runoff or approximately 1.3 cm of rainfall), which was where the fraction of total pollutant load was greatest compared to the fraction of total runoff volume. Of the rainfall characteristics analyzed, rainfall and runoff volume both inversely affected the FF strength of TSS and heavy metals on the impervious watershed. Although the runoff nature of orthophosphate ($O\text{-}PO_4$) at the first portion of the storms did not have a first flush, the relative FF strength for $O\text{-}PO_4$ actually increased with increasing rainfall or runoff. Land use did not influence the first flush strength of the pollutants except for Pb, which had significantly stronger FF effect on the more impervious watershed compared to the heavily wooded one. Disregarding the estimated pollutant load from a large 18.2 cm tropical storm, the 1.3 cm and 2.6 cm of rainfall design volumes could potentially capture and treat on average 64% and 82% of the annual runoff volume and 67% and 85% of the annual pollutant load for all the pollutants on the impervious watershed. Although stormwater BMPs designed to capture the first 2.5 cm of rainfall can potentially treat a substantial fraction of yearly pollutant load, this study suggests that in watersheds with limited and expensive land area it is more efficient to use multiple smaller BMPs near the source that capture the smaller, more frequent storms (1.3 cm of rainfall or less).

Among all the stormwater BMPs currently utilized to reduce peak runoff volumes and remove contaminants from urban runoff, constructed wetlands have emerged as an optimal choice because of their high performance of water quality improvement and ecological benefits. Due to a stormwater wetland's high land requirement, however, they are often difficult to size properly in urban environments. This study also evaluated the pollutant removal efficiencies of a newly constructed flow-through stormwater wetland that is sized to only capture 20% of runoff generated by the recommended design storm in N.C. (first 2.5 cm of rainfall). The wetland was constructed in December 2006 as a retrofit to a failing level-spreader in order to repair a rapidly eroding head-cut between two stormwater outfall channels and the receiving stream. Following addition of the extended detention function, the undersized wetland has initially removed, on average, 71% of the TSS load, between 39% and 60% of the nutrient load, and 60% of the heavy metal load. For all the pollutants except TP and TKN, lower removal efficiencies were observed for the storms with flow bypass (5 out of 9 events since the extended detention function) on average as compared to the smaller events without bypass. When evaluated for all the sampled storms, event mean concentrations proved to be statistically lower at the outlet for all pollutants except Ti and V. For most pollutants, higher influent EMCs were observed for the storms with higher removal efficiencies. It is important to note, however, that these initial results are skewed by a small number of storms with low rainfall depths (median = 0.46 cm). With that considered, the average removal efficiencies are actually higher than predicted for the 1.3 cm design storm BMP. Undersized wetlands with "flow through" design might provide effective and efficient pollutant removals if designed to safely pass the larger storms. Longer term research will provide a more definitive evaluation.

Urban Stormwater: First Flush Analysis and Treatment by an Undersized Constructed Wetland

by

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Biography

Robert Tucker was born on February 1, 1982 in Minneapolis, Minnesota. After living in Newport Beach, CA and twice in Milwaukee, WI, Robert and his family settled in Charlotte, NC by age 5. Nothing of much significance can be reported in Robert's life between from the age of 5 through 18 except he played a lot of soccer. In 2000, Robert started college at N.C. State in electrical engineering but shortly switched to the field of environmental engineering which was in more accordance with his passion for environmental preservation, particularly water resources. Shortly after receiving his B.S. degree in December of 2004, Robert discovered that a plant is more beneficial to water quality and the natural environment than a rock and thus started working for the NCSU Water Quality Group and an M.S. in Biological and Agricultural Engineering. Following the completion of graduate school, Robert plans to apply what he has learned so far towards a career in ecological wastewater and stormwater management and reuse, permaculture, and sustainable community development.

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Table of Contents

List of Tables

CHAPTER 1

CHAPTER 2

List of Figures

CHAPTER 1

Sampling Materials and Methods

Analytical Methods for the First Flush Characterization Study

Evaluation of Treatable Annual Pollutant Load for FF Design Volumes

Analytical Methods for the First Flush Characterization Study

CHAPTER 2

Site Description

Design of the Constructed Wetland System

Sampling Materials and Methods

Initial Results

CHAPTER 1 ANALYSIS OF THE FIRST FLUSH PHENOMENON AND POLLUTANT RELATIONSHIPS WITHIN STORMWATER RUNOFF FROM TWO SMALL URBAN WATERSHEDS

Abstract

Nonpoint stormwater runoff remains a leading threat to surface water quality in the U.S. Increased impervious surfaces, climate change, and increasing water demands put even more pressure on stormwater managers to improve stormwater management practices with regards to cost effectiveness, removal performance, and ecological sustainability. More effective BMPs can be designed by understanding the nature of pollutant runoff loads with respect to the hydrograph. Many studies have been performed on the first flush (FF) phenomenon (the assumption that the initial portion of a rainfall-runoff event is more polluted than the later portions). However, controversy remains on whether or not the first flush truly exists, which environmental factors influence a first flush, and how best to define the first flush phenomenon. The objective of this study as to evaluate the first flush occurrence in two small urban watersheds (differing in extent of impervious area) using multiple analytical methods and definitions previously published in the literature. The first watershed is 4.8 acres with 67% impervious roadway and the second watershed is 5.6 acres with 87% wooded land cover. Statistical tests were performed to analyze for site-specific correlations between first flush strength and rainfall characteristics (e.g. rainfall depth, peak flow rate, runoff volume, peak rainfall intensity, and antecedent dry period) and determine differences in FF strength between different land uses and pollutants. Furthermore, the FF study was utilized to perform an annual treatable load analysis in order to evaluate the effectiveness of two hypothetical BMPs sized to treat stormwater from the highly impervious watershed based on the 1.3 cm, 1.9 cm, 2.6 cm and 3.2 cm of rainfall water quality volumes.

A year-long study captured stormwater samples from over 33 storm events and analyzed for TSS, turbidity, nutrients and heavy metals. Samples were collected using flow-based sampling frequencies that yield a more accurate quantification of pollutant mass transport

throughout the storm event than time-paced sampling used in most of the previous first flush studies. For each collected storm, normalized cumulative pollutant load (L') and runoff volume curves (V') were generated for each pollutant with a minimum of seven discrete curve points to quantify the first flush effect and evaluate for first flush occurrence based on several published methods and definitions (e.g., max L'>V', max L'-V' > 0.2, and 80% of total load runoff in first 30% of total runoff volume). Linear regression analyses were performed to determine the first flush coefficient (*b*) for the power function $L' = V'^{b}$ to quantify the FF strength. Relationships between the first flush strength and rainfall characteristics were examined. Analysis of covariance (ANCOVA) was utilized to determine if FF strength (i.e. *b*-value) significantly differed between wooded and impervious watersheds, and a nonparametric ANOVA (Kruskal-Wallis test) was used to evaluate differences in FF strength among the pollutants within each watershed.

As indicated by all the methods utilized in this study, most pollutants exhibit a slight FF effect on average but substantial pollutant loading still occurred in the latter portion of the storm's total runoff volume. Thus, to treat the majority of a storm's total pollutant load requires capturing almost the same fraction of runoff volume. Although the FF phenomenon was not dominant, this study did define a "most efficient" design volume (first 40% of runoff or approximately 1.3 cm of rainfall), which was where the fraction of total pollutant load was greatest compared to the fraction of total runoff volume. Of the rainfall characteristics analyzed, rainfall and runoff volume both inversely affected the FF strength of TSS and heavy metals on the impervious watershed. Although the runoff nature of orthophosphate ($O\text{-}PO_4$) at the first portion of the storms did not have a first flush, the relative FF strength for $O\text{-}PO_4$ actually increased with increasing rainfall or runoff. Land use did not influence the first flush strength of the pollutants except for Pb, which had significantly stronger FF effect on the more impervious watershed compared to the heavily wooded one. Disregarding the estimated pollutant load from a large 18.2 cm tropical storm, the 1.3 cm and 2.6 cm of rainfall design volumes could potentially capture and treat on average 64% and 82% of the annual runoff volume and 67% and 85% of the annual pollutant load for all the pollutants on the impervious watershed. Although stormwater BMPs designed to capture the first 2.5 cm

of rainfall can potentially treat a substantial fraction of yearly pollutant load, this study suggests that in watersheds with limited and expensive land area it is more efficient to use multiple smaller BMPs near the source that capture the smaller, more frequent storms (1.3 cm of rainfall or less).

1. Introduction

As cities continue to develop, increasing amounts of urban stormwater runoff are causing numerous adverse effects on urban areas and receiving waters. Flooding, erosion, sedimentation, dissolved oxygen depletion, temperature rise, nutrient enrichment and eutrophication, toxicity, reduced biodiversity, and the degradation to usable water supplies are intensified by the addition of impervious surfaces, particularly roadways which accumulate a large amount of toxic pollutants from motor vehicles (Marsalek and Chocat, 2002). Pavement-tire interaction and abrasion of metal components during vehicle operation generate particulate matter as suspended solids and sediments that can transport constituents like metals and create an oxygen demand in receiving waters (Sansalone and Cristina, 2004). Other sources add to urban stormwater pollution as well. These urban pollutants include but are not limited to: sediments from construction sites and disturbed land, oil and grease from motor vehicles and industrial areas, bacteria from pet waste and leaky sewers, nutrients from atmospheric deposition, fertilized lawns and roadsides, and toxic and synthetic chemicals from pesticides, illegal dumping, and motor vehicles (Deng et al., 2005).

New regulatory guidelines and Best Management Practices (BMPs) are constantly being implemented to not only reduce peak runoff amounts but to treat and remove organic and inorganic contaminants, nutrients, and pathogenic bacteria present in urban stormwater runoff. The required level of water quality treatment and volume of stormwater requiring treatment varies depending on the locality. Currently, many regulatory agencies stipulate that the "first flush" runoff from a storm event be treated to certain water quality standards (Ahlfeld and Minihane, 2004). The first flush (FF) standard is based on the assumption that the initial portion of a rainfall-runoff event is more polluted than the later portions. If the first flush does exist, then stormwater managers can save time and money by designing BMPs that only capture and treat a small volume of runoff in order to remove the majority of the pollutants. However, controversy still remains on whether or not the first flush truly exists, which factors influence a first flush, and how best to define the first flush phenomenon.

2. Literature Review

2.1 First Flush Definitions

Researchers have presented different quantitative definitions of a first flush. Generally, plotting the normalized cumulative pollutant mass curve (L') vs. the normalized cumulative runoff volume curve (V') assesses the first flush, defined by:

$$L' = m(t)/M \quad (1)$$

$$V' = v(t)/V \quad (2)$$

where *m(t)* and *v(t)* are the cumulative mass loads and cumulative volumes of the runoff at time *t* during a storm event, respectively, and M and V are the total load and total volume for the entire runoff event. The maximum values of L' and V' are 1, which corresponds to 100% of the runoff volume or pollutant load.

This method shows the variation of the fraction of total pollutant load removed from the drainage area in relation to the fraction of runoff volume that has also left the drainage area. The L'V' curve is dimensionless and provides an easy way to compare pollutant load distribution with volume for different storm events and watersheds. In addition, the L'V' curves allow the calculation of the volume of runoff to be intercepted in order to treat a certain fraction of total pollutant load. Since many first flush studies performed on different drainage and sewer systems show that L'V' curves vary significantly, a statistical and site specific approach has proven necessary to satisfactorily describe the phenomena and their variability (Bertrand-Krajewksi et al., 1998). As each storm event is different, deductively each L'V' curve for a given pollutant is different.

Helsel et al. (1979) proposed one of the first L'V' first flush definitions, which simply defines a first flush occurrence when the L'V' curve is above the 45° bisector at any time during the storm event. The 45° line represents the case when pollutant concentration remains constant throughout the runoff. Dilution therefore occurs when the initial slope is below the 45° line. Geiger (1984, 1987) restricted this first flush definition to L'V' curves with an initial slope

greater than 45° as well as a maximum gap between the L'V' curve and the bisector that is greater than 0.2. The drawback of Helsel et al.'s and Geiger's definitions is that the gap greater than 0.2 can occur anywhere on the L'V' curve, thus not corresponding to the first portion of the runoff volume.

Other researchers have proposed modifications of the L'V' definition. According to Gupta and Saul (1996), the first flush volume is the part of the storm up to the point of maximum divergence between the L' curve and V' curve when plotted against normalized cumulative time (T'). Plotting both the L' and the V' curves together as a function of elapsed time in the storm event will yield a first flush for periods when the L' curve is above the V' curve, thus indicating a disproportionately higher pollutant load than runoff volume has been delivered (Sansalone and Buchberger, 1997).

A more popular variation of the L'V' curve definition is to relate L' and V' with a power function,

$$L' = V'^{b} \tag{3}$$

where the first flush coefficient (b) represents the deviation of the curve from the diagonal and therefore the strength of the first flush. The data are first log transformed to yield the new equation,

$$\ln L' = b \ln V' \tag{4}$$

where the b value becomes the slope term from the linear regression model. The regression line is fixed at the y-intercept of zero to ensure that 100% of the total event's pollutant load is delivered at 100% of the runoff volume. A b value of 1 corresponds to the 45° bisector line representing uniform pollutant loading throughout the event. The lower the value of b, the more pronounced the FF. Values of b greater than 1 indicate a dilution effect. Previous studies by Saget et al. (1996), Betrand-Krajewski et al. (1998), Lee et al. (2002), and Taebi and Droste (2004) have all used this definition. In the same order, these researchers found ranges of b values for TSS of 0.15-2.02, 0.24-2.07, 0.43-2.15, and 0.49-1.07; obviously these

values demonstrate large variability in the strength of the FF effect for TSS. Taebi and Droste (2004) also found *b* value ranges for TN, Pb, and Zn of 0.72-1.19, 0.89-1.10, and 0.64-1.64, respectively.

Besides the power function, the third-degree polynomial has proven to be a useful tool to express the L'V' curve and analyze the first flush phenomenon (Lee and Bang, 2000; Lee et al., 2003). This equation takes the form as:

$$L = \gamma V + \beta V^2 + \alpha V^3 \quad (5)$$

where α, β, and γ are constants. More recently, Deng et al. (2005) developed a fractional kinetic model to simulate the first flush phenomenon of urban stormwater pollutants, which has also accurately predicted the characteristics of the first flush for specific sites. However, a laboratory scale setup was used to calibrate the model.

More conventional ways to define the phenomenon are to compare a fraction of the total pollution load to a fraction of runoff load, both calculated from the same point in the first part of the cumulative runoff curve. For example, Vorreiter and Hickey (1994) classify the first flush occurrence based on the pollution load in the first 25% of runoff volume. Deletic (1998) decided to delineate a first flush phenomenon when the percentage of total pollutant load transported by the first 20% of runoff volume, L' (20), is greater than 40% (Def. 20/40). Similarly, Wanielista and Yousef (1993) declared a first flush when greater than 50% of the pollutant load is transported in the first 25% of the runoff volume (Def. 25/50).

Stricter definitions of first flush occurrence also exist. Arguing that other definitions are difficult to quantify and not precise enough to design detention facilities, Bertrand-Krajewski et al. (1998) proposed that a first flush occurs when at least 80% of the total pollution load is transferred in the first 30% of runoff volume (Def. 30/80). Stahre and Urbonas (1992) restrict this definition even more by declaring a first flush when 80% of the pollutant load is transferred in the first 20% of runoff volume (Def. 20/80). However, research has shown that occurrences meeting these definitions are extremely rare and occur in less than 1% of the studied events (Lee et al., 2002; Sansalone and Cristina, 2004).

As a design parameter, the first flush has been defined based on water quality volume criteria. Such criteria include the first 1.3 cm (0.5-inch) of runoff, the runoff from 1.3 cm of rainfall, the volume of runoff from a 1.9 cm (0.75-inch) rainfall event, and the volume of runoff from a 2.6 cm (1-inch) rainfall event, among others. Sansalone and Cristina (2004) showed that BMP design based on the first 1.9 cm of runoff volume eliminated system bypass of pollutants for 7 of the 8 studied sites. The determination of the water quality volume is site specific, however, and separate examination of these criteria is required for different watersheds and climates.

Regardless of the definition used, the first flush phenomenon is complex and site specific. Peak concentrations have been shown to vary with different pollutants during the same storm event, or during different storm events in the same watershed (Gupta and Saul, 1996).

2.2 Does "It" Really Exist?

While a number of studies throughout the world have monitored the first flush effect, results don't always agree on the consistency of a strong, or pronounced, first flush occurrence. From data collected from both separate and combined storm/sewer systems (80 events from 7 separate systems and 117 events from 7 combined systems), Saget et al. (1996) showed that a strong first flush was very scarce, only occurring once for all the events. However, a very strict definition of first flush was used in the study and only SS, COD, and BOD_5 were examined. Analyzing the water quality for two drainage areas in Europe, Deletic (1998) showed only a slight first flush effect for suspended solids and conductivity based on the evaluation of the total load in the first 20% of runoff volume (L' (20)).

In a study conducted by Taebi and Droste (2004) in a mixed residential and commercial urban drainage area, TS, TSS and COD displayed a relatively weak presence of first-flush, but overall TSS was the most susceptible to the phenomenon. Results showed no first flush effect for heavy metals, which is similar to a study conducted by Soller et al. (2005) that failed to show a consistent first flush phenomenon for metals and anions. In another study involving two small urban transportation use watersheds, Sansalone and Cristina (2004) showed that none of the storm events exhibited first flush behavior according to the 20/80

definition by Stahre and Urbonas (1992). The results from Lee et al.'s (2005) study indicated that no FF occurrences based on the 20/80 definition or Bertrand-Krajewski's (1998) 30/80 definition were observed. The first 30% and 80% of the runoff volume transported 34-43% and 82%-88% of the pollutant mass in this study, showing only a slight first flush effect.

Other researchers believe there is sufficient evidence to support the regular occurrence of the first flush phenomenon. According to a study by Lee and Bang (2000), the pollutant concentration peak consistently occurred before the flow peak. Monitoring stormwater runoff for 13 different urban watersheds, Lee et al. (2002) showed strong first flush occurrences as a whole for the pollutants analyzed. The relative first flush strength of each pollutant varied depending on the analysis method used.

2.3 Contributing Components

Since the first flush phenomenon is complex and site specific, the amount of pollutant load transported to receiving waters during a storm event can depend upon hydrologic, watershed and the sewer system characteristics, whose relationship to the first flush phenomenon have been investigated in several studies. These characteristics include watershed area and percent of impervious surface, average slope, time of concentration, rainfall depth and maximum intensity, storm duration, and the antecedent dry weather period. In a combined storm/sanitary system, the first flush load for TSS has been shown to correlate well with the event maximum rainfall intensity, storm duration, and antecedent dry weather period (Gupta and Saul, 1996). Gupta and Saul (1996) analyzed 109 events from two urban watersheds using multiple regression. Similar results were also shown in a study involving separate storm and sewer systems (Taebi and Droste, 2004). Several studies have shown that the degree of strength of the first flush is proportional to rainfall intensity, percent imperviousness, and inversely related to watershed area (Lee and Bang, 2000; Lee et al., 2002). In Lee et al.'s (2002) study, land slopes also influenced the strength of the first flush.

Lee and Bang (2000) defined the criteria watershed area for the occurrence of a first flush as less than 250 acres (100 ha). However, not only did the first flush consistently occur in watersheds smaller than 250 acres with more than 80% impervious area during the study, but

also for watersheds larger than 250 acres with less than 50% impervious area. This exception exemplifies the complexity and variability of the first flush phenomenon.

Saget et al. (1996), however, did not find any relationship between pollutant load distribution and watershed or rainfall characteristics. Others studies have found no correlation between the first flush strength and the antecedent dry weather period (Gupta and Saul, 1996; Lee et al., 2002), while a study by Soller et al. (2005) did show a relationship between the first flush load of dissolved metals and antecedent dry weather period, but not with the storm size.

2.4 Reasons for Inconsistency

Deletic (1998) credits poor quality of data as one reason for the inconsistency of the mentioned results. For example, Gupta and Saul's (1996) study only analyzed storms with at least 4 flow and quality data points in the first hour of the event. Saget et al. (1996) included storm events with at least 5 total measured pollutant concentrations. For short, intense storms that can produce highly polluted runoff, the data collection frequency in these studies was insufficient to correctly record the storm for analysis. Some summer storms can last less than 30 minutes but be very intense. Other studies may have had insufficient sampling frequency in the latter half of the storm event. Lee and Bang (2000) manually sampled every 5-10 minutes for increasing flow stage but one every 1-2 hours for receding flow stage. As studies have showed for individual pollutants, the pollutant concentration peak does not always precede the runoff flow peak (Deletic, 1998).

The majority of the reviewed studies utilized manual time-paced sampling instead of automated flow-paced sampling. Flow-paced sampling is variable and can be programmed to follow the hydrograph, yielding a more accurate quantification of pollutant mass transport throughout the storm event. For example, measuring TSS concentrations at widely spaced time intervals across the hydrograph will not give accurate determinations of mass transport during the event (Sansalone and Cristina, 2004).

While the first flush phenomenon has been shown to exist by some definitions, researchers agree that the first flush is not significant enough to base design criteria on an initial portion

of the event if the goal is to treat the entire pollutant load. It is also agreed upon that the first flush phenomenon is site specific and the variations in first flush load can not be calculated using a universal set of climate, rainfall and runoff characteristics (Deletic, 1998; Deng et al., 2005; Sansalone and Cristina, 2004). Sansalone and Cristina (2004) recommended that in absence of site-specific data (e.g., site conditions, hydrology, and loadings) a strong first flush phenomenon could not be conclusively estimated for a given waterhsed. Under this situation, BMP effectiveness criteria based on mass may require treatment of the entire runoff volume instead of some initial fraction thereof.

2.5 Evaluation of Treatable Annual Pollutant Load for FF Design Volumes

Although the FF definitions previously mentioned are used to characterize the nature of pollutant flushing throughout a storm event, stormwater managers often use a water quality, or FF volume (depth) to size stormwater BMPs. One rationale for defining this initial rainfall/runoff volume uses regional historic rainfall data to determine the average annual rainfall, when multiplied by a safety factor, that yields a design rainfall value including the majority of events in that geographic region. North Carolina uses a design volume of 2.6 cm since the average rainfall in the Mid-Atlantic rain zone is 1.6 cm and multiplied by the safety factor (1.5) is 2.44 cm, approximately 2.6 cm (U.S. EPA, 1992).

A common assumption is that the first 1.3 cm of runoff will flush most of the pollutants on impervious cover. Some researchers have analyzed the fraction of pollutant load in the first 1.3 cm of runoff. A study by the Environmental Resources Management Division for Austin, Texas (1990) found that although the first flush concentration is substantially higher, the pollutant load removed by the first 1.3 cm of runoff on a 90% impervious development averages about only 40% of the total storm load (1990). Using developed relationships between the percentages of storm loads to the annual load versus the storm runoff amount (inches), untreated annual load (load associated with runoff volume greater than 1.3 cm) was found to increase as the percent of impervious cover increased. Conversely, a similar study by Flint and Davis (2007) on a 5,600 m^2 ultra urban site in Washington, D.C. found that management of the first 1.3 cm of runoff was able to capture on average 81-86% of the total

pollutant mass from 32 sampled storm events (June 2002-October 2003), indicating a strong first flush effect.

3. Research Objectives

Considering the controversy concerning the first flush phenomenon, as well as the debate over the appropriate first flush volume with regards to BMP design, the objectives for this study were as follows:

1. Evaluate the first flush occurrence in two small urban watersheds using multiple definitions. Both watersheds not only provide a comparison of different land uses (one is mostly wooded and the other is mostly impervious roadway), but they are also adjacent, and thus the variation in precipitation between the watersheds is minimized.
2. Analyze for site-specific correlations between first flush strength and rainfall characteristics.
3. Determine if land use affects the first flush strength.
4. Analyze for differences in first flush strength between individual pollutants.
5. Using the first flush analyses, determine the percent of yearly sediment load capable of being treated in a stormwater BMP sized to capture the 1.3 cm (0.5-inch) and the 2.6 cm (1-inch) first flush rainfall volumes.

4. Sampling Materials and Methods

4.1 Site Description

The two studied watersheds discharge to a heavily eroding stormwater channel located at the corner of Varsity Drive and Capability Drive on NCSU's Centennial Campus (see Figure 4.1), which empties to a 303(d) listed stream called North Creek. The culverts from the two watersheds are named stormwater outfall channel 3 (SOC 3) and stormwater outfall channel 4 (SOC 4) since SOC1 and SOC2 were assigned to two other eroding stormwater outfall channels located upstream of North Creek. The SOC 3 culvert, which is 0.91 meters (3 ft) in diameter, collects stormwater runoff from an approximately 1.94 hectares (4.8 ac) watershed of 66% impervious roadway (Curve Number = 86). The watershed draining to the SOC 4 culvert, which is 0.61 meters (2 ft) in diameter, is 2.26 hectares (5.6 ac) and 87% wooded with the remaining land area roadway and dense lawn (Curve Number = 69). The soil types composing the majority of the two watersheds are listed in Table 4.1 along with the water feature data (NRCS Soil Survey).

Figure 4.1: Drainage areas and locations of SOC 3 and SOC 4

Table 4.1: In-situ soil types and water features

Soil Name and Symbol	Hydrologic Group	Surface Runoff
Cecil sandy loam (CeC2), moderately eroded	B	Medium
Pacolet clay loam (PcE3), severely eroded	B	High
Worsham, undrained	D	Very High

4.2 Instrumentation

The two stormwater outfalls were sampled inside the culverts just up-gradient of the flared-end sections. The culvert outlets were monitored using ISCO automated water samplers (3700 and 6700 series). For the majority of the study, an ISCO area-velocity meter was used in junction with the 6700 sampler at SOC 3. Since flow through this culvert was outlet controlled due to the large amount of sediment continuously being deposited at the rip-rap apron, development of a stable rating curve was impractical. Therefore, the area-velocity meter was necessary for flow calculation instead of a programmed ISCO 4230 flow meter. A 120° v-notch weir flow control structure was installed inside the SOC 4 culvert for an ISCO 4230 flow meter to measure depth and calculate flow rate using a weir equation (although it is not as accurate at low flow depths). Since peak flow through this culvert was less than 10% on average of the peak flows through SOC 3, the weir proved satisfactory and recorded flow from the majority of the storm events within its measurable range.

4.3 Sampling Methods

Both flow meters were programmed to produce flow-paced composite stormwater samples from the culverts. Flow-based sampling captures samples after a specified volume of water has passed through the pipe or channel. Automated sampling on a flow-basis allows for variable sampling frequency that follows the hydrograph. This is important for targeting pollutant load variations instead of concentration variations throughout an event. Conversely, measuring pollutant concentrations at equally spaced time intervals does not account for the varying hydrology of a storm and can generate misleading results in pollutant loads throughout a storm event (Sansalone and Cristina, 2004).

Each automated sampler contained 24 plastic, 1-liter ISCO sampler bottles. Depending on the size of the anticipated storm event, the flow-pacing was adjusted to sufficiently capture the entire storm within 24 bottles. Each sampler bottle contained between 1 and 4 individual flow-weighted samples depending on the programming. Contingent upon the size of the storm, the sampler bottles were analyzed discretely to quantify variations in pollutant concentrations throughout the hydrograph. For larger storms, some of the sampler bottles were combined for analysis, particularly towards the falling peak of the hydrograph where pollutant concentrations are expected to plateau around zero (Sansalone and Cristina, 2004). Both samplers were disabled at water depths of 1.5 cm (to prevent dry samples) but continued to add up the volume of water flowing through the culverts. Table 4.2 shows typical programming parameters for the automated samplers.

Table 4.2: Typical automated sample details

Site	Pacing	Freq.	Sample Vol.	Samples Per Bottle
SOC 3	Flow	7570 L (2000 gal)	330 ml	3
SOC 4	Flow	1514 L (400 gal)	1000 ml	1

4.4 Analysis Protocol

The stormwater samples were analyzed for the following contaminants:

- Total suspended solids (TSS)
- Turbidity
- Ammonia (NH_3-N)
- Nitrate/nitrite (NO_3/NO_2-N)
- Total Kjeldahl nitrogen (TKN)
- Soluble reactive (ortho) phosphates (O-PO_4)
- Total phosphorus (TP)
- Arsenic (As)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Nickel (Ni)
- Titanium (Ti)
- Vanadium (V)
- Zinc (Zn)

Beryllium, antimony and selenium were initially included in the analysis but early results yielded concentrations below the detectable limits and received no further analysis.

After collection in the field, the sampler bottles were separated into pre-labeled analysis bottles for each pollutant. The sample for metals analyses were combined into one bottle and the nitrate/nitrite and TKN analysis were also combined into one bottle. Table 4.3 lists the analysis bottle details used for each pollutant.

Table 4.3: Analysis bottle details

Pollutant	Container Type	Container Size	Acid Preservative?	Preservation & Transport
NH_3	Glass	30-mL	No	On ice, 1-4° C
TKN/NO_3-NO_2	Polyethylene plastic	125-mL	Yes[1]	H_2SO_4, pH<2, On ice, 1-4° C
O-PO_4	Brown Glass	60-mL	No	On ice, 1-4° C
TP	Brown Glass	60-mL	No	On ice, 1-4° C
Heavy metals	HDPE plastic	125-mL	No	On ice, 1-4° C

[1] The Nitrate/nitrite and TKN analysis bottle was preserved with 2-mLs of sulfuric acid (H_2SO_4).

To help prevent contamination, latex gloves were worn during collection of the sampler bottles from the automated samplers and during the partitioning into the analysis bottles. A clean 90-mL syringe was used for partitioning the ammonia and O-PO_4 bottles. The O-PO_4 samples were pre-filtered with a 0.45-µm glass fiber and nylon membrane syringe filter prior injection into the analysis bottle. All analysis bottles were then stored between 1-4° C before delivery to the lab.

Analysis Labs

Every storm water sample was analyzed for TSS and turbidity, while nutrient and metals analyses were only performed for storm events with sufficient samples for a first flush analysis. TSS and turbidity analyses were conducted in a department lab. The NCSU Soil Analysis Laboratory performed total metals analyses and NCSU's Applied Aquatic Ecology (AAE) Lab, which is North Carolina state-certified to quantify key nutrients, analyzed the samples for nutrients and cleaned the ISCO sampler and lab analysis bottles.

Table 4.4 lists the analysis methods utilized for each pollutant. The methods were from

either the APHA Standard Methods (APHA, 1995) or from EPA Methods (U.S. EPA, 1983a). Also included in the table are the detection limits and maximum holding times for each pollutant analysis.

Table 4.4: Lab analysis methods

Parameter	Method	Analytical Method	Detection Limit	Maximum Holding Time
TP	S.M. 4500 P E	Lachat 31-115-01-4-A	10 µg/L	28 days
$O\text{-}PO_4$	S.M. 4500 P F	Lachat 31-115-01-1-H	6 µg/L	48 hours
TKN	EPA 351.1	Traacs 786-86T	140 µg/L	28 days
NH_3-N	S.M. 4500 NH_3 H	Traacs 780-86T	7 µg/L	28 days
NO_3/NO_2	S.M. 4500 NO_3 F	Traacs 781-86T	5.6 µg/L	28 days
Metals (total)	See below	NA	5-10 µg/L	6 months
Residue, TSS	S.M. 2540 D	NA	1 mg/L	7 days
Turbidity	S.M.	NA	0.1 NTU	48 hours

Metals Analysis Protocol - Acid Extraction with a Hot Block:

The steps are essentially these:

1. *Settle the solids*.

   A specific type of polyacrylamide known to work with the mineralogy of the samples was added to flocculate the suspended sediment. Inherent in this step is the assumption that all the metals are associated with the solid phase. This assumption was made based on the metals of interest and the nature of the runoff (i.e. rainfall pH and composition).

   The only element with some doubt was arsenic since this one might be more associated with organic matter, but the flocculent settled the organic matter as well.

   Note: Filtering the medium would yield the same result, but it would take longer and be more difficult.

2. Decant off liquid.

The bottles treated with flocculent were let stand for several days in the refrigerator at (4°C). Excess liquid in bottle was siphoned out until the solution was down to about 1/4 of original volume. A rubber policeman was then used to re-suspend the solids from the bottom of the bottle and the side walls. Suspension then transferred into 125 mL Teflon bottles with minimal DI water to keep volume of water low. The suspension was frozen and then freeze-dried to remove all the water and further concentrate solids.

3. Acid Reflux.

To the freeze dried Teflon bottles, 2.5 mL of Ultra Pure Grade HNO3 and 1 mL of Ultra Pure Grade HCl were added. Also added was about 0.25 mL of concentrated HF. These mixtures were allowed to stand overnight and then heated on sand bath to reflux the acid mixture for 30 to 45 minutes. The caps were kept on the Teflon bottle during this procedure but not tight to avoid pressure build up. The refluxing is not designed to dissolve all the solids. A little HF acid was added to promote dissolution of the Ti present which is most likely as TiO2. This compound does not dissolve in acids and requires HF to promote dissolution.

4. Spectrometer Analysis

After samples allowed to stand and cool they were transferred to 15 mL screw cap centrifuge tubes. A little DI was first added and swirled, then the sample was transferred to the tubes. More DI then added, then tube was capped and shaken well to rinse twice. Thereafter, the total volume in the centrifuge tubes were increased to 14 mL, then capped and mixed well for spectrometer analysis. Since this digestate was pretty acidic, a Meinhart C nebulizer was used to over come acid strength effects when using the ICP Emission Spectrometer.

Note: One could use microwave digestion for this procedure but it would be an enormous amount of effort given the small sediment size in the samples. When the intra-element correlations within the data are considered, it is obvious there is good dissolution and mobilizing of most metals except perhaps for those within the clay mineral lattice.

Cleaning

After each use, the ISCO sampler bottles and caps were cleaned with phosphate-free soap (LiquiNox), rinsed five times with deionized water, washed with a 10% solution of hydrochloric acid (HCl), rinsed eight times with deionized water and three more times with Milli-Q water. The plastic TKN/NO3-NO2 analysis bottles and caps were washed according to the same procedure as the ISCO sampler bottles. The glass TP and O-PO_4 bottles and caps cleaning procedure were similar except the bottles were acid-washed with a 100% solution of H_2SO_4. The glass NH_3 serum bottles were first soaked in deionized water overnight. The next day, the bottles were filled with 10% HCl solution and the caps were placed in a beaker of 10% HCl solution and both soaked again overnight. Thereafter, the bottles and caps were rinsed eight times with deionized water and rinsed three times with Milli-Q water. After rinsing, the bottles were filled with Milli-Q water and capped for storage.

Quality Control

Approximately 10% of the samples collected in the field for analysis were duplicated. A field blank was also sent to the lab for every 10 samples. Within the lab, 10% of the samples were duplicated for analysis and a blank was analyzed for every 10 samples per analysis. In addition, 20% of the samples were spiked per analysis and they were expected to fall within 90-110% recovery.

5. Analytical Methods for First Flush Characterization Study

As mentioned earlier, a first flush (FF) phenomenon occurs when most of the pollutant load in a storm event is transported in the initial portion of the runoff. Various definitions and methods have been proposed to more precisely define and quantify the FF occurrence. This study attempted to characterize the nature of pollutant load distribution with runoff volume in two urban watersheds using several of these published definitions.

Between October 2005 and September 2006, 32 storm events were sampled and analyzed for the FF phenomenon from two adjacent urban drainage areas (labeled storm water outfalls SOC 3 and SOC 4). Sampling was performed with automated samplers using flow-paced

sampling. Only events with sufficient samples to perform a FF analysis were analyzed for metal and nutrient concentrations while every sample collected underwent total suspended solids (TSS) and turbidity analysis. Additional data that were recorded and used in the FF analysis included rainfall depth, rainfall intensity, antecedent dry period, and runoff flow rates and volumes. The event mean concentrations (EMC) for each pollutant evaluated for the FF effect were also calculated. Since pollutant concentrations can vary by orders of magnitude during a runoff event, an event mean concentration (EMC) was used to characterize storm event concentrations. The EMC represents a flow average concentration computed as the total pollutant load (mass) divided by the total runoff volume for an event of duration *t*, as shown by the following equation:

$$\text{EMC} = \frac{M}{V} = \frac{\int_0^t c(t)q(t)dt}{\int_0^t q(t)dt} \qquad (6)$$

where M = total pollutant mass over entire storm event (dimensional units of mass, M), V = total volume over storm event (dimensional units of cubic length), c(t) = time variable pollutant concentration (M/L^3), t = time (dimensional units of time, T), and q(t) = time variable flow (V/T).

A dimensionless plot of pollutant load versus cumulative volume is required for comparative study of the FF effect for different storm events and drainage areas. A curve was created to show the variation of the fraction of total pollutant load removed from the drainage area in relation to the fraction of runoff volume that had also left the drainage area. This curve takes the form of a normalized cumulative load (cumulative pollutant mass divided by total pollutant mass for each sample, L') plotted versus the normalized cumulative volume (cumulative volume divided by the total volume for each sample, V'). This curve is denoted by L'V'. All three methods, described in the following sections, utilized to determine the frequency and magnitude of a FF occurrence in the two watersheds involved a combination of L', V' and time.

Method 1

Proposed by Gupta and Saul (1996), Method 1 compared curves of both L' and V' plotted versus normalized cumulative time for each storm event. The FF volume is then defined as the portion of the storm runoff volume up to the maximum divergence between the two curves (see Figure 5.1 as an example for TSS).

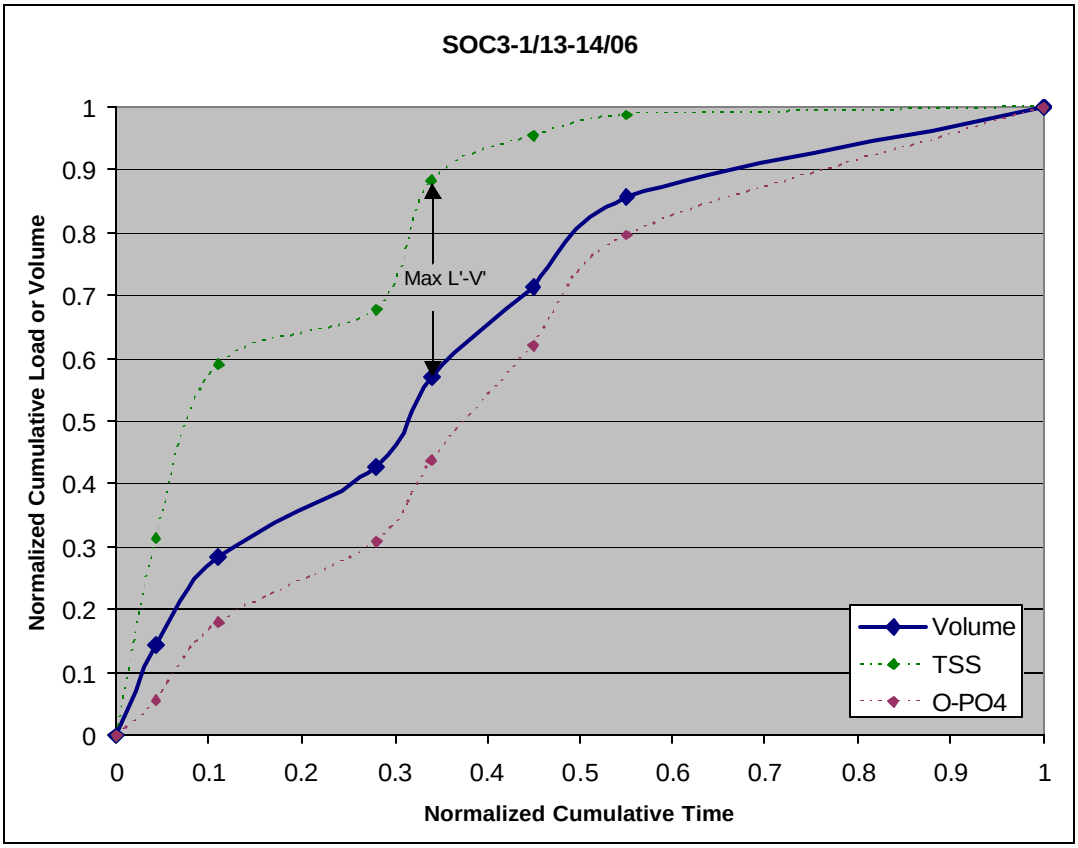

Figure 5.1: Method 1 first flush example - normalized cumulative TSS or O-PO4 load (L') or volume (V') vs. normalized cumulative time (T'). Data from SOC 3 were utilized.

Method 2

This method, actually proposed earlier by Geiger (1984), compares the curve of L' plotted against V' to a 45° line representing constant pollutant concentration throughout the runoff event. Based on this method, the FF is significant if the gap is greater than 0.2 between the L'V' curve and the bisector line. Figure 5.2 shows an example of this method for FF analyses

of TSS from the drainage area SOC 3. Since a gap greater than 0.2 can occur anywhere over the portion of the L'V' curve, the V' location of the gap was also recorded for those events where this magnitude of divergence occurred. This location indicates where in relation to the total runoff volume a significant FF effect is occurring. Note that the divergence values for Method 1 and Method 2 are mathematically equivalent.

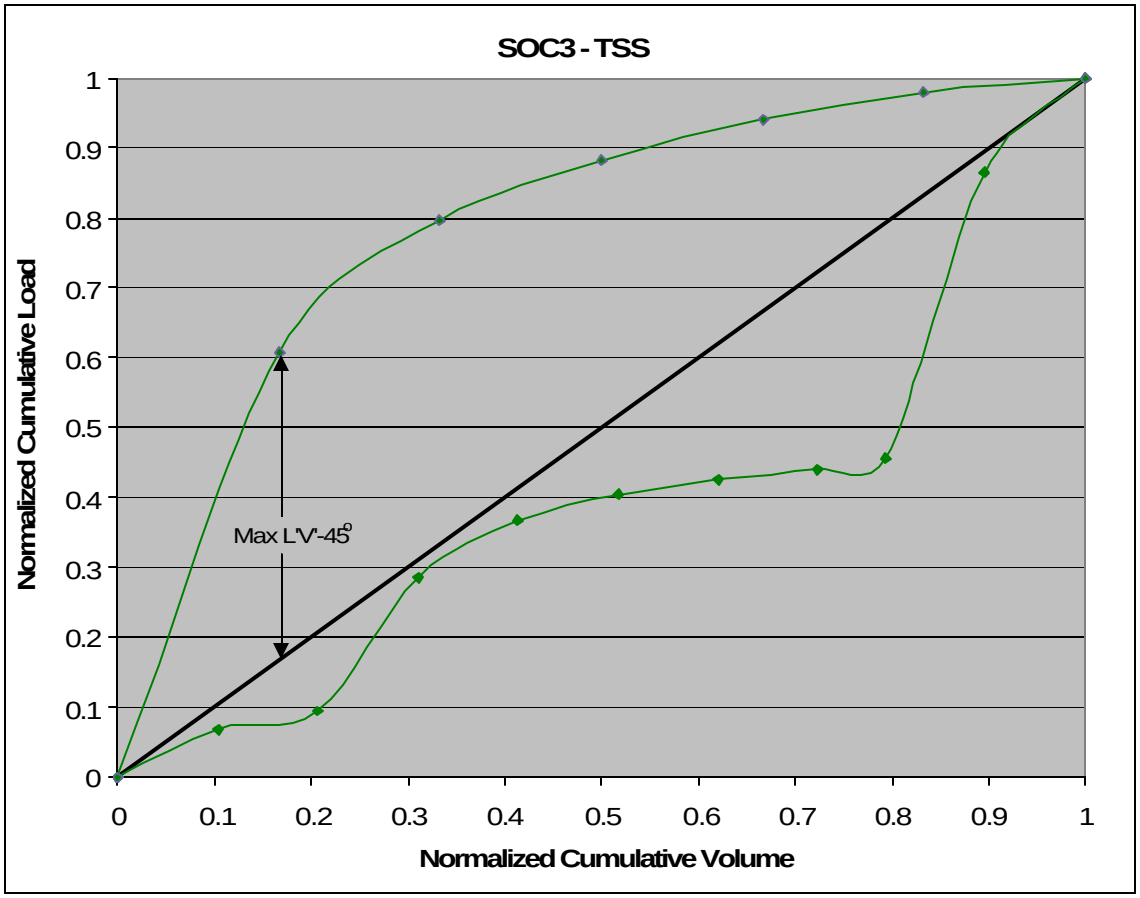

Figure 5.2: Method 2 first flush example - normalized cumulative TSS load (L') vs. normalized cumulative runoff volume (V'). Graph shows 2 events from SOC3.

Method 3

Method 3 involved the power law and FF coefficient analysis,

$$L' = V'^{b} \qquad (3)$$

A regression analysis was performed to compute the FF coefficient (*b*), which indicates the strength of the FF. The data were first log transformed to yield the new equation,

$$\ln L' = b \ln V' \qquad (4)$$

where the b coefficient becomes the slope term from the linear regression model. A value of 1 corresponds to the 45° bisector line representing uniform pollutant loading throughout the event. The lower the value of b, the more pronounced the FF. Slope values above 1 represent a dilution effect. The regressions were fixed to the y-intercept at zero to ensure that 100% of the pollutant load equals 100% of the runoff volume. Figure 5.3 shows an example of Method 3 with regression lines for TSS and O-PO_4, representing either first flush slopes or dilution slopes. All the *b* values from every storm event and pollutant that were analyzed for a FF effect are included in Appendix 1.

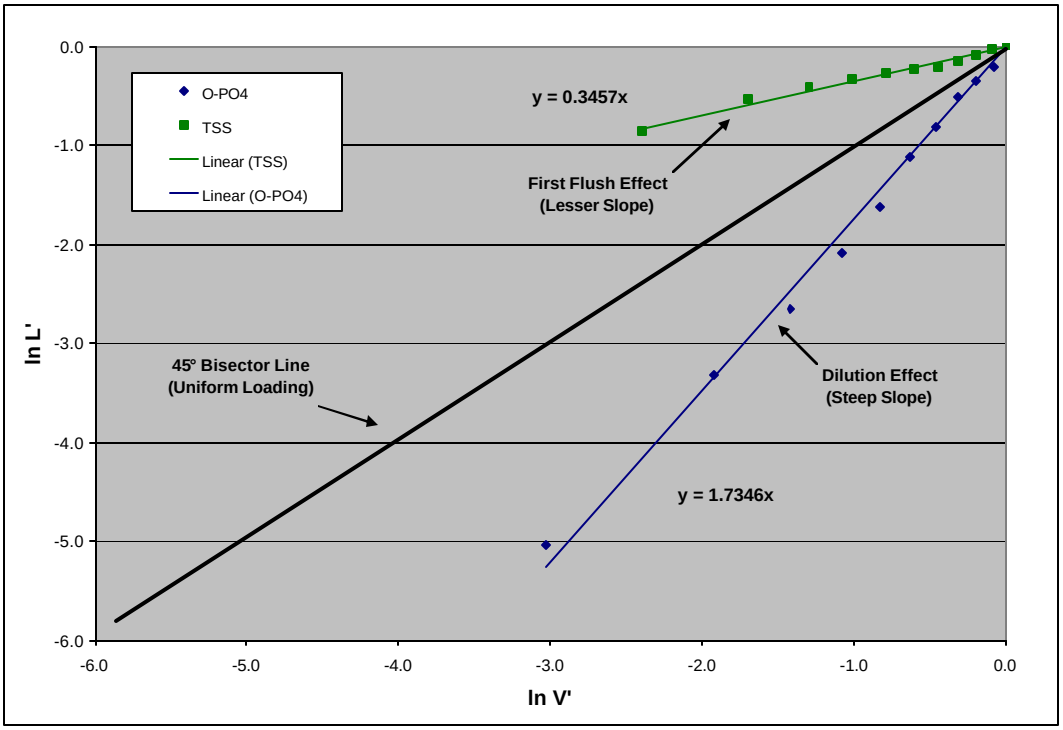

Figure 5.3: Method 3 example of regression lines and slope estimates (*b* values)

Conventional Definitions

Utilizing either Method 1 or 2, a more restrictive but common way to define the FF phenomenon is to compare a fraction of the total pollution load to a fraction of runoff load, both calculated from the same point in the first part of the cumulative runoff curve. Stahre and Urbonas (1990) first proposed a very restricted definition that declares a FF when 80% of the pollutant load is transferred in the first 20% of runoff volume (Def. 20/80). Arguing that other definitions are difficult to quantify and not precise enough to design detention facilities, Bertrand-Krajewski et al. (1998) proposed that a FF occurs when at least 80% of the total pollution load is transferred in the first 30% of runoff volume (Def. 30/80). Published around the same time, Deletic (1998) proposed a much less restrictive definition that delineates a FF phenomenon when the percentage of total pollutant load transported by the first 20% of runoff volume, L' (20), is greater than 40% (Def. 20/40). Similar to Deletic's 20/40 FF definition is also the 25/50 FF definition, first recommended by Wanielista and Yousef (1993). Each L'V' curve from the study was evaluated for a FF occurrence based on the 20/80, the 30/80, the 20/40 or the 25/50 definitions.

Effects of Rainfall Characteristics on First Flush Strength

Simple linear regression analyses were conducted to evaluate the effect of various rainfall characteristics on the strength, or intensity, of the first flush effect. Relationships were analyzed separately for each pollutant and drainage area. The first flush coefficient (*b*) represented the FF strength as the dependent variable, while the rainfall characteristics were the independent variables. Again, these variables are:

- Rainfall depth
- Peak rainfall intensity (5 min. interval)
- Peak runoff flow rate
- Runoff volume
- Antecedent dry period
- EMC

Land Use Comparison of FF Strength

An analysis of covariance (ANCOVA) was performed in order to answer the question of whether land use affected the FF strength. The storms collected were not sufficiently matched between the two different watersheds, thus eliminating the ability to perform a

paired t-test. ANCOVA was utilized to account for the heterogeneity among the different storms through the inclusion of a covariate variable. The covariates included in the ANCOVA model were the rainfall characteristics proven to significantly influence the FF strength based on the previous linear regressions. Similar to the simple linear regressions, the ANCOVA used the first flush *b*-values as the response variable on the y-axis and the covariate as the independent variable on the x-axis. The ANCOVA model, however, contained two regression lines, one for each watershed (site variable). ANCOVA compares the difference in y-intercepts evaluated at the adjusted treatment means (LS means), which corrects the observed treatment means for the effect of the covariate. A significant difference in FF strength between the two land uses is evident if the difference in y-intercepts holds statistical significance ($p < 0.05$). If the slope estimate for the covariate yields statistical significance, then there is evidence that the covariate influences FF strength. An ANCOVA was performed for each pollutant using each covariate.

Initially, the full models were performed that included an interaction term to test if the covariate affected the FF strength differently depending on the land use. The interaction term allows the regression lines to have different slopes (e.g., allow the FF response to changing rainfall or runoff amounts to be different between the two watersheds). If the slope estimate for the interaction term in the model yielded insignificant results ($p > 0.05$), reduced models were utilized instead that excluded the interaction term and forced the regression lines to have equivalent slopes. An example of a reduced model ANCOVA for Ni using runoff volume as a covariate is shown below in Figure 5.4.

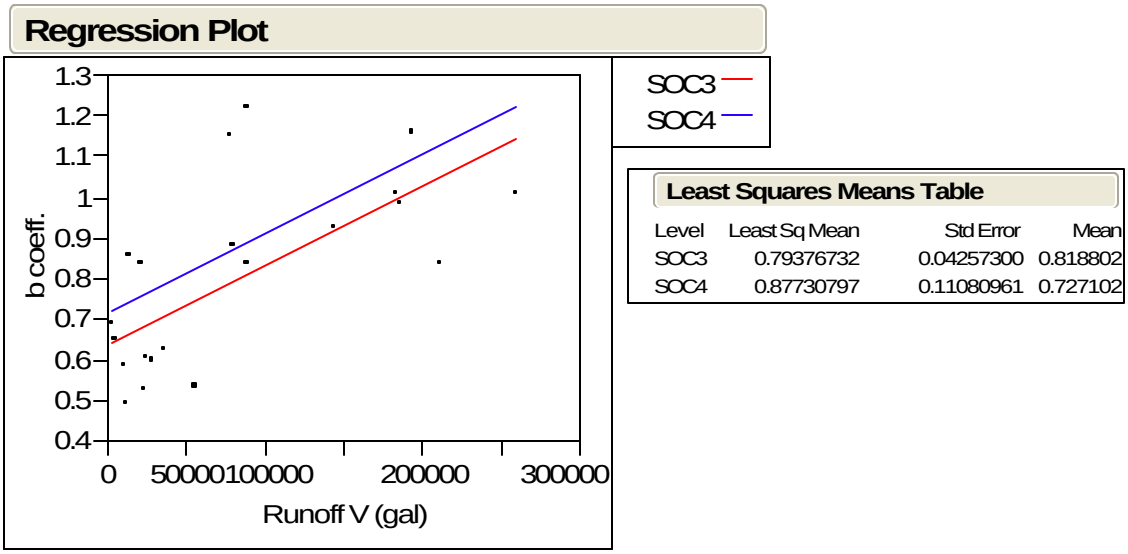

Figure 5.4: Reduced model ANCOVA example with Ni

Pollutant Comparison

The oneway analysis of variance (ANOVA) technique was utilized to compare FF strength (*b*-values) among pollutants for each watershed. Since the analysis was performed separately for each watershed, the pollutants were compared for the same storm events. A non-parametric test was required, however, because the *b*-values did have normal distributions for most of the pollutants (skewed). For multi-sample hypotheses, the Kruskal-Wallis test is an alternative to the parametric ANOVA test when the assumption of normality is not met. Like most non-parametric tests, the Kruskal-Wallis test uses ranks of the data rather than the raw values to calculate the test statistic (H) and evaluate the equality of the medians among sample groups. For this study, two general hypotheses will be tested using the Kruskal-Wallis test:

H_o: The FF strength (*b*-value) is equivalent for all pollutants in both populations

H_a: The FF strength is not equal for all pollutants in both populations

The result of the analysis is the Chi Squared test statistic which represents the variance among the different pollutants; high values indicate larger differences.

As in the parametric ANOVA, rejecting the null hypothesis (H_o) by the Kruskal-Wallis test does not indicate which pollutants differ from which other pollutants. If the null hypothesis was rejected by the Kruskal-Wallis test (evidence that at least one difference in FF strength

exists among the pollutants), a nonparametric multiple comparison with unequal sample sizes was utilized to evaluate several pre-planned comparisons. First, the standard error (SE) had to be calculated by:

$$SE = \sqrt{\left(\frac{N(N+1)}{12}\right)\left(\sum \frac{c_i^2}{n_i}\right)} \quad (7)$$

where N is the total number samples from all the pollutants, c_i is the linear contrast coefficient for each pollutant i, and n_i is the sample size for pollutant i. The test statistic (Q) is then calculated by:

$$Q = \frac{\bar{R}_B - \bar{R}_A}{SE} \quad (8)$$

where $\bar{R}$ indicates a mean rank from the Kruskal-Wallis test. Critical values from this test, $Q_{a,k}$, were obtained from a statistics textbook (Zar, 1996). Rejection of the null hypothesis occurred if the calculated test statistic was greater than the critical value.

If the nonparametric ANOVA test provided sufficient evidence that the FF strength of at least one of the pollutants was different from the rest, then a pre-planned nonparametric multiple comparisons was performed to compare the FF strength of the pollutants (particularly dissolved nutrients since dissolved metals were not analyzed for) to the FF nature of suspended sediment (TSS). Several reasons exist for this comparison, such as previous FF studies have indicated that particulate matter coincides with the hydrograph (Cristina and Buchberger, 2002), particulate bound metals correspond to the FF nature of TSS (Hewitt and Rashed, 1992; Han et al., 2006) and dissolved metals have stronger FF occurrences than particulate metals (Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997). Also, in states like North Carolina where sediment remains a pollutant of concern in stormwater runoff, many BMPs are designed and monitored more frequently for TSS. Knowing which pollutants have loading intensities similar to that of TSS could help estimate treatment percentages for other pollutants using TSS monitoring data.

Quantile box and whisker plots were created to visualize the distribution of 25th, 50th (medians) and 75th percentiles of all the pollutants for each watershed. The grand mean of all the *b*-values for each watershed was also plotted as a horizontal line. Figure 5.5 shows an example of a typical quantile box plot. More details about the parts of the box plot will be described in the results section.

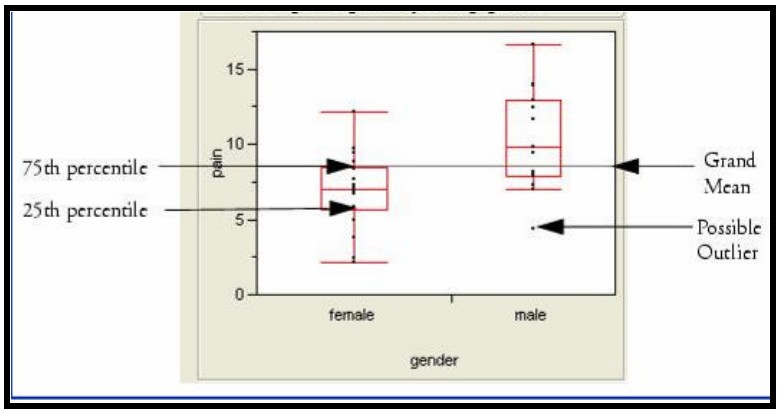

Figure 5.5: Example of quantile box plots

6. Evaluation of Treatable Annual Pollutant Load for FF Design Volumes

Part of the FF study was to determine the percentage of the total load from the sampled year (9/1/05-8/31/06) that could potentially be treated by a BMP sized for the runoff from 1.3 cm (0.5-inch), 1.9 cm (0.75 inch), 2.5 cm (1-inch) or 3.2 cm (1.25-inch) of rainfall. These rainfall depths are most frequently used to define the FF water quality volume to treat in a particular watershed, with 2.5 cm typically used for BMP design in North Carolina.

This study only estimated a yearly treatable load for the more impervious drainage area (SOC 3). SOC 3 is representative of the pollutant runoff characteristics from highly impervious urban areas.

Procedure for Estimating Treatable Annual Pollutant Load (TAPL)

The method for calculating the TAPL consisted of the following steps:

1. Potential runoff volumes for each rainfall design depth were calculated using the NRCS curve number (CN) method (USDA, 1986). Runoff volumes were calculated discretely for each cover type in the watershed (roadway, lawn, woods) using a B hydrologic soil group and an average antecedent runoff condition.

2. Although runoff volumes on SOC 3 were measured for most of the rainfall events during the studied year, a linear relationship between runoff volume and rainfall depth was developed to estimate runoff for the missing events (see Figure 6.1).

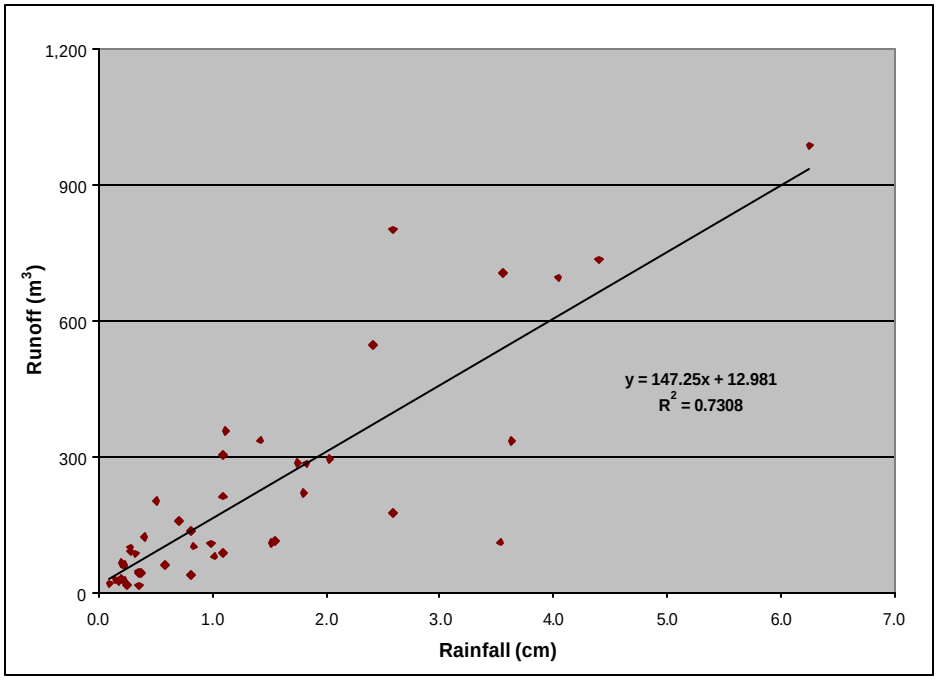

Figure 6.1: Example of rainfall/runoff regression

3. Using the results collected from the first flush analysis, relationships between pollutant load and runoff were estimated for each pollutant using linear regression, with runoff as the independent variable. Figure 6.2 shows a regression example for copper.

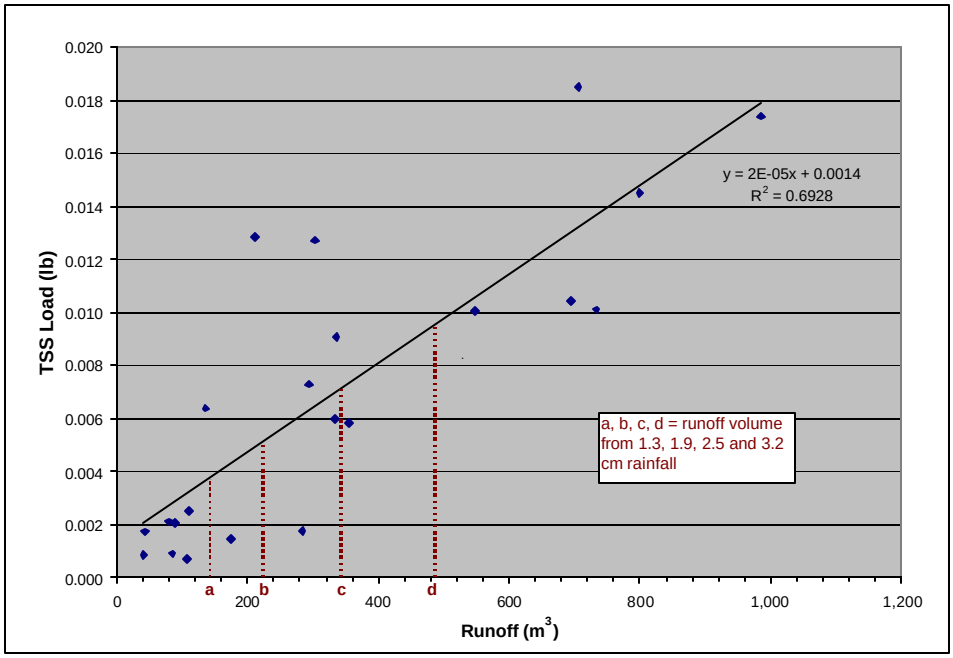

Figure 6.2: Example of runoff/load regression for copper

4. The total pollutant loads were estimated for the 30 missing storms between September 1, 2005 and August 31, 2006 by inputting measured or estimated runoff volumes into the runoff/pollutant load regression equations.

5. The percentage of load potentially treated by the FF BMP (1.3, 1.9, 2.5, or 3.2 cm's) for sampled storms was determined by using the developed L'V' curves for storms with runoff volumes greater than design volume. The percent of the total pollutant load captured for potential treatment by a BMP sized for that runoff volume was calculated by interpolating the L'V' curve for V' equal to the fraction of design storage volume to the total storm runoff volume.

6. To develop a relationship between percent of load captured for potential treatment and runoff, the 'percent of load captured' values from Step 5 were linearly regressed with runoff as the independent variable for the sampled storms greater than the design volume. See Figure 6.3 below for an example with copper.

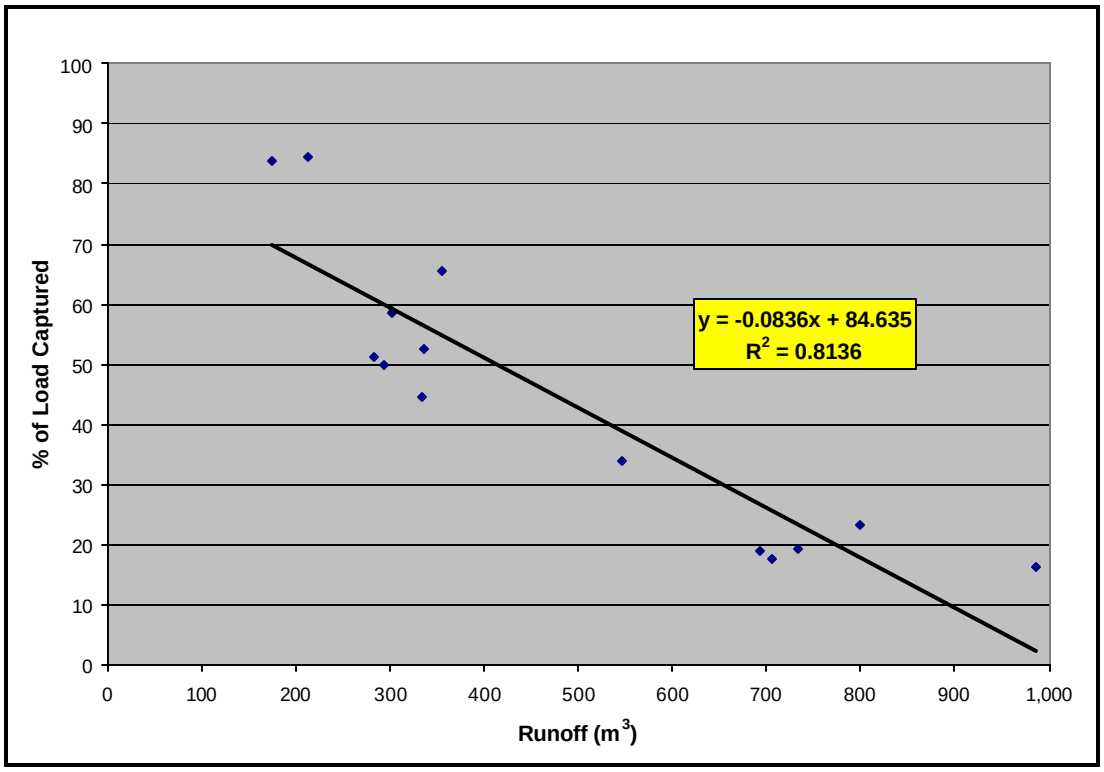

Figure 6.3: Regression of % of load treated and rainfall depth for copper (1.3 cm design storm)

7. Using the developed relationships, the treatable load was estimated for the missing storms that exceeded the FF design volume.

8. Utilizing the analyzed (when available) or estimated treatable loads from every storm event, the TAPL was calculated for each pollutant.

Limitations

For the one-year period starting on September 1, 2005, a total of 56 rain events occurred but only 25 of these were analyzed for a first flush effect from SOC 3 (although all of the 56 events were monitored for rainfall and most for runoff). This means that only these events had an adequate number of discrete samples analyzed to create an L'V' curve and therefore estimate the fraction of pollutant load for a fraction of runoff volume. Of the sampled storms, two of these were only analyzed for TSS. Thus, the runoff loads from a considerable number of storm events during the study year had to be estimated from the fraction of data collected. In addition, only 7 of the 25 sampled events (21%) had runoff volumes that

exceeded the design volume for 2.5 cm of rainfall, limiting the number of points in the regression for the runoff and percent of treatable load variables. In comparison, 12 of the 56 events (21%) that occurred during the study year had runoff volumes that exceeded 2.5 cm of rainfall design volume.

In addition, a large tropical storm occurred on 6/14/06 that delivered 18.2 cm (7.16 inches) of rain on the watershed. Since this storm was an extreme outlier and loads could not be accurately estimated, total TAPL was estimated for both inclusion and exclusion of this event. BMPs are typically not designed to capture and treat these excessively large storms, although they can deliver a considerable pollutant load. Therefore, knowing the fraction of TAPL capable of capture and treatment by BMPs sized for the more frequent and smaller events is of more importance.

Assumptions

In order to perform this analysis, several assumptions were made, including:

- Stormwater runoff volumes exceeding the design storage volume will bypass the BMP and receive no treatment.
- 100% of pollutant load from storms with runoff less than the design volume is available for treatment. This assumes that no back-to-back storms occur and the detention time is always less than then antecedent dry period.

Note: For the outlying 18.2 cm tropical storm, the treated load was calculated by entering the design runoff volume into the load vs. runoff regression equation. The load associated with the remaining 15.6 cm (6.16 inches) of rainfall was assumed to bypass the BMP and be unavailable for treatment.

In summary, the fitted regression equations were utilized to estimate pollutant loads for missing storms, and for the storms greater than the specific design volume, the percent of the treatable load could also be estimated. Assuming that runoff from storms with volumes less than the design volume was completely available for treatment in the BMP, the fraction of treatable annual pollutant load to the total annual pollutant load in the runoff from SOC3 was estimated.

7. Results

This section separately presents the results from the first flush study for each method and definition analyzed. Table 7.1 lists the rainfall depths and total runoff volumes from each storm event analyzed for a first flush effect. Note that SOC3 has a smaller drainage area but a much larger impervious area and greater runoff volume compared to SOC4. As a result, more discrete samples were able to be collected from SOC3 and thus more storms were analyzed for a first flush than those from SOC4.

The complete data set of rainfall depths, rainfall intensities, antecedent dry periods, and runoff flow rates and volumes for storms that met the criteria to analyze for the first flush study are listed in Appendix 1. Table 7.2 shows a brief summary of the three rainfall characteristics and Table 7.3 shows a summary of the two runoff characteristics.

Table 7.1: Rain and total runoff volumes for FF storms

Storm Date	Sites Sampled	Rainfall (cm)	Total Runoff Volume (m^3)
10/6/05	SOC3	6.07	1,375[a]
11/21/05	SOC3	6.25	1,100
11/29/05	SOC3	3.56	705[b]
12/5/05	SOC3	4.39	870
12/9/05	SOC4	1.55	155
12/15/05	SOC3	4.04	740
12/18/05	SOC4	0.86	195
1/14/06	SOC3	1.09	210[b]
1/18/06	SOC3	1.12	355[b]
1/31/06	SOC3	0.81	135[b]
2/4/06	SOC3	2.03	305
2/23/06	SOC3	1.42	360
3/21/06	BOTH	2.41	580
4/3/06	SOC3	1.09	310
4/27/06	SOC4	3.58	1,105
5/7/06	SOC4	3.76	1,100
5/14/06	SOC4	4.55	50[c]
5/18/06	SOC4	1.17	15[c]
6/2/06	SOC4	2.64	230
6/4-5/06	SOC3	0.51	210
6/23/06	SOC3	0.99	120
6/25-26/06	BOTH	1.83	300
7/6/06	SOC3	2.59	205
7/19/06	SOC3	0.28	90
7/22/06	SOC3	0.36	45
7/23/06	SOC3	0.20	65
7/23/06	SOC4	1.27	12
7/25/06	SOC3	0.33	90
7/26/06	BOTH	1.52	135
8/20/06	SOC3	0.38	60
8/30/06	SOC3	0.30	60
9/1/06	SOC3	3.63	585
9/5/06	SOC3	1.02	145

a Event consisted of 2 peaks; only first peak analyzed for first flush

b SOC3 flow only; flow meter error on SOC4

c SOC4 flow only; flow meter error on SOC3

Table 7.2: Summary of observed rainfall characteristics

Rainfall Characteristic	*High*	*Low*	*Mean*	*Median*
Depth (cm)	6.25	0.20	2.03	1.52
Antecedent Dry Period (days)	16	0.3	4.2	3
Maximum Intensity (cm/hr)	6.43	0.61	2.74	2.59

Table 7.3: Summary of observed runoff characteristics

Runoff Characteristic	SOC3				SOC4			
	High	*Low*	*Mean*	*Median*	*High*	*Low*	*Mean*	*Median*
Peak Flow Rate (LPM)	13,100	550	4,250	2,490	5,670	90	1,620	890
Runoff Volume (L)	985,000	41,260	313,000	212,000	174,100	11,900	47,100	38,100

The event mean concentrations (EMC) for each pollutant evaluated for the FF effect were also calculated and included in Appendix 1. However, the summary of EMCs for each pollutant and site are listed in Table 7.4. Also included in Table 7.4 are median EMC values for selected pollutants from the Nationwide Urban Runoff Program (US EPA, 1983b).

Table 7.4: Summary of EMCs (TSS & nutrients in mg/L, metals in ug/L)

POLLUTANT	SOC3				SOC4				NURP
	n	*Mean*	*Max*	*Min*	*n*	*Mean*	*Max*	*Min*	*Median*
TSS	25	140.7	422.4	25.2	11	42.0	84.7	18.9	100
O-PO_4	21	0.089	0.412	0.023	9	0.033	0.056	0.012	0.12
NH_3-N	22	0.445	1.181	0.083	9	0.257	0.525	0.111	NA
NO_3/NO_2	22	0.455	1.666	0.107	9	0.257	0.425	0.130	0.68
TP	23	0.288	0.793	0.123	9	0.095	0.155	0.054	0.33
TKN	23	1.248	6.407	0.632	9	0.765	1.091	0.494	1.5
Cr	22	6.76	34.7	1.8	6	1.57	2.1	0.97	NA
Cu	22	12.0	27.5	3.56	8	3.19	5.41	1.48	34
Ti	22	233.8	559.5	35.3	9	100.2	180.8	10.7	NA
V	22	13.7	29.14	4.17	7	3.71	5.83	2.11	NA
Zn	22	58.3	133.1	16.3	9	18.3	36.7	8.19	160
As	7	1.50	2.40	0.53	2	1.70	2.0	1.4	NA
Ni	18	3.08	4.77	1.19	3	1.03	1.24	0.71	NA
Pb	21	10.9	27.0	3.37	3	4.41	8.19	1.98	144

7.1 Method 1- First Flush Volume

Plotting both L' and V' versus T', Method 1 determines the point during a storm event where the fraction of total pollutant load is greatest compared to the fraction of total runoff. For events where the V'T' curve remained above the L'T' curve throughout an event, a value of zero was returned for the maximum L'-V' divergence. The V' location was recorded at each maximum divergence value for events where at least one positive divergence value occurred during the event. The complete data set for the Method 1 analysis is included in Appendix 1.

Table 7.5 presents a summary of the results from the Method 1 analysis ranked by the mean of the maximum L'-V' divergence values for SOC3. For all the pollutants, the mean of the maximum L'-V' divergence is 0.15 for SOC3 and 0.16 for SOC4. The average mean V' locations where the maximum divergences occur are at 39% for SOC3 and 37% for SOC4. In other words, where the FF is most pronounced during a storm event, the fraction of total load is on average 15% greater than the fraction of total runoff volume at that point in time, which is approximately at the first 40% of the runoff volume on average for both sites.

Table 7.5: Method 1 results summary

Pollutant	Site	# of Storms	Max L'-V'			V' Location at Max		
			High	*Low*	*Mean*	*High*	*Low*	*Mean*
TSS	SOC3	25	0.75	0	0.243	0.88	0.08	0.44
	SOC4	11	0.45	0.11	0.277	0.75	0.08	0.37
Zn	SOC3	22	0.55	0.01	0.203	0.93	0.08	0.36
	SOC4	9	0.41	0.05	0.191	0.77	0.17	0.36
Cr	SOC3	22	0.51	0	0.184	0.88	0.09	0.46
	SOC4	6	0.26	0.03	0.168	0.87	0.29	0.53
Ti	SOC3	22	0.51	0	0.182	0.88	0.08	0.44
	SOC4	9	0.40	0.02	0.212	0.87	0.25	0.45
V	SOC3	22	0.47	0	0.173	0.88	0.09	0.44
	SOC4	7	0.36	0.03	0.191	0.87	0.25	0.47
Pb	SOC3	21	0.46	0	0.169	0.82	0.08	0.39
	SOC4	3	0.25	0.04	0.128	0.33	0.22	0.28
NH_3	SOC3	22	0.35	0	0.160	0.56	0.08	0.29
	SOC4	9	0.36	0.01	0.185	0.71	0.17	0.36
Cu	SOC3	22	0.37	0.01	0.148	0.88	0.08	0.41
	SOC4	8	0.40	0.05	0.185	0.53	0.17	0.32
Ni	SOC3	18	0.31	0	0.142	0.93	0.08	0.48
	SOC4	3	0.33	0.04	0.170	0.53	0.33	0.40
TKN	SOC3	23	0.36	0.01	0.139	0.64	0.08	0.29
	SOC4	9	0.30	0.04	0.138	0.33	0.05	0.22
TP	SOC3	23	0.30	0	0.107	0.92	0.08	0.34
	SOC4	9	0.19	0	0.082	0.83	0.11	0.31
NO_3/NO_2	SOC3	22	0.30	0	0.106	0.60	0.08	0.28
	SOC4	9	0.36	0	0.152	0.50	0.10	0.24
As	SOC3	7	0.12	0	0.051	0.8	0.20	0.61
	SOC4	2	0.04	0.00	0.018	0.83	0.08	0.46
$O\text{-}PO_4$	SOC3	21	0.23	0	0.044	0.89	0.06	0.39
	SOC4	9	0.16	0	0.020	0.88	0.18	0.63
Total	**SOC3**	**292**	**0.75**	**0.00**	**0.15**	**0.93**	**0.06**	**0.39**
	SOC4	**103**	**0.45**	**0.00**	**0.16**	**0.88**	**0.05**	**0.37**

Figures 7.1 (TSS and nutrients) and 7.2 (heavy metals) help illustrate how the mean maximum L'-V' divergence values compare among pollutants. Likewise, Figures 7.3 and 7.4 show the average V' locations for each pollutant. Note that during the study only 9 FF events for As were analyzed due to concentration results often below detection limits and, therefore, the FF strength of As should be regarded with limited statistical validity. The higher the divergence value and the smaller the V' location, the more pronounced the first flush effect.

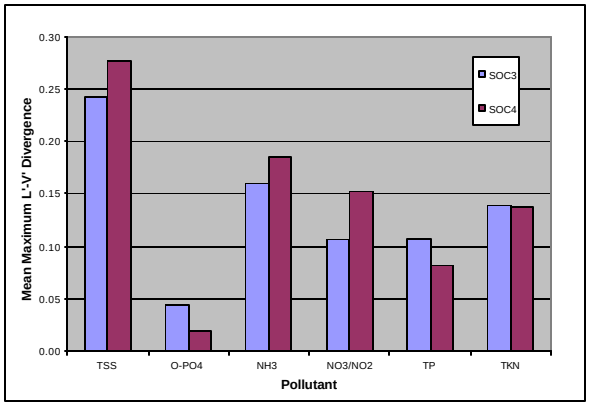

Figure 7.1: Mean max L'-V' for TSS and nutrients

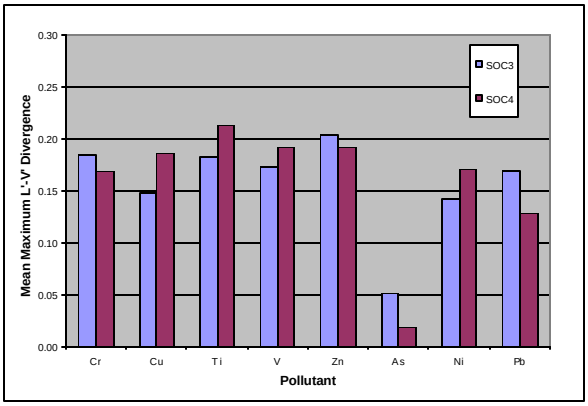

Figure 7.2: Mean max L'-V' for heavy metals

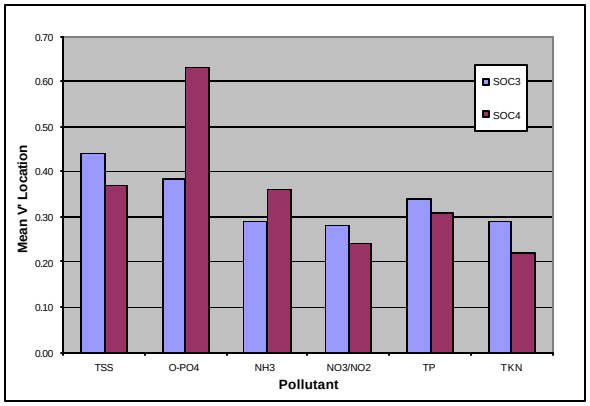

Figure 7.3: Mean V' locations for TSS and nutrients

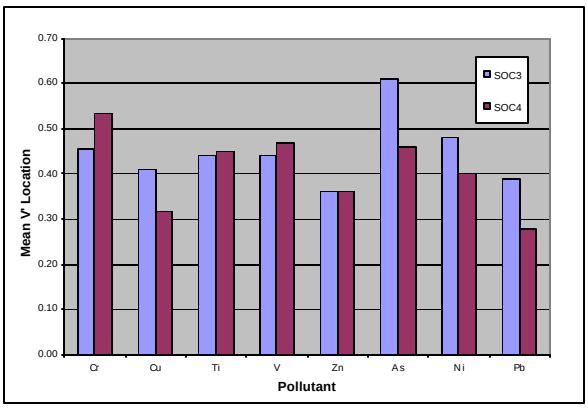

Figure 7.4: Mean V' locations for heavy metals

Based on Method 1, O-PO_4 appears to have a weak first flush effect on both sites since the maximum divergence value is small and the V' location is large. Conversely, TSS, Zn and Ti have a more prominent first flush for both sites with larger convergence values and lower V' locations.

7.2 Method 2 – First Flush Frequency

Unlike Method 1, Method 2 provides a specific criterion to quantify the frequency that storms exhibit a significant first flush. Instead of plotting both L' and V' versus T', Method 2 plots L' against V' and compares the curve to the 45 degree bisector line. Based on this method, a first flush is evident if the L'V' curve is above the 45 degree bisector line. The curves below the 45 degree line indicate a dilution effect where the fraction of the load in the first part of the storm is disproportionably lower than the fraction of runoff volume. However, Method 2 restricts a first flush occurrence only if the positive gap between the L'V' curve and the bisector is greater than 0.2.

The complete set of L'V' curves created from Method 2 are included in Appendix 2 for each pollutant and drainage area. Figures 7.5 (TSS/nutrients) and 7.6 (heavy metals) display the Method 2 first flush frequencies for both sites. A complete summary of the Method 2 results is included in Table 7.6 with the percentages of Method 2 FF occurrences and the quartiles of the V' locations where the maximum positive divergences from the bisector occurred.

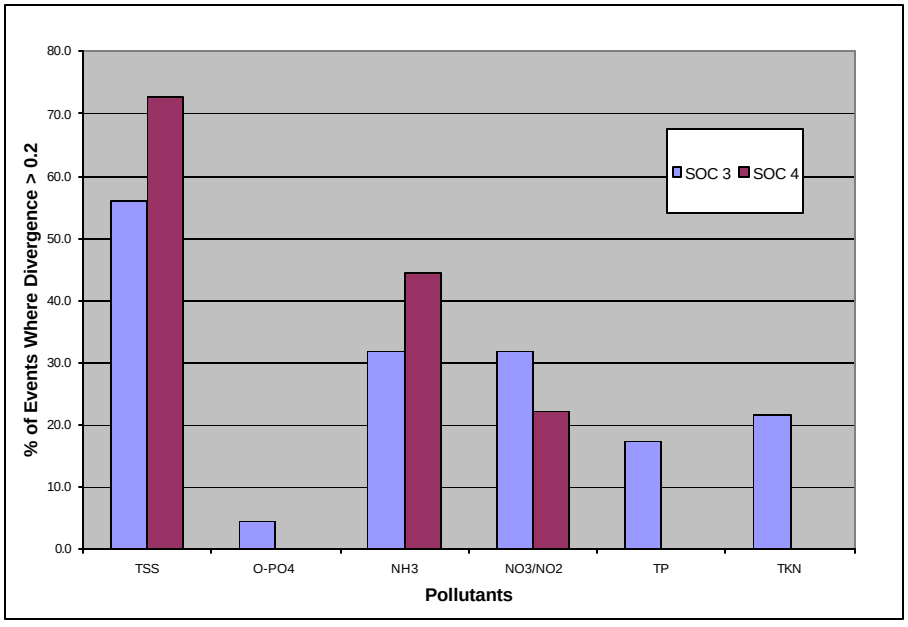

Figure. 7.5: Method 2 FF frequencies for TSS and nutrients

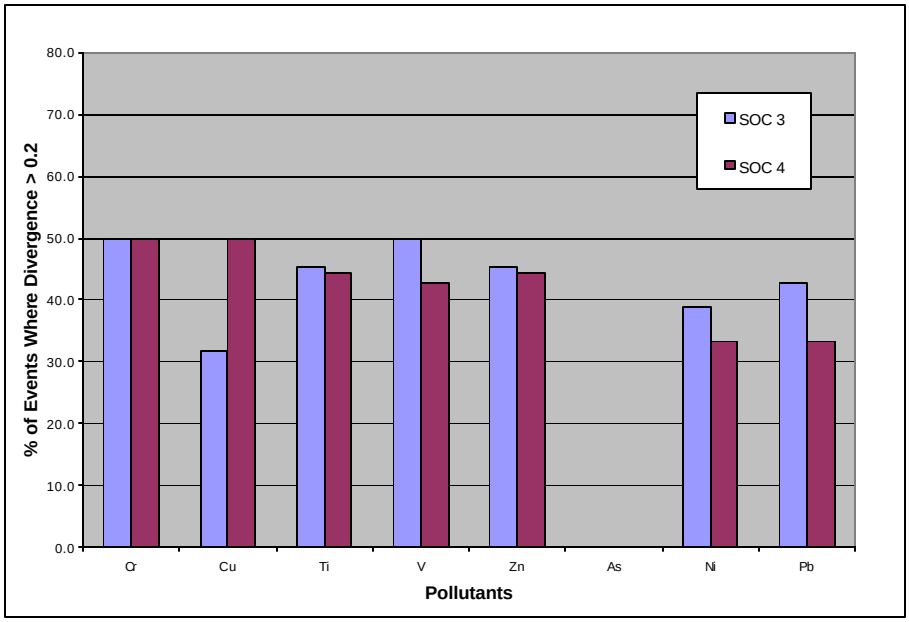

Figure 7.6: Method 2 FF frequencies for heavy metals

Using Method 2, a combined site rank of each pollutant's likelihood to show a significant FF effect in descending order are TSS, Cr, V, Ti, Zn, Pb, Ni, Cu, NH3, NO3/NO2, TKN, TP, O-PO4, As. Again, regard As with limited statistical validity due to a small sample size for both sites. This ranking shows which pollutants will have a higher proportion of total pollutant load that is stored and treated in a BMP designed to treat first flush pollutants. Combining the sites and pollutants, a Method 2 FF occurs for 36% of the storm events and the V' location where the maximum > 0.2 gap occurs is at approximately 32% of the runoff volume.

Table 7.6: Method 2 results summary

Pollutant	COMBINED				SOC 3				SOC 4			
	> 0.2 Gap		**V' Location**		**> 0.2 Gap**		**V' Location**		**> 0.2 Gap**		**V' Location**	
TSS	#	22	75%	0.41	#	14	75%	0.46	#	8	75%	0.36
	total	36	Median	0.33	total	25	Median	0.33	total	11	Median	0.33
	%	**61.1**	25%	0.26	%	56.0	25%	0.26	%	72.7	25%	0.15
$O\text{-}PO_4$	#	1	75%	0.33	#	1	75%	0.33	#	0	75%	NA
	total	31	Median	0.33	total	22	Median	0.33	total	9	Median	NA
	%	**3.2**	25%	0.33	%	4.5	25%	0.33	%	0.0	25%	NA
NH_3	#	11	75%	0.33	#	7	75%	0.34	#	4	75%	0.33
	total	31	Median	0.25	total	22	Median	0.20	total	9	Median	0.28
	%	**35.5**	25%	0.17	%	31.8	25%	0.13	%	44.4	25%	0.19
NO_3/NO_2	#	9	75%	0.35	#	7	75%	0.36	#	2	75%	0.33
	total	31	Median	0.28	total	22	Median	0.28	total	9	Median	0.25
	%	**29.0**	25%	0.17	%	31.8	25%	0.18	%	22.2	25%	0.17
TP	#	4	75%	0.44	#	4	75%	0.44	#	0	75%	NA
	total	32	Median	0.23	total	23	Median	0.23	total	9	Median	NA
	%	**12.5**	25%	0.18	%	17.4	25%	0.18	%	0.0	25%	NA
TKN	#	8	75%	0.31	#	5	75%	0.42	#	3	75%	0.33
	total	32	Median	0.25	total	23	Median	0.25	total	9	Median	0.25
	%	**25.0**	25%	0.18	%	21.7	25%	0.16	%	33.3	25%	0.17
Cr	#	14	75%	0.51	#	11	75%	0.44	#	3	75%	0.53
	total	28	Median	0.37	total	22	Median	0.33	total	6	Median	0.50
	%	**50.0**	25%	0.25	%	50.0	25%	0.18	%	50.0	25%	0.33
Cu	#	11	75%	0.33	#	7	75%	0.40	#	4	75%	0.33
	total	30	Median	0.29	total	22	Median	0.29	total	8	Median	0.31
	%	**36.7**	25%	0.17	%	31.8	25%	0.17	%	50.0	25%	0.20
Ti	#	14	75%	0.40	#	10	75%	0.41	#	4	75%	0.33
	total	30	Median	0.32	total	22	Median	0.31	total	9	Median	0.32
	%	**46.7**	25%	0.23	%	45.5	25%	0.18	%	44.4	25%	0.26
V	#	14	75%	0.46	#	11	75%	0.50	#	3	75%	0.33
	total	29	Median	0.33	total	22	Median	0.40	total	7	Median	0.33
	%	**48.3**	25%	0.23	%	50.0	25%	0.18	%	42.9	25%	0.25
Zn	#	14	75%	0.40	#	10	75%	0.41	#	4	75%	0.33
	total	31	Median	0.33	total	22	Median	0.33	total	9	Median	0.29
	%	**45.2**	25%	0.23	%	45.5	25%	0.25	%	44.4	25%	0.19
As	#	0	75%	NA	#	0	75%	NA	#	0	75%	NA
	total	9	Median	NA	total	7	Median	NA	total	2	Median	NA
	%	**0.0**	25%	NA	%	0.0	25%	NA	%	0.0	25%	NA
Ni	#	8	75%	0.43	#	7	75%	0.44	#	1	75%	0.33
	total	21	Median	0.31	total	18	Median	0.29	total	3	Median	0.33
	%	**38.1**	25%	0.20	%	38.9	25%	0.18	%	33.3	25%	0.33
Pb	#	10	75%	0.43	#	9	75%	0.45	#	1	75%	0.33
	total	24	Median	0.28	total	21	Median	0.27	total	3	Median	0.33
	%	**41.7**	25%	0.18	%	42.9	25%	0.18	%	33.3	25%	0.33
Total	#	140	75%	0.40	#	103	75%	0.40	#	37	75%	0.33
	total	389	Median	0.32	total	293	Median	0.29	total	103	Median	0.33
	%	**36.0**	25%	0.20	%	35.2	25%	0.18	%	35.9	25%	0.25

7.3 Method 3 – First Flush Strength

The results from Method 3 provide a quantifiable value for first flush strength. Using a log transformed power function of $L'=V'^{b}$, the slope values become the indicator for the intensity of the first flush. Lower slopes (smaller b-values) represent stronger FF effects while steeper slopes (larger *b*-values) represent weaker first flush effects. All the *b*-values from every storm event and pollutant analyzed for a FF effect are listed in Appendix 1. The average *b*-values for each pollutant are listed in Table 7.7. The pollutants are listed by combined site rank of decreasing first flush strength.

Table 7.7: Method 3 mean *b*-values

Pollutant	Mean *b* Coefficients		
	Combined	**SOC 3**	**SOC 4**
Zn	0.67	0.66	0.70
TSS	0.72	0.75	0.64
NH_3	0.72	0.73	0.68
Cu	0.73	0.74	0.72
TKN	0.75	0.76	0.73
Pb	0.77	0.75	0.92
Ni	0.78	0.80	0.73
V	0.79	0.79	0.64
Ti	0.82	0.82	0.81
Cr	0.83	0.82	0.83
TP	0.85	0.83	0.88
NO_3/NO_2	0.90	0.97	0.74
As	1.09	1.08	1.09
$O\text{-}PO_4$	1.19	1.13	1.34
Total	**0.82**	**0.89**	**0.81**

All the pollutants except As and O-PO_4 show an overall first flush nature since their average *b*-values are less than 1 (uniform loading). Arsenic and O-PO4 exhibit a dilution effect; their fraction of pollutant load is typically disproportionately lower than the fraction of runoff volume and any given point during the storm. The pollutant's FF strength can also be ranked using the *b*-values (Method 3). As indicated by both rankings (Method 2 and Method 3), TSS and Zn exhibit the strongest and most frequent FF behavior while O-PO_4, As, and TP exhibit the weakest and least frequent. The remaining pollutant FF strengths show high variability between the Method 2 and Method 3 rankings.

7.4 Conventional First Flush Definitions

Of 396 individual FF analyses from 36 storm events and each pollutant at each watershed, the 20/80 or the 30/80 definitions occurred only once, and that was for TSS on January 13-14, 2006. This rare event that exhibited such a strong first flush is highlighted in Figure 7.7. The extremely uncommon FF occurrence based on either of these more restrictive FF definitions observed in this study concurs with previous research. The percentages of occurrence that the first 20% of the runoff volume transported 40% or more of the load (20/40) are given in Table 7.8. Comparing the total number of FF occurrences to the total number of FF analyses for all the pollutants, the 20/40 FF definition was met in only 22% of 293 total FF analyses on SOC3 and in only 17% of the 103 FF analyses on SOC4. Likewise, the 25/50 FF definition occurred in only 15% and 17% of the recorded events on SOC3 and SOC4, respectively. The 25/50 FF was less frequent than the 20/40 FF for most pollutants. However, based on both definitions, TSS, Zn, NH_3-N and Ti exhibited a FF effect most often while TP was the least frequent and As and O-PO_4 FF effects were non-existent. Overall, even for the two less restrictive conventional FF definitions, FF effect was not a dominant phenomenon among the analyzed events.

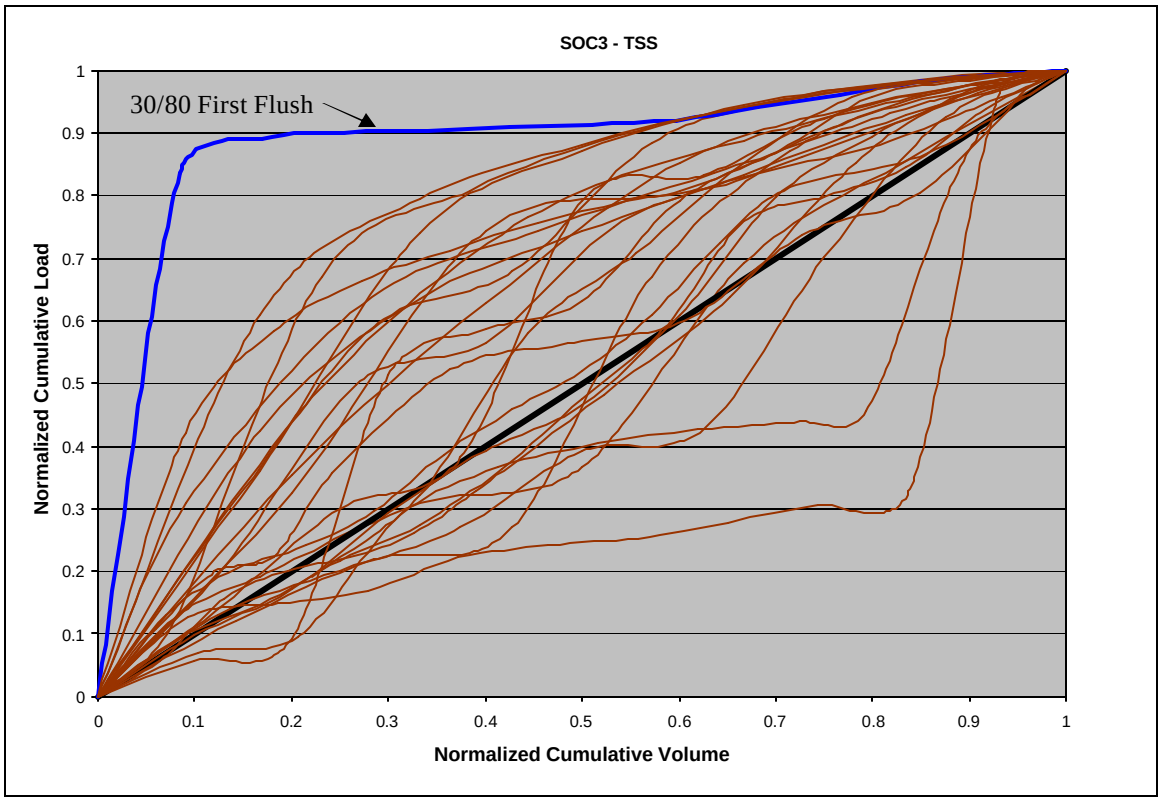

Figure 7.7: TSS L'V' curves from SOC3 showing 30/80 FF occurrence

Table 7.8: Percentages of 20/40 FF occurrence

Pollutant	% 20/40			% 25/50		
	Combined	SOC3	SOC4	Combined	SOC3	SOC4
TSS	39	36	45	39	36	45
$O\text{-}PO_4$	0	0	0	0	0	0
$NH_3\text{-}N$	29	23	44	19	14	33
NO_3/NO_2	19	18	22	13	9	22
TP	9	13	0	6	9	0
TKN	22	17	33	13	9	22
Cr	21	27	0	11	14	0
Cu	20	23	13	10	9	13
Ti	27	32	11	23	27	11
V	24	27	14	14	14	14
Zn	29	36	11	29	32	22
As	0	0	0	0	0	0
Ni	14	17	0	14	11	33
Pb	13	14	0	13	14	0
Total	21	22	17	16	15	17

Figure 7.8 shows a comparison between the 20/40 and the Method 2 FF occurrences. Both of these FF definitions require that the fraction of total pollutant load must be greater than the fraction of total runoff volume by 20%, but the Method 2 definition allows this deviation to occur at any point during the storm while the 20/40 definition limits the 20% deviation to the first 20% of runoff volume. For all pollutants on both watersheds, the Method 2 FF occurrence is more frequent.

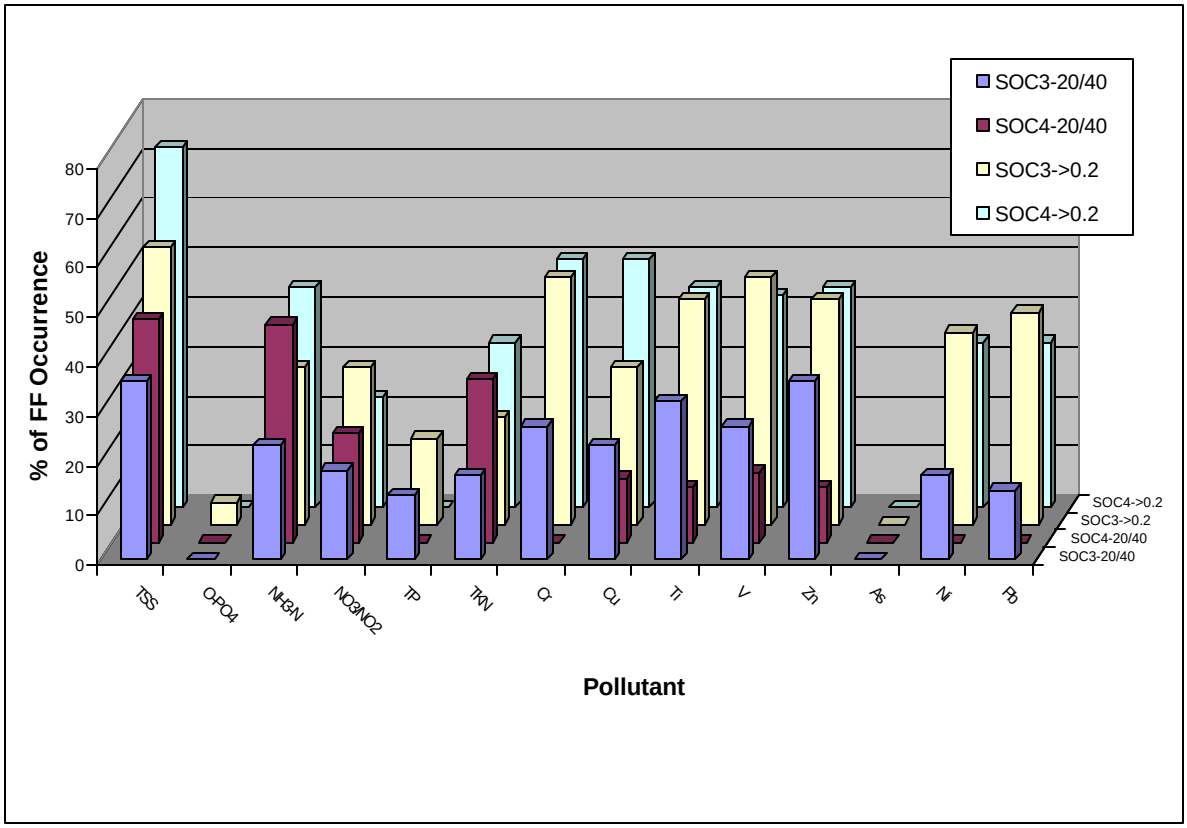

Figure 7.8: Percent of occurrence for 20/40 and 25/50 FF Def.

Tables 7.9 through 7.12 provide a statistical summary of the L'(20) and L'(30) values for both watersheds in order to better understand the fraction of pollutant load actually delivered in the first 20% and 30% of the runoff. As shown by the max and min values for all the pollutants, the fraction of pollutant load delivered in the early portion of runoff volume varies significantly among storm events. The FF effect is strongest in both the first 20% and 30% of the runoff volume for TSS, Zn, NH_3-N, and Cu respectively, and weakest for O-PO_4, As,

and TP. Based on the mean values, an overall weak FF effect occurs at both L'(20) and L'(30) for all the pollutants except As and O-PO_4, which exhibit a slight dilution effect.

Table 7.9: Statistical summary of L'(20) values for SOC3

Pollutant	Mean (%)	Max (%)	Min (%)	Std. Dev. (%)	# of Storms
Zn	**34.5**	73.1	16.1	13.6	22
TSS	**33.3**	89.5	9.2	19.9	25
NH_3-N	**33.2**	52.4	14.2	10.3	22
TKN	**30.8**	53.9	16.1	9.0	23
Cu	**30.5**	55.5	16.5	11.3	22
Pb	**30.5**	64.5	12.9	12.3	21
V	**29.7**	64.9	9.0	13.3	22
Cr	**29.6**	69.3	3.5	15.0	22
Ti	**29.4**	68.4	8.3	16.1	22
TP	**27.1**	48.4	10.4	9.2	23
Ni	**27.1**	44.9	13.2	11.1	18
NO_3/NO_2	**26.0**	49.8	4.2	12.3	22
O-PO_4	**17.7**	32.1	5.3	7.1	22
As	**17.3**	27.6	11.3	6.4	7

"FF line"

Table 7.10: Statistcal summary of L'(20) values for SOC4

Pollutant	Mean (%)	Max (%)	Min (%)	Std. Dev. (%)	# of Storms
TSS	**38.7**	64.5	20.0	14.8	11
NH_3-N	**35.4**	51.1	19.6	11.6	9
Zn	**34.8**	60.7	20.8	11.3	9
Cu	**34.2**	58.8	22.8	11.3	9
NO_3/NO_2	**32.5**	54.9	18.3	12.8	8
TKN	**32.1**	44.7	19.8	9.7	9
*Ni**	**31.7**	39.3	22.2	8.7	3
V	**31.1**	55.3	12.6	13.1	9
Ti	**30.4**	59.1	4.0	15.2	6
Cr	**28.2**	36.4	10.5	9.2	7
*Pb**	**26.7**	28.6	23.4	2.8	3
TP	**25.9**	38.3	12.4	7.9	9
*As**	**16.0**	21.6	10.5	7.8	2
O-PO_4	**14.0**	35.7	5.5	9.1	9

"FF line"

* Not enough samples for statistical comparison

Table 7.11: Statistical Summary of L'(30) values for SOC3

Pollutant	Mean (%)	Max (%)	Min (%)	Std. Dev. (%)	# of Storms
Zn	**46.8**	76.2	22.8	14.2	18
TSS	**46.2**	90.2	18.1	20.3	22
NH_3-N	**43.0**	61.5	23.5	9.9	22
Pb	**42.0**	68.4	22.8	12.6	7
Cu	**41.7**	60.4	28.3	10.6	22
V	**41.4**	67.6	20.9	13.2	23
TKN	**41.2**	66.0	27.0	9.0	21
Cr	**41.1**	72.1	4.8	15.8	22
Ti	**40.9**	70.2	20.1	16.2	22
Ni	**38.3**	60.9	19.5	13.4	22
TP	**37.5**	59.2	21.5	9.2	22
NO_3/NO_2	**35.9**	56.9	11.6	13.8	23
"FF line"					
As	**26.9**	38.9	19.3	7.2	22
O-PO_4	**26.9**	41.3	9.4	8.1	25

Table 7.12: Statistical summary of L'(30) values for SOC4

Pollutant	Mean (%)	Max (%)	Min (%)	Std. Dev. (%)	# of Storms
TSS	**52.1**	73.0	27.2	14.5	11
Zn	**48.1**	68.3	31.2	12.1	9
NH_3-N	**46.5**	64.6	31.0	12.0	9
*Ni**	**46.3**	60.1	30.4	NA	3
Cu	**46.1**	65.4	34.7	10.4	9
Ti	**44.6**	69.8	13.1	17.8	6
V	**44.1**	65.4	22.1	14.4	9
NO_3/NO_2	**42.3**	65.3	27.1	13.7	8
TKN	**41.8**	57.9	26.8	10.9	9
*Pb**	**41.1**	51.1	34.0	NA	3
Cr	**40.8**	53.5	19.2	12.4	7
TP	**34.5**	45.3	18.9	8.8	9
"FF line"					
*As**	**23.5**	29.4	17.6	NA	2
O-PO_4	**21.3**	44.8	10.2	9.8	9

* Not enough samples for statistical comparison

7.5 Effect of Rainfall Characteristics on First Flush

Using previously mentioned rainfall and runoff characteristics, simple linear regression analyses were conducted to determine which, if any, influenced the strength of the first flush (*b* values). SOC4, which had a much smaller data set than SOC3, yielded no statistically

significant relationship between rainfall characteristics and first flush strength. The SOC3 data, however, did reveal significant relationships. For TSS and heavy metals, the strength of the FF decreased as rainfall depth or runoff volume increased. Conversely, the FF strength for O-PO_4 significantly increased as rainfall depth or runoff volume increased. No other characteristics proved to influence FF strength on SOC3. Listed in Table 7.13 are the p-values of the slope estimates for each linear regression. The slope estimates are listed for pollutants whose FF strength is significantly influenced by rainfall depth or runoff volume. Note that higher *b*-values indicate weaker FF effects, so positive slope estimates specify a decrease in FF strength as the rainfall characteristic value increases and vice versa.

Table 7.13: Statistical results for regression of b-values and rainfall/runoff volume

Pollutant	Site	*b* vs Rainfall		*b* vs Volume	
		p-value for slope	***Slope Estimate***	***p-value for slope***	***Slope Estimate***
TSS	**SOC3**	**0.004**	**0.296**	**0.018**	**2.1E-06**
	SOC4	0.236		0.204	
O-PO_4	**SOC3**	**0.021**	***-0.227***	**0.014**	***-2.0E-06***
	SOC4	0.397		0.858	
NH_3	SOC3	0.278		0.582	
	SOC4	0.963		0.606	
NO_3/NO_2	SOC3	0.440		0.090	
	SOC4	0.806		0.744	
TP	SOC3	0.345		0.138	
	SOC4	0.057		0.558	
TKN	SOC3	0.639		0.557	
	SOC4	0.603		0.954	
Cr	**SOC3**	**0.021**	**0.281**	**0.007**	**3.2E-06**
	SOC4	0.379		0.453	
Cu	**SOC3**	**0.005**	**0.194**	**0.004**	**1.7E-06**
	SOC4	0.990		0.188	
Ti	**SOC3**	**0.004**	**0.310**	**0.003**	**2.7E-06**
	SOC4	0.204		0.932	
V	**SOC3**	**0.008**	**0.232**	**0.011**	**1.9E-06**
	SOC4	0.487		0.544	
Zn	**SOC3**	**0.010**	**0.192**	**0.037**	**1.4E-06**
	SOC4	0.834		0.339	
As	SOC3	0.073		0.129	
	SOC4	NA		NA	
Ni	**SOC3**	**0.002**	**0.241**	**0.003**	**2.0E-06**
	SOC4	0.108		0.187	
Pb	**SOC3**	**0.005**	**0.204**	**0.003**	**1.8E-06**
	SOC4	0.797		0.607	

7.6 Land Use Comparison of First Flush Strength

As shown by Figure 7.9, the relationship between rainfall and runoff on the two drainage area varies drastically due to land use. In an attempt to verify whether this land use variation affects first flush strength (*b*-value), an analysis of covariance was performed using the site (watershed) variable as the explanatory variable and either rainfall or runoff volume as the covariate. The interaction term in the full model was statistically insignificant for every pollutant, indicating that the FF response to changing rainfall or runoff amounts was not different between the two watersheds. After accounting for the heterogeneity among storm events with the inclusion of the rainfall depth or runoff volume covariates in the reduced model, neither analysis yielded a statistically significant difference in FF strength between the two drainage areas except for Pb. The FF strength of Pb did significantly differ between land uses when runoff volume was used as a covariate, as determined by the p-values of the difference in y-intercepts evaluated at the LS means (p-value = 0.010). Exhibited in Figure 7.10, the ANCOVA model yielded a difference in magnitude of LS means between the two site regressions of 0.319 (1.054-0.735) with SOC4 having the higher *b*-value (weaker FF). This indicates that for a given runoff volume, the FF strength of Pb on SOC3 will be stronger than on SOC4 by a difference in *b*-values of 0.319. In addition, the statistical significance of the pooled slope estimate (p-value = .0016) indicates that the FF strength of Pb decreases (b-value increases) as the runoff volume increases.

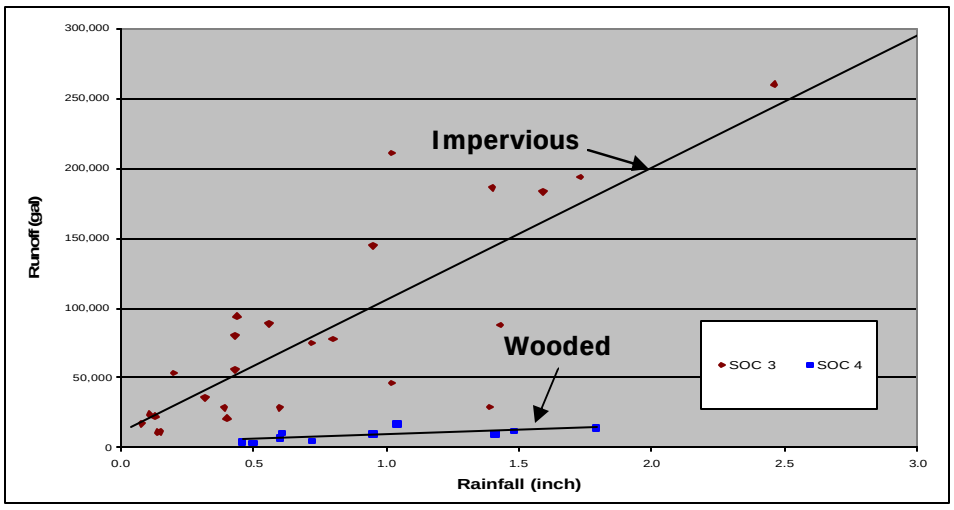

Figure 7.9: Rainfall/runoff relationship for both drainage areas

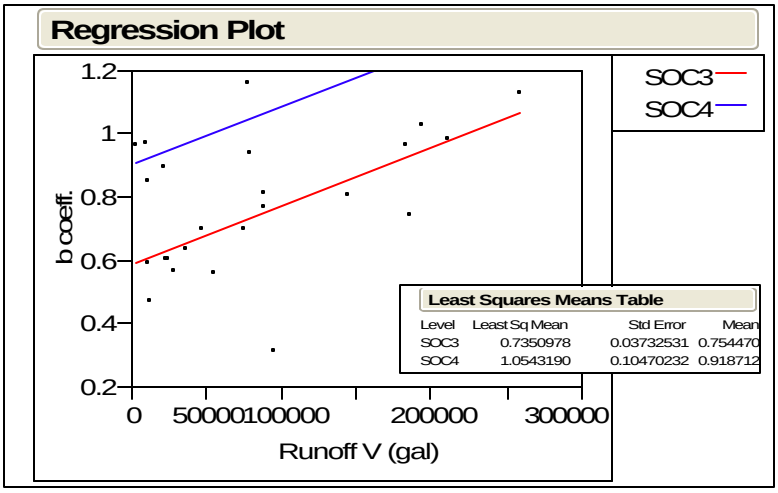

Figure 7.10: ANCOVA land use results for Pb

7.7 Pollutant Comparison of First Flush Strength

The quantile plots for the oneway analysis are displayed in Figures 7.11 and 7.12, for SOC3 and SOC4, respectively. The solid gray line in each plot represents the grand median for each watershed. The "whiskers" extend from the ends of the box (which represents the interquartile range) to the outermost data point that fall within the distance calculated by:

upper quartile + 1.5*(interquartile range), lower quartile – 1.5*(interquartile range)

When all the pollutant groups were analyzed collectively, the non-parametric Kruskal-Wallis test rejected the null hypotheses for both sites, concluding that at least one of the pollutants had a statistically different FF strength. The Chi Square values were 43.58 for SOC3 (p-value = <.0001) and 29.03 for SOC4 (p-value = 0.0065). Tables 7.14 and 7.15 exhibit the Rank Sum results from the Kruskal-Wallis test for SOC3 and SOC4, listed in ascending order of mean ranks.

When nutrients and metals were analyzed separately, the Kruskal-Wallis test failed to reject the null hypothesis for heavy metals at either site, but the null hypothesis was rejected for nutrients at both sites. This indicates that at least one of the nutrients had a statistically different FF strength from the other pollutants, but the metals behaved similarly.

In order to determine if any of the pollutants had FF strengths that significantly differed from that of suspended sediment, a nonparametric multiple comparison was performed independently for each pollutant. As shown by Tables 7.16 and 7.17, the null hypothesis was only rejected for O-PO_4 at both watersheds, indicating that only O-PO_4 has a FF strength that statistically differs from suspended sediment.

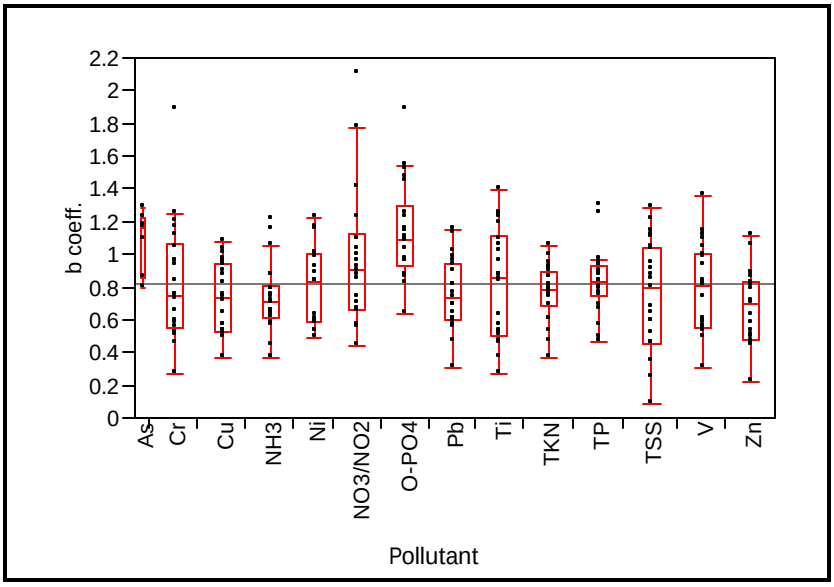

Figure 7.11: Quantile box plots of *b*-values by pollutant (SOC3)

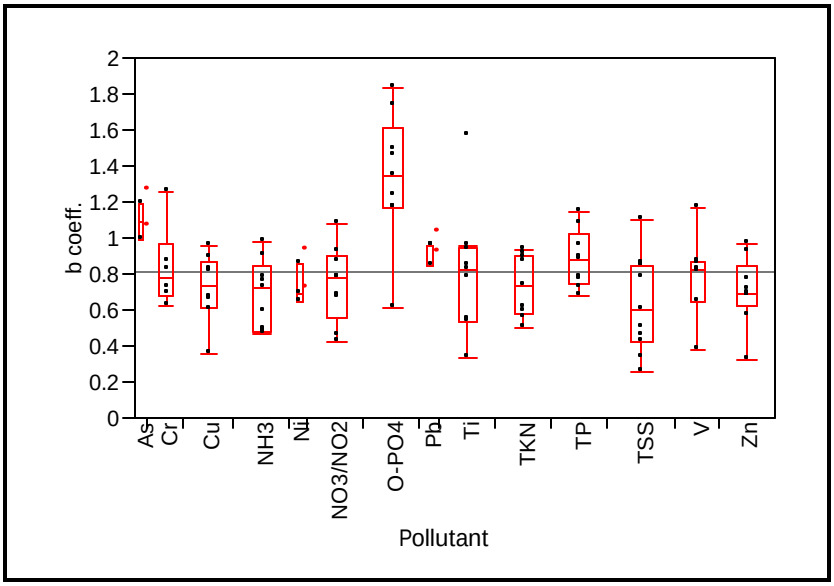

Figure 7.12: Quantile box plots of *b*-values by pollutant (SOC4)

Table 7.14: Kruskal-Wallis Rank Sum results (SOC3)

Pollutant	# of Storms	Score Sum	Score Mean	Std. Score
Zn	22	2272	103.3	-2.52
NH_3	22	2620	119.1	-1.61
Cu	22	2791	126.9	-1.16
Pb	21	2739	130.4	-0.93
TKN	23	3035	132.0	-0.89
TSS	25	3308	132.3	-0.90
V	22	3067	139.4	-0.44
Cr	22	3121	141.9	-0.29
Ti	22	3268	148.5	0.09
Ni	18	2719	151.1	0.21
TP	23	3556	154.6	0.45
NO_3/NO_2	22	3863	175.6	1.64
O-PO4	22	5091	231.4	4.86
As	7	1621	231.6	2.67

Table 7.15: Kruskal-Wallis Rank Sum results (SOC4)

Pollutant	# of Storms	Score Sum	Score Mean	Std. Score
TSS	11	385	35.0	-1.99
NH_3	9	351	39.0	-1.36
Zn	9	372	41.3	-1.12
Ni	3	127	42.3	-0.56
Cu	8	351	43.9	-0.80
NO_3/NO_2	9	409	45.4	-0.68
TKN	9	415	46.1	-0.61
Ti	9	464	51.6	-0.04
V	7	368	52.6	0.05
Cr	6	326	54.3	0.19
TP	9	577	64.1	1.27
Pb	3	220	73.3	1.25
$O\text{-}PO_4$	9	809	89.9	3.98
As	2	182	91.0	1.85

Table 7.16: Multiple comparison between TSS and pollutants (SOC3)

Comparison	R_B-R_A	SE	Q	$Q_{.05,14}$	Conclusion
TSS vs As	99.3	36.23	2.739	3.456	Accept
TSS vs Cr	9.5	24.77	0.385	3.456	Accept
TSS vs Cu	5.5	24.77	0.220	3.456	Accept
TSS vs NH_3	13.2	24.77	0.534	3.456	Accept
TSS vs Ni	18.7	26.19	0.715	3.456	Accept
TSS vs NO_3/NO_2	43.3	24.77	1.747	3.456	Accept
TSS vs O-PO_4	99.1	24.77	4.001	3.456	Reject
TSS vs Pb	1.9	25.08	0.075	3.456	Accept
TSS vs Ti	16.2	24.77	0.655	3.456	Accept
TSS vs TKN	0.4	24.48	0.015	3.456	Accept
TSS vs TP	22.3	24.48	0.911	3.456	Accept
TSS vs V	7.1	24.77	0.286	3.456	Accept
TSS vs Zn	29.0	24.77	1.173	3.456	Accept

Table 7.17: Multiple comparison between TSS and pollutants (SOC4)

Comparison	R_B-R_A	SE	Q	$Q_{.05,14}$	Conclusion
TSS vs As	56.0	22.97	2.438	3.456	Accept
TSS vs Cr	19.3	15.16	1.275	3.456	Accept
TSS vs Cu	8.9	13.88	0.639	3.456	Accept
TSS vs NH_3	4.0	13.43	0.298	3.456	Accept
TSS vs Ni	7.3	19.46	0.377	3.456	Accept
TSS vs NO_3/NO_2	10.4	13.43	0.778	3.456	Accept
TSS vs O-PO_4	54.9	13.43	4.087	3.456	Reject
TSS vs Pb	38.3	19.46	1.970	3.456	Accept
TSS vs Ti	16.6	13.43	1.233	3.456	Accept
TSS vs TKN	11.1	13.43	0.827	3.456	Accept
TSS vs TP	29.1	13.43	2.168	3.456	Accept
TSS vs V	17.6	14.45	1.216	3.456	Accept
TSS vs Zn	6.3	14.45	0.438	3.456	Accept

7.8 Evaluation of Treatable Annual Pollutant Load for FF Design Volumes

Summary statistics for all 56 storm events that occurred during the study year (September 1, 2005 – August 31, 2006) are included in Table 7.18. Note that the values for runoff volume include the 11 events estimated using the rainfall/runoff regression equations. Table 7.19 shows the runoff volumes calculated for each of the four design storms using the NRCS Curve Number Method. The table includes the discrete runoff volumes calculated for each land use in the impervious watershed (SOC3).

Table 7.18: Summary statistics for all 56 storms occurring during evaluation year

Rainfall Characteristic	*High*	*Low*	*Mean*	*Median*
Depth (cm)	18.2	0.10	1.74	1.05
Runoff Volume (m^3)	2691	15	269	129

Table 7.19: Runoff volumes calculated for design storms on SOC3

Land Use	**CN**	**Area (m^2)**	**Q (m^3)**			
			1.3	**1.9**	**2.5**	**3.2**
Road	98	12,748	138	214	289	378
Lawn	61	2,995	0.01	7.0	25.0	56.6
Wooded	60	3,683	0.02	5.7	22.2	52.1
Total	**86**	**19,426**	**138**	**226**	**337**	**487**

Figures 7.13 through 7.16 display the percentages of annual load potentially treated by FF BMPs designed to capture runoff from either the first 1.3, 1.9, 2.5, or 3.2 cm's of rainfall by utilizing data from SOC3. For all FF design volumes, NH_3 and NO_3/NO_2 have the greatest annual load available for treatment while Cr, Ti and O-PO_4 have the least amount. By not including the outlier tropical storm, the yearly load treatment is substantially increased, as shown by Figures 7.17 and 7.20. All figures include a line representing the percent of annual runoff volume potentially captured by the associated first flush BMP. Pollutants with treatable annual load percentages above the captured runoff volume line represent some degree of an overall first flush effect for the year while those below it (e.g., O-PO_4, Cr and Ti) represent an overall dilution effect.

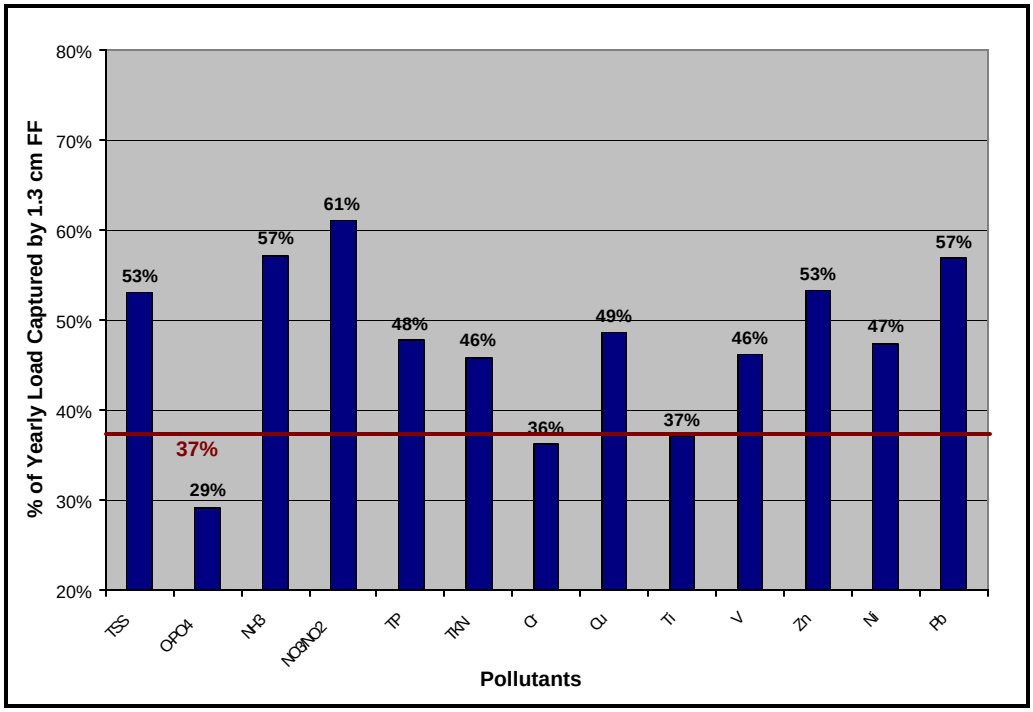

Figure 7.13: Percentages of TAPL for 1.3 cm FF BMP.
Includes impact of Tropical Storm Alberto (18.2 cm of rainfall)

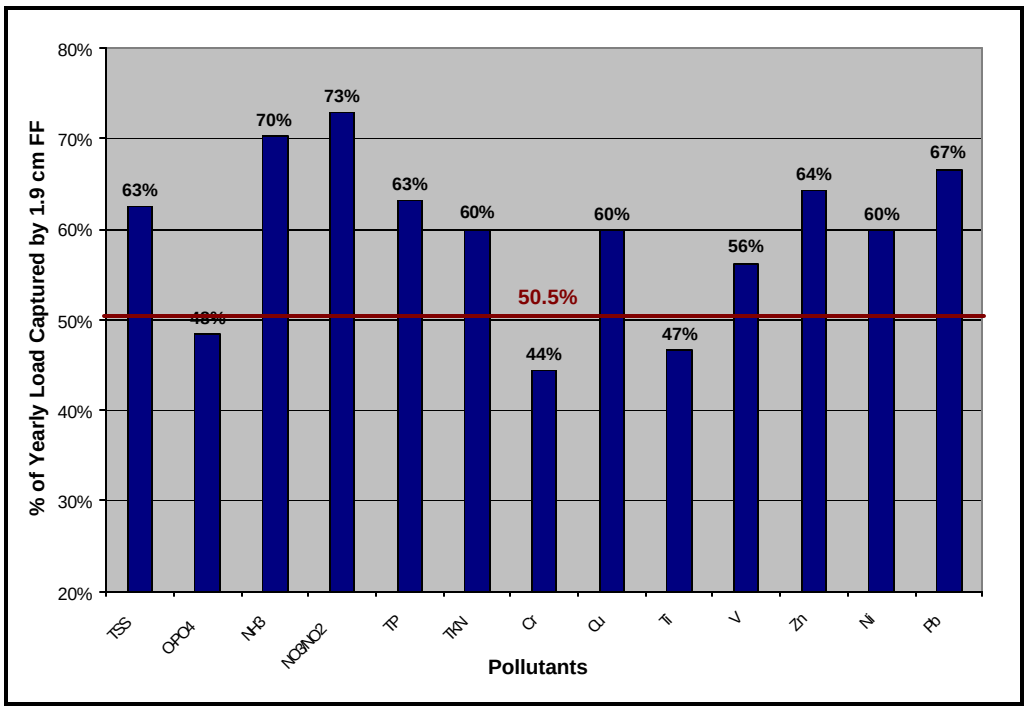

Figure 7.14: Percentages of TAPL for 1.9 cm FF BMP.
Includes impact of Tropical Storm Alberto (18.2 cm rainfall)

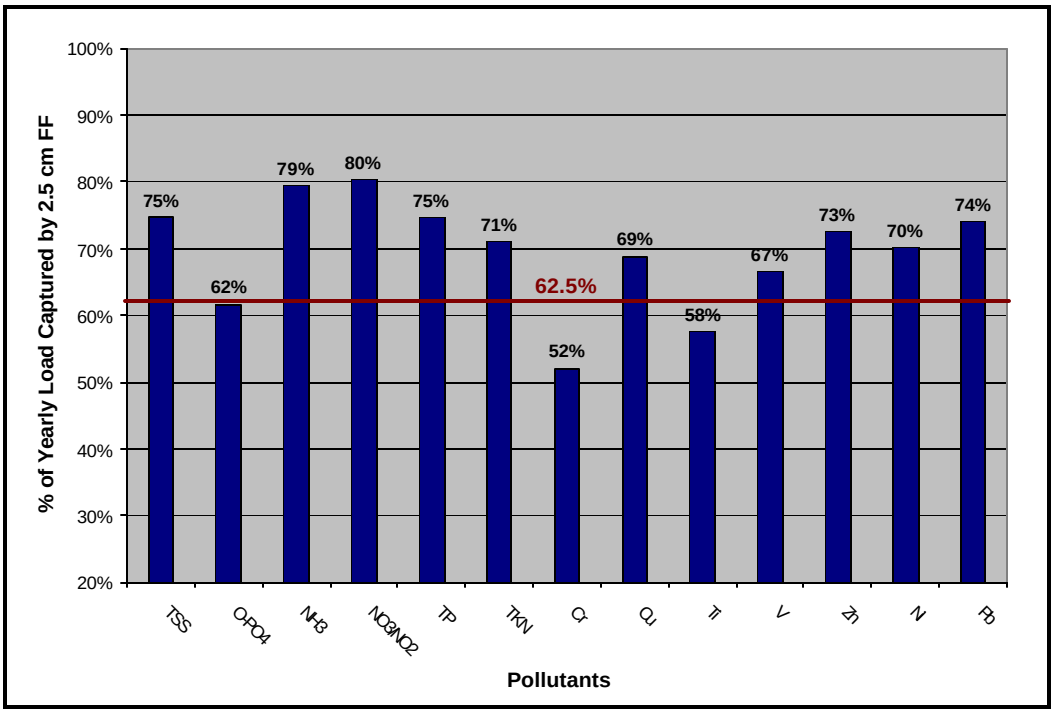

Figure 7.15: Percentages of TAPL for 2.5 cm FF BMP.
Includes impact of Tropical Storm Alberto (18.2 cm rainfall)

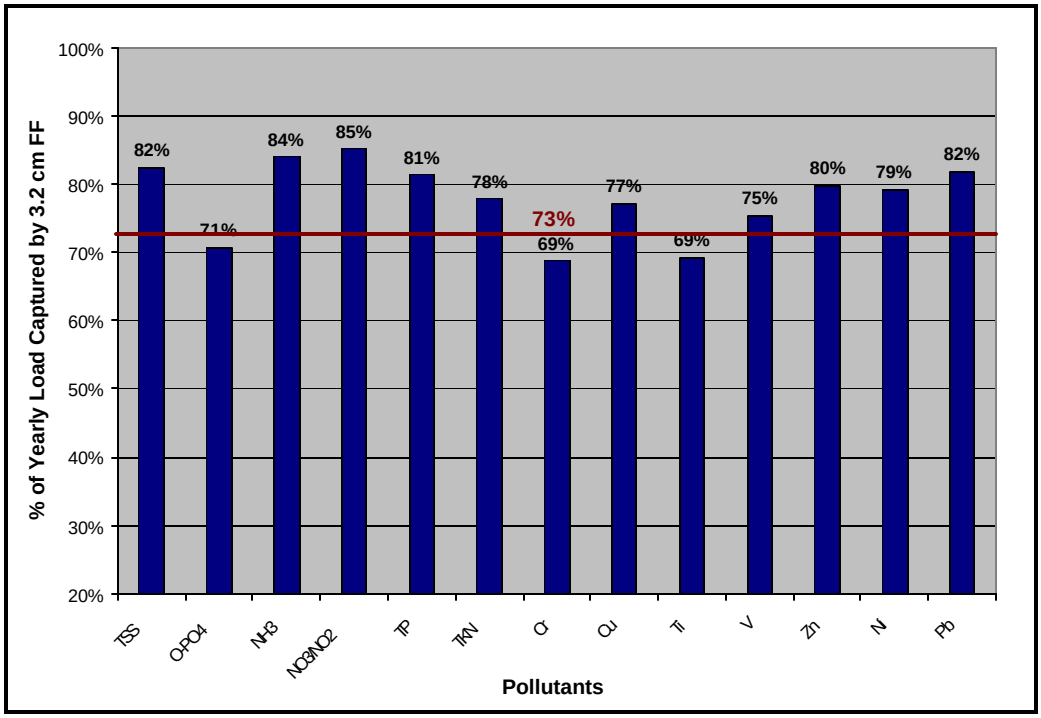

Figure 7.16: Percentages of TAPL for 3.2 cm FF BMP.
Includes impact of Tropical Storm Alberto (18.2 cm rainfall)

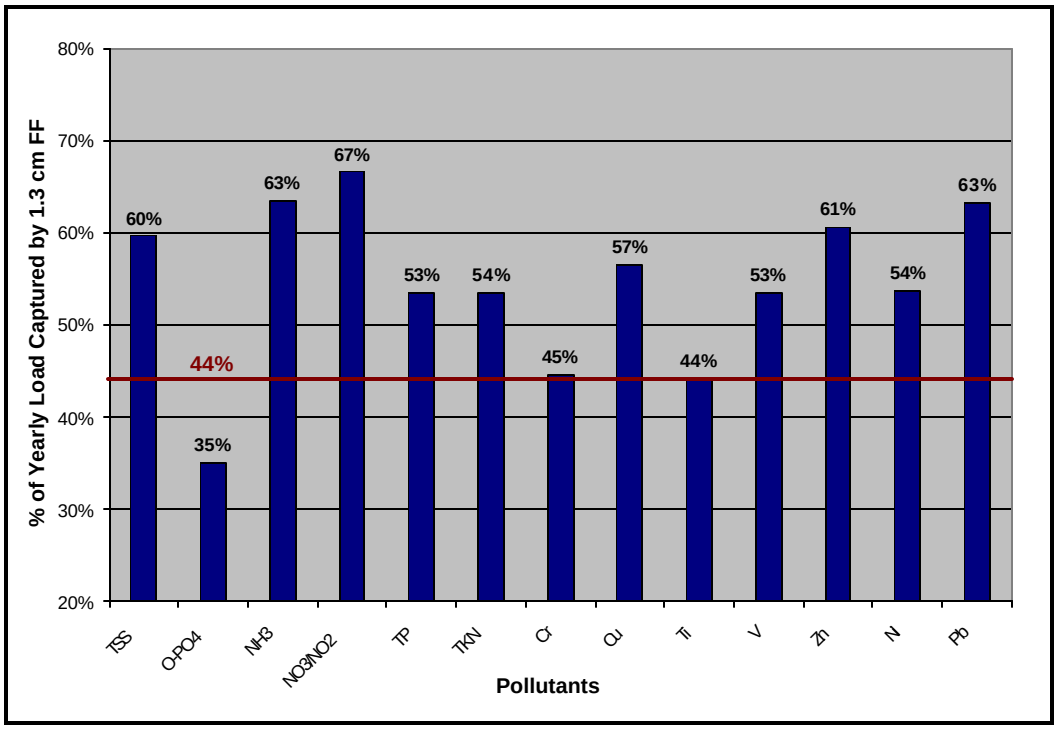

Figure 7.17: Percentage of TAPL for 1.3 cm BMP (minus outlier storm)

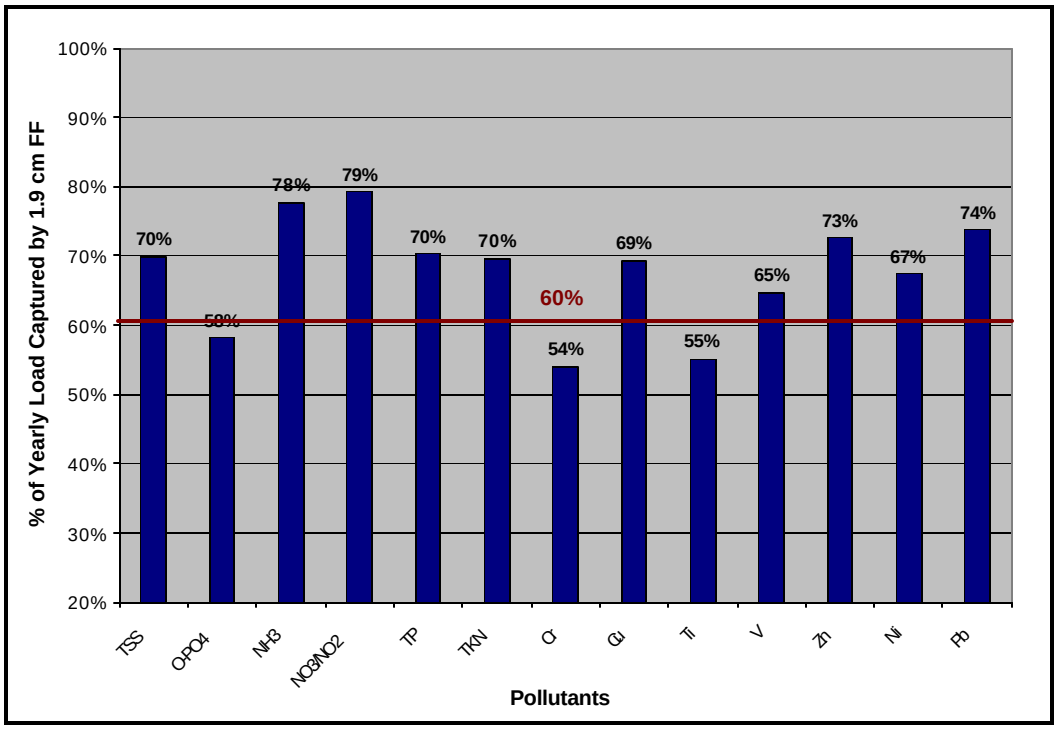

Figure 7.18: Percentage of TAPL for 1.9 cm BMP (minus outlier storm)

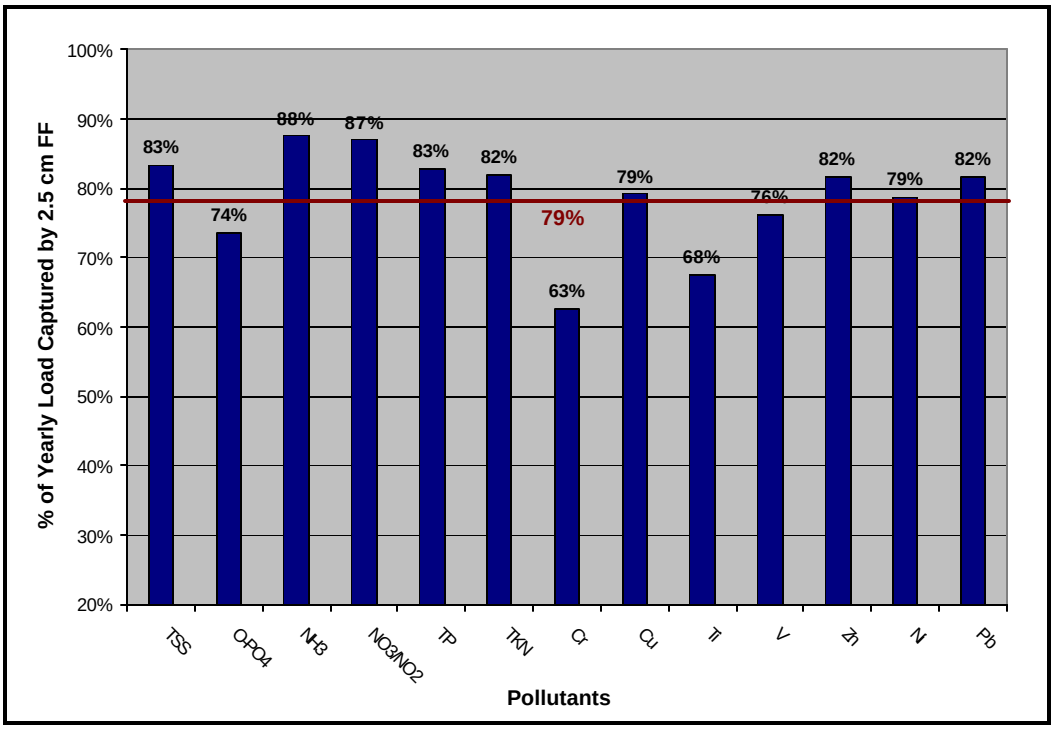

Figure 7.19: Percentage of total TAPL for 2.5 cm BMP (minus outlier storm)

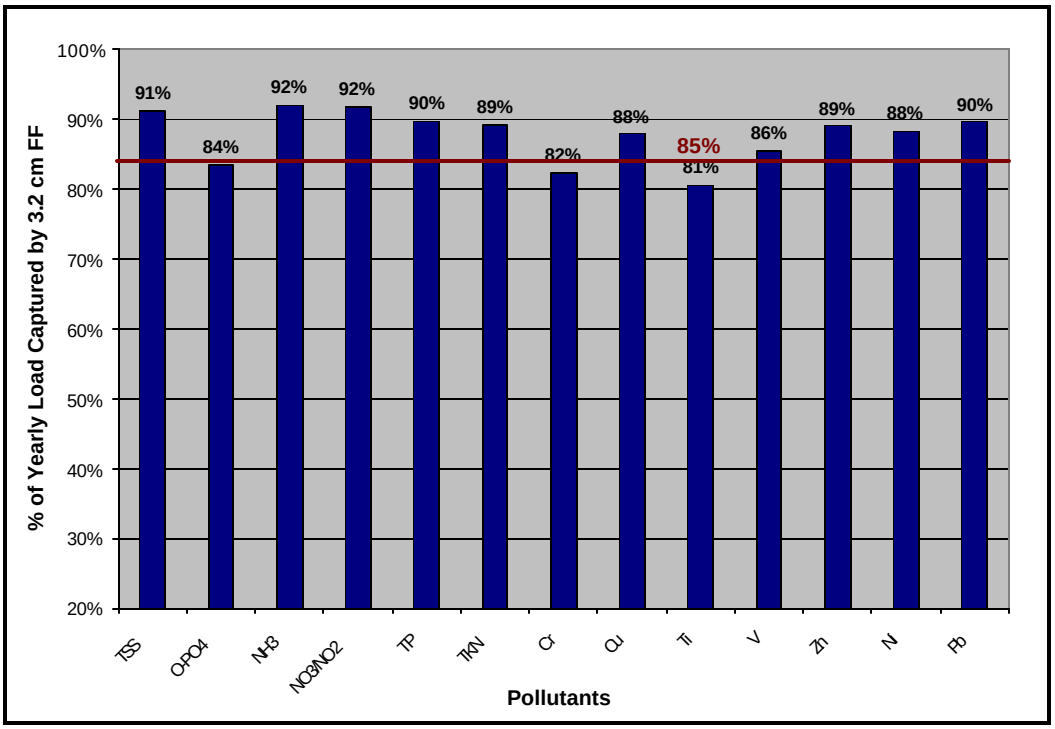

Figure 7.20: Percentage of TAPL for 3.2 cm BMP (minus outlier storm)

Tables 7.20 and 7.21 show a summary of the TAPL percentages for the major pollutants of concern in North Carolina (e.g., TSS, TN, TP). Included is the percent of total annual runoff captured by each BMP. Taking an average of the TAPL's for all the pollutants from the one year study, an estimated 48%, 60%, 70% and 78% of the annual pollutant load could have been captured and potentially treated by the 1.3 cm, 1.9 cm, 2.5 cm, and 3.2 cm FF BMP, respectively. Not including the outlying 18.2 cm tropical storm, approximately 54%, 68%, 79%, and 88% of the annual load could have potentially been captured for treatment by the FF BMPs. Either scenario shows an overall first flush effect in the average total runoff load over the course of the studied year since the fraction of captured load is greater than the corresponding fraction of captured runoff volume.

Table 7.20: TAPL percentages for major pollutants (including outlier storm)

Pollutant	BMP Design Volume			
	1.3 cm	1.9 cm	2.5 cm	3.2 cm
Runoff	*37*	*50.5*	*62.5*	*73*
TSS	53	63	75	82
$NO_3 + NO_2$	61	73	80	85
TKN	46	60	71	78
TP	48	63	75	81

Table 7.21: TAPL percentages for major pollutants (minus outlier storm)

Pollutant	BMP Design Volume			
	1.3 cm	1.9 cm	2.5 cm	3.2 cm
Runoff	*44*	*60*	*73*	*85*
TSS	60	70	83	91
$NO_3 + NO_2$	67	79	87	92
TKN	54	70	82	89
TP	53	70	83	90

8. Discussion

Consistent with much of the prior research regarding the first-flush phenomenon and the characteristics of pollutant load variations in stormwater runoff, this study found high inconsistency in the occurrence of the first flush effect for all definitions utilized. While the majority of the events exhibited some degree of first flush, pollutant loadings often remained uniform throughout the sampled storms. As convenient as a reliable and pronounced first flush occurrence would be to stormwater managers and practice engineers, the phenomenon simply is not pronounced. As a result, future BMP designs should consider the realistic nature of pollutant runoff in small urban watersheds as indicated by this study.

Defining the FF Volume

The first flush volume definition (Method 1) provided an average value that assesses the intensity of the FF effect for each pollutant, in addition to the fraction of runoff volume where this maximum FF intensity occurs. This study found the first 40% of the runoff volume to contain the largest deviation between the total pollutant load and total runoff volume for both watersheds. The practicality of this outcome is the "most efficient" design volume for BMP sizing (40% of total storm runoff), which is particularly pertinent in urban watersheds where land area is limited and/or expensive. The challenge, however, still remains in choosing the appropriate design storm to base the 40% of the total runoff volume. Ideally, statistical rainfall data should be utilized along with a safety factor to choose a storm size that contains around 90% of the rainfall events in that climatic region. For smaller watersheds (6 acres or less), this study concluded that sizing a BMP to capture 40% of a design storm's total runoff (e.g., 40% of runoff from 2.6 cm of rainfall by NC design recommendations) will potentially treat the most pollutants per unit volume of stored runoff. It is important to note, however, that capturing this most efficient runoff volume will not typically treat the majority of an event's total pollutant load as pollutant load delivered by the remaining 60% of the runoff can often be substantial, if not a majority. Consequently, pollutants exhibiting stronger and more frequent FF natures (e.g., TSS and Zn) will receive a higher percentage of treatment by capturing the first 40% compared to others.

When provided a minimum intensity value of 0.2 to define a first flush using Method 2 (i.e. fraction of total pollutant load must be greater than 20% of the total runoff volume at any point during a storm event), the first flush occurred for up to 56% of the events for TSS on SOC3 (roadway) and for up to 73% of the events for TSS on SOC4 (wooded). On average, the first flush was more common for heavy metals than nutrients on both watersheds. As previously mentioned, this definition does not limit the FF occurrence to any specific L' value. However, after combining the pollutants the Method 2 first flush occurred on average at approximately the first 32% of total runoff volume for both watersheds. This "most efficient" design volume is closely comparable to the result from Method 1.

L' Specific Definitions

Storms meeting the most restrictive of the conventional, L' specific, FF definitions were extremely rare. Only once was 80% of the pollutant load delivered in the first 30% of the runoff volume, which occurred for TSS and was an extreme outlier compared to the remaining 389 L'V' curves evaluated. Results from the less conservative definitions (e.g., 20/40 and 25/50) indicated a more frequent FF occurrence. These definitions occurred in up to 36% and 45% of the events for TSS on SOC3 and SOC4 but never for O-PO_4. The study by Flint and Davis (2007), which utilized the 25/50 FF criteria on a 0.56 ha, ultra urban drainage area, found somewhat similar FF frequencies, as shown by Table 8.1. While FF occurrences for TSS and Zn were considerably greater for this study on both watersheds, nutrient FF occurrences were significantly less frequent on the impervious watershed as compared to Flint and Davis (2007). The nitrogen species on the wooded watershed, however, exhibited FF frequencies similar to the ultra urban watershed studied by Flint and Davis (2007).

Table 8.1: Percentages of 25/50 FF occurrence

Pollutant	SOC3 (roadway)	SOC4 (wooded)	Flint and Davis, 2007 (ultra urban)
TSS	36	45	17
TP	9	0	27
NO_2^-	9	22	33
NO_3^-			22
TKN	9	22	22
Cu	9	12	21
Zn	32	22	14
Pb	14	0	13

Increasing the L' value to the first 30% of the runoff volume, the corresponding mean pollutant loads for the sampled events range from 25% (O-PO_4) to 48% (TSS). These mean values resemble those of Lee et al. (2005), whom found a weak FF effect in the first 30% of runoff volume with total pollutant loads ranging between 34-43%. Based on the results from this study, an overall dilutive effect occurs for the soluble O-PO_4 by the first 30% of the runoff volume while the remaining pollutants have a slight first flush effect, with TSS and Zn being the most pronounced. These results indicate that FF treatment is not very promising; implying that treatment of the majority of an events pollutant load typically requires the capture of almost the equal fraction of total runoff volume.

First Flush Strength Analysis

Saget et al. (1996) suggested ranges of *b*-values that correspond to deviations from the 45º diagonal, and thus indicating the strength of the FF effect. First flush *b*-values greater than 0.185 and less than 0.862 represent a moderate first flush strength, while values greater than 0.862 and less than 1.0 correspond to a weak first flush; according to Saget et al. (1996). Likewise, *b*-values greater than 1.0 but less than 1.159 indicates a weak dilution effect and values greater than 1.159 and less than 5.395 indicate a moderate dilution effect. When analyzed for the combined watersheds, all of the pollutants from this study except O-PO_4,

NO_3/NO_2, and As have average *b*-values (0.67-0.85) that fit into the weaker end of the moderate FF range, while NO_3/NO_2 fits into the weak FF range, As in the weak dilution range, and O-PO_4 in the moderate dilution range (b = 1.19). A rank of these average *b*-values determines which pollutants will have higher capture and potential treatment in a given BMP.

Effect of Land Use on FF Strength

The FF *b*-value results are the same when analyzed by watershed, except Pb has an overall moderate FF effect on SOC 3 (Least Squared mean = 0.74) but a weak FF effect on SOC4 (Least Squared mean = 1.05). As a result, only for Pb (out of 14 total pollutants analyzed) can a higher proportion of load be expected in the initial portion of a storm's runoff volume as a watershed's impervious area increases. These results concur with most of the previous studies, which found no significant relationships between FF strength and watershed characteristics for the pollutants analyzed.

Influence of Rainfall/Runoff Characteristics

Although multiple rainfall/runoff characteristics have proven to influence the FF effect in other previous studies using various FF definitions, this study only found rainfall depth and runoff volume to influence the FF strength (*b*-value) on the impervious watershed (SOC3). In contrast to other studies, this study showed that these two characteristics are inversely related to FF strength for TSS and heavy metals but directly related to the FF strength of O-PO_4. Although the runoff loadings for O-PO_4 had more of a dilution effect within the first portion of each storm rather than a first flush effect, the relative strength of O-PO_4's FF effect increases as rainfall or runoff increases. Not only is O-PO_4 in a dissolved phase in stormwater runoff, but it was also the only pollutant in this study that had a statistically weaker FF flush based on the *b*-values than the other pollutants. The only suggestion is that it takes higher volumes of rainfall before O-PO_4 becomes available for runoff. In concurrence with most other similar studies (Geiger, 1984; Saget et al., 1996; Gupta and Saul, 1996; Lee et al., 2002), neither antecedent dry-weather period nor rainfall intensity significantly affected the FF strength in this study. These findings further contribute to previous conclusions that the nature of the FF phenomenon is complex and site specific, and

no universal set of rainfall or watershed characteristics can be used to predict the frequency or strength of its occurrence.

Pollutant Comparison for FF Strength

Based on the methods and definitions analyzed, the FF effect appeared on average to be more pronounced and more frequent for TSS, followed by Zn and NH_3. Using a nonparametric ANOVA, the FF strength (*b*-value, Method 3) was evaluated for statistical differences between the pollutants in each watershed. When analyzed separately, the test indicated sufficient evidence that one of the nutrients had a different FF strength compared to the others on both watersheds, while no difference was indicated between the metals. The multiple comparisons with TSS showed that only O-PO_4 had a FF nature that significantly deviated from that of suspended sediment. As a result, the treatment percentages of the other pollutants will be similar to that of TSS for a particular storm event. Considering the diluted runoff nature of O-PO_4 at the beginning of a storm, the capture and treatment of the majority of the O-PO_4 runoff load will thus require the capture of the majority of a storm's runoff volume.

It can not be assumed from this study that the particulate-bound pollutants exhibited a more frequent FF occurrence compared to the dissolved pollutants. This study only analyzed for particulate bound metals, neglecting the dissolved fraction, but found significant FF occurrences for the heavy metals (except As) as a whole compared to the dissolved nutrients. Two previous studies (Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997) compared the FF nature of heavy metals partitioned as either dissolved or particulate bound phases. Both studies found a strong first flush effect for the predominately dissolved metals (Zn, Cd, Cu) while the runoff behavior of the particulate bound metals (Pb) either showed a weak FF effect or followed that of the suspended solids. Due to lab analysis protocols, it was not possible to separately analyze heavy metals for both phases in this study. Future work, however, should account for this dualistic association of heavy metals in stormwater runoff.

Yearly Treatable Load

The results from this study should be reassuring to stormwater managers in North Carolina, where runoff from the 2.5 cm (1 inch) of rainfall is the standard for sizing BMPs. The estimations used in this study predicted that a BMP sized to capture runoff from the first 2.5 cm of rainfall can potentially treat anywhere between 63% and 88% of the total annual pollutant load depending on the pollutant and approximately 73% of the yearly runoff volume from the impervious drainage area. In situations where land area is severely limited for BMP construction and design volumes are limited to runoff from the first 1.3 cm (0.5 inch) FF of rainfall, between 35% and 67% (54% average) of the annual pollutant load and 44% of the yearly runoff volume is available for treatment. These predictions disregard the large outlying tropical storm whose pollutant loads and treatment percentages could not be accurately estimated, thus justifying exclusion from the analysis. In addition, stormwater BMPs are not designed to capture and treat the large 50-year or greater storms (even though they can contribute a considerable fraction of total annual load) so it is of more practical importance to know the treatable load from the majority of the yearly storm events.

For all the pollutants except NO_3/NO_2, the TAPL results were as expected based on the FF analysis. NO_3/NO_2 is generally a weak FF pollutant on SOC3 but had the highest TAPL values among the pollutants for all four design storms. Although the relationship between FF strength and runoff volume was insignificant for NO_3/NO_2, the average *b*-values for the storms exceeding the design value (and thus untreatable bypass) has noticeably lower *b*-values than the smaller storms that yielded no flow bypass. Using the 1.9 cm TAPL analysis as an examble, the average *b*-value for the bypass storms was 0.81 (moderate FF) while the average *b*-value for no-bypass storms was 1.13 (weak dilution). As a result, most of the annual NO_3/NO_2 load can be assumed to be associated with the smaller storms although the FF effect within the smaller storms is typically weak.

Compared to the study by Flint and Davis (2007), the mean percents of annual pollutant load associated with runoff from the first 1.3 cm of rainfall were considerably less in this study as shown by Table 8.2. Out of the 32 storm events sampled by Flint and Davis (2007) during a

16 month study, 16 events were less than 1.3 cm of runoff (corresponding to 100% pollutant containment). This study sampled 25 events over a 12 month study but used regression equations to estimate the pollutant loads and fractions of the load associated with the first 1.3 cm of runoff for the missing events during that 1-year period. Of the 25 sampled events, only 9 were less than the 1.3 cm of runoff.

Table 8.2: Mean percent of load in first 1.3 cm of runoff compared to Flint and Davis (2007)

Pollutant	This Study (SOC3-impervious)	Flint and Davis (2007)
TSS	60	81
TP	53	86
NO_2^- & NO_3^-	67	82
TKN	54	85
Cu	57	86
Zn	61	86
Pb	63	86

In addition, the fraction of annual runoff volume to the total pollutant load captured by each BMP size was calculated in order to compare how the FF efficiencies vary as BMP volume increases (see Table 8.3). Low fraction values indicate strong FF effects for the portion of runoff captured during the studied year, while a value of 1 indicates overall uniform pollutant loading for the year. An overall FF effect was observed on the impervious watershed during the studied year for all BMP volumes, although the FF effect decreases as the BMP volume increases. Table 8.3 also shows the percent increase in annual runoff volume and load associated with each BMP design storm value above 1.3 cm. The largest water quality returns are yielded by increasing the BMP design volume to 1.9 cm of runoff, with diminishing returns thereafter as BMP volume increases.

Table 8.3: Efficiency comparisons for FF BMP volumes

BMP Design Value	Annual Runoff Volume/Load Fraction	% Annual Volume Increase	% Load Increase
1.3 cm	0.81	Base storm	Base storm
1.9 cm	0.88	15.5	14
2.5 cm	0.93	13.7	13
3.2 cm	0.97	11.6	7

To help determine the validity of these findings, the magnitude and frequency of the observed storms during the study were compared to historical rainfall data. Out of the 56 events that occurred during the studied year, the number of events that had precipitation depths greater than 0.3, 1.3, and 2.6 cm's were 45, 21, and 13, respectively. Historical rainfall frequencies collected from a gage at Raleigh Durham International Airport during 1971-2000 indicated that the yearly average number of storms exceeding these rainfall depths is 62, 29.8 and 11.2. The observed storms differ from the historical averages by -27.4%, -29.5% and +16.1%, indicating that the observed events less than 2.6 cm were noticeably less than the average historical occurrence. As a result, the percent of yearly treatable pollutant load was likely underestimated compared to the 'normal' rainfall year.

Importance of Findings

As indicated by all the methods utilized in this study, most pollutants exhibit a slight FF effect on average, but significant pollutant loading still occurs in the latter portion of a storms total runoff volume. Thus, treatment of the majority of a storm's total pollutant load requires capturing almost the same fraction of runoff volume. Although stormwater BMPs designed to capture the first 2.5 cm of rainfall can potentially treat a significant fraction of yearly pollutant load, this study suggests that in limited/expensive land area watersheds it is more efficient to use multiple smaller BMPs near the source that are sized to capture the smaller, more frequent storms (1.9 cm of rainfall or less). Based on this study for the year evaluated, increasing the design volume by 100% from 1.3 cm to 2.5 cm of rainfall only captured 24% more pollutant load and 29% more runoff volume on average, during the year 9/1/05 to

9/1/06. The first 1.3 cm of rainfall corresponds to the "most efficient" capture volume determined by Methods 1 and 2 (first 40% of runoff), assuming 2.5 cm of rainfall is used as the water quality design volume.

Disregarding long-term maintenance costs, it is often more cost and treatment efficient in urban areas to implement smaller (undersized) BMPs into the landscape and architecture in lieu of using large-scale controls that require much larger parcels of land. These smaller BMPs can be installed in areas like road and parking lot medians that are close to the runoff source. This design approach is referred to as source reduction, which is similar to the design methods defined by Low Impact Development (LID) where runoff is controlled on a micro-scale using multiple decentralized BMPs that are distributed throughout the watershed closer to the pollutant source. Using treatment goals of retention, storage, evapotranspiration and infiltration, discharge volumes are drastically reduced through LID practices and the pre-development hydrology can be better reproduced (Coffman et al., 1998). If stormwater BMPs are to be designed according to the "most efficient" design volume (40% of runoff or 1.3 cm of rainfall as related to this study), the overflow from the larger storms still requires management and treatment downgradient in the watershed. However, the subsequent BMPs receiving the runoff overflow will require substantially less land area and the influent stormwater (effluent and/or overflow from initial BMPs) may have received some prior treatment and energy/discharge dissipation.

Suggested NC DENR Credits

According to the N.C. Department of Environment and Natural Resources (NC DENR), constructed stormwater wetlands, for example, receive pollutant removal credits of 85%, 40%, and 35% for TSS, TN, and TP, respectively, when sized to capture runoff from the first 2.5 cm of rainfall. Using the TAPL results calculated from this study, alternative pollutant removal credits were calculated for 2 undersized BMPs and 1 oversized BMP relative to the credits currently received for the recommended 2.5 cm design storm. Note that this calculation assumes that undersized BMPs (e.g., constructed wetlands) have the same pollutant removal efficiencies as a BMP sized for the 2.5 cm storm.

Table 8.4: Suggested NC DENR credits for alternatively sized constructed wetlands

TSS	1.3 cm	1.9 cm	2.5 cm	3.2 cm
Annual Load Captured (kg)	740	868	1033	1132
x 85% Load Treated (kg)	629	738	878	962
Suggested Credit	61%	71%	85%	93%
TN	**1.3 cm**	**1.9 cm**	**2.5 cm**	**3.2 cm**
Annual Load Captured (kg)	14.4	18.4	21.4	23.2
x 40% Load Treated (kg)	5.8	7.4	8.6	9.3
Suggested Credit	27%	34%	40%	43%
TP	**1.3 cm**	**1.9 cm**	**2.5 cm**	**3.2 cm**
Annual Load Captured (kg)	1.6	2.0	2.4	2.6
x 35% Load Treated (kg)	0.56	0.70	0.84	0.91
Suggested Credit	23%	29%	35%	38%

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Appendices

Appendix 1. First Flush Characterization for all Pollutants from Storm Water Outfalls SOC3 and SOC4

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	10/6/05	TSS	0.91	0.046		1.02	0.48	16	1760	211,300	57.33
SOC3	10/6/05	$O\text{-}PO_4$	0.87	0.044		1.02	0.48	16	1760	211,300	0.092
SOC3	10/6/05	NH_3	0.61	0.261	0.33	1.02	0.48	16	1760	211,300	0.328
SOC3	10/6/05	NO_3/NO_2	0.56	0.203	0.17	1.02	0.48	16	1760	211,300	0.183
SOC3	10/6/05	TP	0.93	0.026		1.02	0.48	16	1760	211,300	0.129
SOC3	10/6/05	TKN	0.78	0.142		1.02	0.48	16	1760	211,300	0.632
SOC3	10/6/05	Cr	1.88	0.277	0.67	1.02	0.48	16	1760	211,300	0.035
SOC3	10/6/05	Cu	0.82	0.066		1.02	0.48	16	1760	211,300	0.012
SOC3	10/6/05	Ti	0.96	0.028		1.02	0.48	16	1760	211,300	0.189
SOC3	10/6/05	V	0.80	0.079		1.02	0.48	16	1760	211,300	0.014
SOC3	10/6/05	Zn	0.81	0.068		1.02	0.48	16	1760	211,300	0.049
SOC3	10/6/05	Ni	0.83	0.066		1.02	0.48	16	1760	211,300	0.003
SOC3	10/6/05	Pb	0.98	0.023		1.02	0.48	16	1760	211,300	0.008
SOC3	11/21/05	TSS	1.04	0.073		2.46	0.24	4	2344	260,200	81.63
SOC3	11/21/05	$O\text{-}PO_4$	0.82	0.095		2.46	0.24	4	2344	260,200	0.191
SOC3	11/21/05	NH_3	0.70	0.149		2.46	0.24	4	2344	260,200	0.323
SOC3	11/21/05	NO_3/NO_2	0.91	0.042		2.46	0.24	4	2344	260,200	0.233
SOC3	11/21/05	TP	0.83	0.072		2.46	0.24	4	2344	260,200	0.244
SOC3	11/21/05	TKN	0.74	0.213	0.59	2.46	0.24	4	2344	260,200	4.263
SOC3	11/21/05	Cr	1.20	0.050		2.46	0.24	4	2344	260,200	0.005
SOC3	11/21/05	Cu	0.94	0.058		2.46	0.24	4	2344	260,200	0.011
SOC3	11/21/05	Ti	1.24	0.061		2.46	0.24	4	2344	260,200	0.271
SOC3	11/21/05	V	1.04	0.058		2.46	0.24	4	2344	260,200	0.013
SOC3	11/21/05	Zn	0.82	0.073		2.46	0.24	4	2344	260,200	0.052
SOC3	11/21/05	Ni	1.00	0.057		2.46	0.24	4	2344	260,200	0.003
SOC3	11/21/05	Pb	1.12	0.077		2.46	0.24	4	2344	260,200	0.006
SOC3	11/29/05	TSS	1.03	0.092		1.40	0.72	1	3458	186,400	124.42
SOC3	11/29/05	$O\text{-}PO_4$	1.09	0.227	0.33	1.40	0.72	1	3458	186,400	0.177
SOC3	11/29/05	TP	1.24	0.013		1.40	0.72	1	3458	186,400	0.267
SOC3	11/29/05	TKN	0.91	0.043		1.40	0.72	1	3458	186,400	1.324
SOC3	11/29/05	Cr	0.93	0.064		1.40	0.72	1	3458	186,400	0.009
SOC3	11/29/05	Cu	1.00	0.060		1.40	0.72	1	3458	186,400	0.015
SOC3	11/29/05	Ti	1.01	0.050		1.40	0.72	1	3458	186,400	0.496
SOC3	11/29/05	V	1.00	0.070		1.40	0.72	1	3458	186,400	0.020
SOC3	11/29/05	Zn	0.81	0.115		1.40	0.72	1	3458	186,400	0.063
SOC3	11/29/05	As	1.29	0.000		1.40	0.72	1	3458	186,400	0.002
SOC3	11/29/05	Ni	0.98	0.054		1.40	0.72	1	3458	186,400	0.004
SOC3	11/29/05	Pb	0.74	0.157		1.40	0.72	1	3458	186,400	0.013

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	12/5/05	TSS	1.11	0.050		1.73	0.48	6	1326	193,700	54.71
SOC3	12/5/05	$O\text{-}PO_4$	1.22	0.000		1.73	0.48	6	1326	193,700	0.057
SOC3	12/5/05	NH_3	1.15	0.000		1.73	0.48	6	1326	193,700	0.155
SOC3	12/5/05	NO_3/NO_2	0.99	0.019		1.73	0.48	6	1326	193,700	0.164
SOC3	12/5/05	TP	0.78	0.251	0.50	1.73	0.48	6	1326	193,700	0.354
SOC3	12/5/05	TKN	0.94	0.192		1.73	0.48	6	1326	193,700	1.516
SOC3	12/5/05	Cr	1.12	0.013		1.73	0.48	6	1326	193,700	0.004
SOC3	12/5/05	Cu	1.02	0.009		1.73	0.48	6	1326	193,700	0.008
SOC3	12/5/05	Ti	1.23	0.020		1.73	0.48	6	1326	193,700	0.274
SOC3	12/5/05	V	1.12	0.022		1.73	0.48	6	1326	193,700	0.011
SOC3	12/5/05	Zn	0.86	0.080		1.73	0.48	6	1326	193,700	0.038
SOC3	12/5/05	As	1.16	0.000		1.73	0.48	6	1326	193,700	0.002
SOC3	12/5/05	Ni	1.16	0.011		1.73	0.48	6	1326	193,700	0.002
SOC3	12/5/05	Pb	1.02	0.039		1.73	0.48	6	1326	193,700	0.006
SOC4	12/9/05	TSS	0.86	0.215	0.71	0.61	2.16	3	777	10,300	63.57
SOC4	12/9/05	$O\text{-}PO_4$	0.62	0.159		0.61	2.16	3	777	10,300	0.055
SOC4	12/9/05	NH_3	0.72	0.196		0.61	2.16	3	777	10,300	0.525
SOC4	12/9/05	NO_3/NO_2	0.68	0.171		0.61	2.16	3	777	10,300	0.425
SOC4	12/9/05	TP	0.78	0.189		0.61	2.16	3	777	10,300	0.155
SOC4	12/9/05	TKN	0.87	0.041		0.61	2.16	3	777	10,300	0.857
SOC4	12/9/05	Cr	0.83	0.114		0.61	2.16	3	777	10,300	0.002
SOC4	12/9/05	Cu	0.66	0.202	0.29	0.61	2.16	3	777	10,300	0.005
SOC4	12/9/05	Ti	0.82	0.165		0.61	2.16	3	777	10,300	0.123
SOC4	12/9/05	V	0.82	0.138		0.61	2.16	3	777	10,300	0.005
SOC4	12/9/05	Zn	0.71	0.156		0.61	2.16	3	777	10,300	0.037
SOC4	12/9/05	Pb	0.84	0.092		0.61	2.16	3	777	10,300	0.003
SOC3	12/15/05	TSS	1.03	0.098		1.59	2.52	6	1570	183,300	80.50
SOC3	12/15/05	$O\text{-}PO_4$	0.95	0.021		1.59	2.52	6	1570	183,300	0.109
SOC3	12/15/05	NH_3	0.64	0.175		1.59	2.52	6	1570	183,300	0.255
SOC3	12/15/05	NO_3/NO_2	0.95	0.029		1.59	2.52	6	1570	183,300	0.306
SOC3	12/15/05	TP	0.96	0.029		1.59	2.52	6	1570	183,300	0.204
SOC3	12/15/05	TKN	0.85	0.057		1.59	2.52	6	1570	183,300	1.152
SOC3	12/15/05	Cr	1.04	0.044		1.59	2.52	6	1570	183,300	0.006
SOC3	12/15/05	Cu	0.95	0.045		1.59	2.52	6	1570	183,300	0.010
SOC3	12/15/05	Ti	1.18	0.039		1.59	2.52	6	1570	183,300	0.365
SOC3	12/15/05	V	1.09	0.044		1.59	2.52	6	1570	183,300	0.014
SOC3	12/15/05	Zn	0.78	0.103		1.59	2.52	6	1570	183,300	0.054
SOC3	12/15/05	As	1.22	0.017		1.59	2.52	6	1570	183,300	0.002
SOC3	12/15/05	Ni	1.00	0.042		1.59	2.52	6	1570	183,300	0.003
SOC3	12/15/05	Pb	0.95	0.059		1.59	2.52	6	1570	183,300	0.007
SOC4	12/18/05	TSS	0.25	0.45	0.08	0.34	1.20	3	237	46,000	18.917

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	1/14/06	TSS	0.51	0.311	0.57	0.43		11	2614	56,000	422.43
SOC3	1/14/06	$O\text{-}PO_4$	1.44	0.000		0.43		11	2614	56,000	0.034
SOC3	1/14/06	NH_3	0.74	0.123		0.43		11	2614	56,000	0.187
SOC3	1/14/06	NO_3/NO_2	0.84	0.114		0.43		11	2614	56,000	0.265
SOC3	1/14/06	TP	0.76	0.168		0.43		11	2614	56,000	0.446
SOC3	1/14/06	TKN	0.75	0.156		0.43		11	2614	56,000	1.544
SOC3	1/14/06	Cr	0.55	0.260	0.29	0.43		11	2614	56,000	0.009
SOC3	1/14/06	Cu	0.56	0.229	0.29	0.43		11	2614	56,000	0.027
SOC3	1/14/06	Ti	0.52	0.278	0.29	0.43		11	2614	56,000	0.246
SOC3	1/14/06	V	0.53	0.281	0.29	0.43		11	2614	56,000	0.029
SOC3	1/14/06	Zn	0.50	0.441	0.29	0.43		11	2614	56,000	0.133
SOC3	1/14/06	Ni	0.53	0.314	0.29	0.43		11	2614	56,000	0.005
SOC3	1/14/06	Pb	0.55	0.269	0.29	0.43		11	2614	56,000	0.016
SOC3	1/18/06	TSS	0.08	0.751	0.09	0.44	2.16	4	2779	94,000	274.62
SOC3	1/18/06	$O\text{-}PO_4$	1.14	0.000		0.44	2.16	4	2779	94,000	0.032
SOC3	1/18/06	NH_3	0.61	0.235	0.34	0.44	2.16	4	2779	94,000	0.279
SOC3	1/18/06	NO_3/NO_2	0.57	0.272	0.34	0.44	2.16	4	2779	94,000	0.247
SOC3	1/18/06	TP	0.49	0.300	0.17	0.44	2.16	4	2779	94,000	0.151
SOC3	1/18/06	TKN	0.59	0.210	0.26	0.44	2.16	4	2779	94,000	1.026
SOC3	1/18/06	Cr	0.27	0.512	0.17	0.44	2.16	4	2779	94,000	0.002
SOC3	1/18/06	Cu	0.37	0.366	0.17	0.44	2.16	4	2779	94,000	0.007
SOC3	1/18/06	Ti	0.27	0.507	0.17	0.44	2.16	4	2779	94,000	0.058
SOC3	1/18/06	V	0.31	0.468	0.17	0.44	2.16	4	2779	94,000	0.007
SOC3	1/18/06	Zn	0.22	0.552	0.17	0.44	2.16	4	2779	94,000	0.031
SOC3	1/18/06	Pb	0.31	0.459	0.17	0.44	2.16	4	2779	94,000	0.004
SOC3	1/31/06	TSS	0.45	0.320	0.44	0.32	0.24	8	910	36,000	75.00
SOC3	1/31/06	$O\text{-}PO_4$	1.24	0.002		0.32	0.24	8	910	36,000	0.034
SOC3	1/31/06	NH_3	0.62	0.174		0.32	0.24	8	910	36,000	0.517
SOC3	1/31/06	NO_3/NO_2	0.73	0.131		0.32	0.24	8	910	36,000	0.570
SOC3	1/31/06	TP	0.79	0.085		0.32	0.24	8	910	36,000	0.123
SOC3	1/31/06	TKN	0.68	0.144		0.32	0.24	8	910	36,000	1.550
SOC3	1/31/06	Cr	0.64	0.204	0.44	0.32	0.24	8	910	36,000	0.002
SOC3	1/31/06	Cu	0.64	0.174		0.32	0.24	8	910	36,000	0.021
SOC3	1/31/06	Ti	0.63	0.222	0.44	0.32	0.24	8	910	36,000	0.056
SOC3	1/31/06	V	0.60	0.245	0.44	0.32	0.24	8	910	36,000	0.007
SOC3	1/31/06	Zn	0.45	0.317	0.44	0.32	0.24	8	910	36,000	0.036
SOC3	1/31/06	Ni	0.62	0.225	0.44	0.32	0.24	8	910	36,000	0.001
SOC3	1/31/06	Pb	0.63	0.199		0.32	0.24	8	910	36,000	0.005

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	2/4/06	TSS	1.28	0.000		0.80	2.28	2	2197	77,700	335.916
SOC3	2/4/06	O-PO_4	1.13	0.096		0.80	2.28	2	2197	77,700	0.027
SOC3	2/4/06	NH_3	0.87	0.068		0.80	2.28	2	2197	77,700	0.253
SOC3	2/4/06	NO_3/NO_2	0.86	0.083		0.80	2.28	2	2197	77,700	0.205
SOC3	2/4/06	TP	1.30	0.000		0.80	2.28	2	2197	77,700	0.264
SOC3	2/4/06	TKN	1.05	0.009		0.80	2.28	2	2197	77,700	1.851
SOC3	2/4/06	Cr	1.25	0.000		0.80	2.28	2	2197	77,700	0.008
SOC3	2/4/06	Cu	0.89	0.073		0.80	2.28	2	2197	77,700	0.015
SOC3	2/4/06	Ti	1.39	0.000		0.80	2.28	2	2197	77,700	0.248
SOC3	2/4/06	V	1.35	0.000		0.80	2.28	2	2197	77,700	0.027
SOC3	2/4/06	Zn	0.88	0.092		0.80	2.28	2	2197	77,700	0.055
SOC3	2/4/06	As	1.18	0.000		0.80	2.28	2	2197	77,700	0.001
SOC3	2/4/06	Ni	1.15	0.000		0.80	2.28	2	2197	77,700	0.004
SOC3	2/4/06	Pb	1.15	0.000		0.80	2.28	2	2197	77,700	0.013
SOC3	2/23/06	TSS	0.84	0.099		0.56	0.24	11	657	88,660	84.357
SOC3	2/23/06	O-PO_4				0.56	0.24	11	657	88,660	
SOC3	2/23/06	NH_3	0.65	0.173		0.56	0.24	11	657	88,660	0.993
SOC3	2/23/06	NO_3/NO_2	0.66	0.226	0.36	0.56	0.24	11	657	88,660	0.593
SOC3	2/23/06	TP	0.83	0.059		0.56	0.24	11	657	88,660	0.321
SOC3	2/23/06	TKN	0.74	0.105		0.56	0.24	11	657	88,660	2.475
SOC3	2/23/06	Cr	0.74	0.121		0.56	0.24	11	657	88,660	0.004
SOC3	2/23/06	Cu	0.73	0.122		0.56	0.24	11	657	88,660	0.013
SOC3	2/23/06	Ti	0.86	0.083		0.56	0.24	11	657	88,660	0.068
SOC3	2/23/06	V	0.82	0.099		0.56	0.24	11	657	88,660	0.010
SOC3	2/23/06	Zn	0.70	0.125		0.56	0.24	11	657	88,660	0.059
SOC3	2/23/06	As	0.80	0.123		0.56	0.24	11	657	88,660	0.001
SOC3	2/23/06	Ni	0.83	0.154		0.56	0.24	11	657	88,660	0.004
SOC3	2/23/06	Pb	0.76	0.112		0.56	0.24	11	657	88,660	0.009
SOC3	3/21/06	TSS	0.79	0.158		0.95	0.24	6	866	144,470	52.394
SOC3	3/21/06	O-PO_4	0.64	0.146		0.95	0.24	6	866	144,470	0.055
SOC3	3/21/06	NH_3	0.44	0.300	0.18	0.95	0.24	6	866	144,470	0.562
SOC3	3/21/06	NO_3/NO_2	0.44	0.303	0.18	0.95	0.24	6	866	144,470	0.527
SOC3	3/21/06	TP	0.87	0.054		0.95	0.24	6	866	144,470	0.140
SOC3	3/21/06	TKN	0.47	0.262	0.12	0.95	0.24	6	866	144,470	1.586
SOC3	3/21/06	Cr	0.74	0.116		0.95	0.24	6	866	144,470	0.002
SOC3	3/21/06	Cu	0.74	0.107		0.95	0.24	6	866	144,470	0.009
SOC3	3/21/06	Ti	0.87	0.056		0.95	0.24	6	866	144,470	0.035
SOC3	3/21/06	V	0.82	0.084		0.95	0.24	6	866	144,470	0.005
SOC3	3/21/06	Zn	0.70	0.144		0.95	0.24	6	866	144,470	0.033
SOC3	3/21/06	Ni	0.92	0.070		0.95	0.24	6	866	144,470	0.002
SOC3	3/21/06	Pb	0.80	0.091		0.95	0.24	6	866	144,470	0.004

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC4	3/21/06	TSS	0.84	0.106		0.95	0.24	6	45	9,327	21.000
SOC4	3/21/06	O-PO_4	1.17	0.000		0.95	0.24	6	45	9,327	0.025
SOC4	3/21/06	NH_3	0.78	0.090		0.95	0.24	6	45	9,327	0.209
SOC4	3/21/06	NO_3/NO_2	0.92	0.043		0.95	0.24	6	45	9,327	0.264
SOC4	3/21/06	TP	0.88	0.078		0.95	0.24	6	45	9,327	0.070
SOC4	3/21/06	TKN	0.73	0.130		0.95	0.24	6	45	9,327	0.564
SOC4	3/21/06	Cu	0.96	0.051		0.95	0.24	6	45	9,327	0.005
SOC4	3/21/06	Ti	0.93	0.146		0.95	0.24	6	45	9,327	0.011
SOC4	3/21/06	Zn	0.92	0.062		0.95	0.24	6	45	9,327	0.013
SOC4	3/21/06	Pb	0.96	0.041		0.95	0.24	6	45	9,327	0.002
SOC3	4/3/06	TSS	0.94	0.185		0.43	0.96	2	2672	80000	274.222
SOC3	4/3/06	O-PO_4	0.87	0.059		0.43	0.96	2	2672	80000	0.059
SOC3	4/3/06	NH_3	0.71	0.142		0.43	0.96	2	2672	80000	0.401
SOC3	4/3/06	NO_3/NO_2	0.55	0.224	0.22	0.43	0.96	2	2672	80000	0.722
SOC3	4/3/06	TP	0.88	0.134		0.43	0.96	2	2672	80000	0.392
SOC3	4/3/06	TKN	0.76	0.162		0.43	0.96	2	2672	80000	2.996
SOC3	4/3/06	Cr	0.95	0.167		0.43	0.96	2	2672	80000	0.007
SOC3	4/3/06	Cu	0.93	0.179		0.43	0.96	2	2672	80000	0.021
SOC3	4/3/06	Ti	1.06	0.175		0.43	0.96	2	2672	80000	0.132
SOC3	4/3/06	V	0.93	0.179		0.43	0.96	2	2672	80000	0.019
SOC3	4/3/06	Zn	0.82	0.193		0.43	0.96	2	2672	80000	0.080
SOC3	4/3/06	Ni	0.88	0.185		0.43	0.96	2	2672	80000	0.004
SOC3	4/3/06	Pb	0.93	0.168		0.43	0.96	2	2672	80000	0.012
SOC4	4/27/06	TSS	0.33	0.392	0.10	1.41	0.6	0.5	24	10072	34.667
SOC4	4/27/06	O-PO_4	1.24	0.000		1.41	0.6	0.5	24	10072	0.029
SOC4	4/27/06	NH_3	0.90	0.065		1.41	0.6	0.5	24	10072	0.153
SOC4	4/27/06	NO_3/NO_2	0.87	0.103		1.41	0.6	0.5	24	10072	0.219
SOC4	4/27/06	TP	1.08	0.000		1.41	0.6	0.5	24	10072	0.081
SOC4	4/27/06	TKN	0.93	0.036		1.41	0.6	0.5	24	10072	0.661
SOC4	4/27/06	Cr	1.26	0.034		1.41	0.6	0.5	24	10072	0.001
SOC4	4/27/06	Cu	0.89	0.100		1.41	0.6	0.5	24	10072	0.002
SOC4	4/27/06	Ti	1.57	0.018		1.41	0.6	0.5	24	10072	0.102
SOC4	4/27/06	V	1.17	0.029		1.41	0.6	0.5	24	10072	0.002
SOC4	4/27/06	Zn	0.97	0.046		1.41	0.6	0.5	24	10072	0.013

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC4	5/7/06	TSS	1.10	0.159		1.48	0.6	8	234	11758	33.917
SOC4	5/7/06	$O\text{-}PO_4$	1.46	0.000		1.48	0.6	8	234	11758	0.026
SOC4	5/7/06	NH_3	0.49	0.317	0.25	1.48	0.6	8	234	11758	0.190
SOC4	5/7/06	NO_3/NO_2	0.46	0.351	0.17	1.48	0.6	8	234	11758	0.258
SOC4	5/7/06	TP	0.89	0.061		1.48	0.6	8	234	11758	0.080
SOC4	5/7/06	TKN	0.59	0.223	0.17	1.48	0.6	8	234	11758	0.716
SOC4	5/7/06	Cr	0.86	0.132		1.48	0.6	8	234	11758	0.001
SOC4	5/7/06	Ti	0.96	0.115		1.48	0.6	8	234	11758	0.125
SOC4	5/7/06	V	0.81	0.142		1.48	0.6	8	234	11758	0.002
SOC4	5/7/06	Zn	0.68	0.221	0.25	1.48	0.6	8	234	11758	0.012
SOC4	5/14/06	TSS	0.85	0.176		1.79	2.28	3	1497	13852	84.742
SOC4	5/14/06	$O\text{-}PO_4$	1.73	0.000		1.79	2.28	3	1497	13852	0.056
SOC4	5/14/06	NH_3	0.75	0.135		1.79	2.28	3	1497	13852	0.232
SOC4	5/14/06	NO_3/NO_2	0.77	0.089		1.79	2.28	3	1497	13852	0.203
SOC4	5/14/06	TP	1.14	0.000		1.79	2.28	3	1497	13852	0.153
SOC4	5/14/06	TKN	0.92	0.035		1.79	2.28	3	1497	13852	1.091
SOC4	5/14/06	Cr	0.73	0.212	0.53	1.79	2.28	3	1497	13852	0.002
SOC4	5/14/06	Cu	0.66	0.181		1.79	2.28	3	1497	13852	0.003
SOC4	5/14/06	Ti	0.85	0.180		1.79	2.28	3	1497	13852	0.181
SOC4	5/14/06	V	0.87	0.167		1.79	2.28	3	1497	13852	0.006
SOC4	5/14/06	Zn	0.67	0.172		1.79	2.28	3	1497	13852	0.020
SOC4	5/14/06	Ni	0.85	0.146		1.79	2.28	3	1497	13852	0.001
SOC4	5/18/06	TSS	0.50	0.337	0.33	0.46	2.16	4	651	4276	53.667
SOC4	5/18/06	$O\text{-}PO_4$	1.83	0.020		0.46	2.16	4	651	4276	0.041
SOC4	5/18/06	NH_3	0.98	0.012		0.46	2.16	4	651	4276	0.439
SOC4	5/18/06	NO_3/NO_2	1.07	0.000		0.46	2.16	4	651	4276	0.345
SOC4	5/18/06	TP	0.96	0.029		0.46	2.16	4	651	4276	0.102
SOC4	5/18/06	TKN	0.89	0.046		0.46	2.16	4	651	4276	1.045
SOC4	5/18/06	Cr	0.62	0.263	0.50	0.46	2.16	4	651	4276	0.002
SOC4	5/18/06	Cu	0.60	0.202	0.33	0.46	2.16	4	651	4276	0.001
SOC4	5/18/06	Ti	0.53	0.286	0.33	0.46	2.16	4	651	4276	0.097
SOC4	5/18/06	V	0.64	0.209	0.33	0.46	2.16	4	651	4276	0.003
SOC4	5/18/06	Zn	0.69	0.230	0.33	0.46	2.16	4	651	4276	0.016
SOC4	5/18/06	As	0.99	0.035		0.46	2.16	4	651	4276	0.002
SOC4	5/18/06	Ni	0.64	0.035		0.46	2.16	4	651	4276	0.001

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC4	6/2/06	TSS	0.42	0.364	0.33	1.04	1.08	7	1419	16666	39.458
SOC4	6/2/06	$O\text{-}PO_4$	1.49	0.001		1.04	1.08	7	1419	16666	0.041
SOC4	6/2/06	NH_3	0.47	0.269	0.17	1.04	1.08	7	1419	16666	0.194
SOC4	6/2/06	NO_3/NO_2	0.66	0.148		1.04	1.08	7	1419	16666	0.238
SOC4	6/2/06	TP	0.72	0.111		1.04	1.08	7	1419	16666	0.097
SOC4	6/2/06	TKN	0.50	0.257	0.25	1.04	1.08	7	1419	16666	0.783
SOC4	6/2/06	Cu	0.35	0.401	0.17	1.04	1.08	7	1419	16666	0.002
SOC4	6/2/06	Ti	0.34	0.402	0.25	1.04	1.08	7	1419	16666	0.084
SOC4	6/2/06	V	0.38	0.359	0.25	1.04	1.08	7	1419	16666	0.003
SOC4	6/2/06	Zn	0.33	0.411	0.17	1.04	1.08	7	1419	16666	0.014
SOC4	6/2/06	As	1.19	0.001		1.04	1.08	7	1419	16666	0.001
SOC3	6/4-5/06	TSS	0.46	0.302	0.33	0.20	0.24	1	352	53449	25.167
SOC3	6/23/06	TSS	0.59	0.343	0.40	0.39	0.24	2	146	28444	49.800
SOC3	6/23/06	$O\text{-}PO_4$	0.96	0.048		0.39	0.24	2	146	28444	0.023
SOC3	6/23/06	NH_3	0.56	0.223	0.20	0.39	0.24	2	146	28444	0.527
SOC3	6/23/06	NO_3/NO_2	0.65	0.155		0.39	0.24	2	146	28444	0.592
SOC3	6/23/06	TP	0.56	0.207	0.20	0.39	0.24	2	146	28444	0.157
SOC3	6/23/06	TKN	0.53	0.227	0.20	0.39	0.24	2	146	28444	1.556
SOC3	6/23/06	Cr	0.51	0.286	0.40	0.39	0.24	2	146	28444	0.002
SOC3	6/23/06	Cu	0.52	0.244	0.40	0.39	0.24	2	146	28444	0.004
SOC3	6/23/06	Ti	0.45	0.331	0.40	0.39	0.24	2	146	28444	0.079
SOC3	6/23/06	V	0.54	0.250	0.40	0.39	0.24	2	146	28444	0.005
SOC3	6/23/06	Zn	0.45	0.310	0.40	0.39	0.24	2	146	28444	0.022
SOC3	6/23/06	As	0.86	0.114		0.39	0.24	2	146	28444	0.001
SOC3	6/25-26/06	TSS	0.67	0.231	0.27	0.72	1.08	2	249	74977	63.467
SOC3	6/25-26/06	$O\text{-}PO_4$	1.03	0.082		0.72	1.08	2	249	74977	0.412
SOC3	6/25-26/06	NH_3	0.57	0.295	0.13	0.72	1.08	2	249	74977	1.181
SOC3	6/25-26/06	NO_3/NO_2	1.77	0.000		0.72	1.08	2	249	74977	0.107
SOC3	6/25-26/06	TP	0.89	0.095		0.72	1.08	2	249	74977	0.793
SOC3	6/25-26/06	TKN	0.99	0.055		0.72	1.08	2	249	74977	6.407
SOC3	6/25-26/06	Cr	1.16	0.186		0.72	1.08	2	249	74977	0.002
SOC3	6/25-26/06	Cu	1.08	0.064		0.72	1.08	2	249	74977	0.004
SOC3	6/25-26/06	Ti	1.24	0.200		0.72	1.08	2	249	74977	0.099
SOC3	6/25-26/06	V	1.13	0.207	0.53	0.72	1.08	2	249	74977	0.004
SOC3	6/25-26/06	Zn	1.05	0.087		0.72	1.08	2	249	74977	0.016
SOC3	6/25-26/06	Pb	0.69	0.240	0.27	0.72	1.08	2	249	74977	0.003

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC4	6/25-26/06	TSS	0.61	0.249	0.30	0.72	1.08	2	160	4900	25.50
SOC4	6/25-26/06	$O\text{-}PO_4$	1.35	0.000		0.72	1.08	2	160	4900	0.016
SOC4	6/25-26/06	NH_3	0.59	0.219	0.30	0.72	1.08	2	160	4900	0.263
SOC4	6/25-26/06	NO_3/NO_2	0.77	0.104		0.72	1.08	2	160	4900	0.130
SOC4	6/25-26/06	TP	0.67	0.136		0.72	1.08	2	160	4900	0.065
SOC4	6/25-26/06	TKN	0.62	0.179		0.72	1.08	2	160	4900	0.670
SOC4	6/25-26/06	Cu	0.81	0.077		0.72	1.08	2	160	4900	0.003
SOC4	6/25-26/06	Ti	0.55	0.278	0.30	0.72	1.08	2	160	4900	0.045
SOC4	6/25-26/06	Zn	0.57	0.087		0.72	1.08	2	160	4900	0.008
SOC3	7/6/06	TSS	0.87	0.291	0.50	1.02	1.08	9	200	46356	67.13
SOC3	7/6/06	$O\text{-}PO_4$	0.85	0.083		1.02	1.08	9	200	46356	0.041
SOC3	7/6/06	NH_3	0.36	0.354	0.13	1.02	1.08	9	200	46356	0.338
SOC3	7/6/06	NO_3/NO_2	1.40	0.246	0.50	1.02	1.08	9	200	46356	0.296
SOC3	7/6/06	TP	0.46	0.303	0.25	1.02	1.08	9	200	46356	0.300
SOC3	7/6/06	TKN	0.37	0.363	0.25	1.02	1.08	9	200	46356	2.007
SOC3	7/6/06	Cr	0.72	0.224	0.63	1.02	1.08	9	200	46356	0.004
SOC3	7/6/06	Cu	0.70	0.130		1.02	1.08	9	200	46356	0.005
SOC3	7/6/06	Ti	0.83	0.231	0.63	1.02	1.08	9	200	46356	0.215
SOC3	7/6/06	V	0.73	0.241	0.63	1.02	1.08	9	200	46356	0.009
SOC3	7/6/06	Zn	0.62	0.213	0.63	1.02	1.08	9	200	46356	0.028
SOC3	7/6/06	Pb	0.69	0.209	0.63	1.02	1.08	9	200	46356	0.008
SOC3	7/19/06	TSS	0.35	0.401	0.18	0.11	0.48	5	560	23612	106.82
SOC3	7/19/06	$O\text{-}PO_4$	1.15	0.027		0.11	0.48	5	560	23612	0.114
SOC3	7/19/06	NH_3	1.06	0.041		0.11	0.48	5	560	23612	1.118
SOC3	7/19/06	NO_3/NO_2	1.22	0.000		0.11	0.48	5	560	23612	1.666
SOC3	7/19/06	TP	0.69	0.121		0.11	0.48	5	560	23612	0.318
SOC3	7/19/06	TKN	0.91	0.036		0.11	0.48	5	560	23612	3.885
SOC3	7/19/06	Cr	0.59	0.206	0.18	0.11	0.48	5	560	23612	0.006
SOC3	7/19/06	Cu	0.53	0.158		0.11	0.48	5	560	23612	0.011
SOC3	7/19/06	Ti	0.56	0.236	0.18	0.11	0.48	5	560	23612	0.350
SOC3	7/19/06	V	0.59	0.208	0.18	0.11	0.48	5	560	23612	0.012
SOC3	7/19/06	Zn	0.52	0.256	0.18	0.11	0.48	5	560	23612	0.073
SOC3	7/19/06	Ni	0.60	0.201	0.18	0.11	0.48	5	560	23612	0.002
SOC3	7/19/06	Pb	0.60	0.200	0.18	0.11	0.48	5	560	23612	0.013

Appendix 1 (con't).

Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	7/22/06	TSS	0.45	0.408	0.33	0.14	1.08	3	395	10900	154.67
SOC3	7/22/06	$O\text{-}PO_4$	1.88	0.000		0.14	1.08	3	395	10900	0.040
SOC3	7/22/06	NH_3	0.78	0.095		0.14	1.08	3	395	10900	0.501
SOC3	7/22/06	NO_3/NO_2	1.40	0.000		0.14	1.08	3	395	10900	0.721
SOC3	7/22/06	TP	0.74	0.110		0.14	1.08	3	395	10900	0.245
SOC3	7/22/06	TKN	0.80	0.113		0.14	1.08	3	395	10900	2.558
SOC3	7/22/06	Cr	0.52	0.293	0.33	0.14	1.08	3	395	10900	0.006
SOC3	7/22/06	Cu	0.53	0.278	0.33	0.14	1.08	3	395	10900	0.009
SOC3	7/22/06	Ti	0.47	0.330	0.33	0.14	1.08	3	395	10900	0.281
SOC3	7/22/06	V	0.56	0.283	0.50	0.14	1.08	3	395	10900	0.011
SOC3	7/22/06	Zn	0.46	0.345	0.33	0.14	1.08	3	395	10900	0.067
SOC3	7/22/06	Ni	0.58	0.268	0.50	0.14	1.08	3	395	10900	0.002
SOC3	7/22/06	Pb	0.59	0.271	0.50	0.14	1.08	3	395	10900	0.014
SOC3	7/23/06	TSS	1.14	0.155		0.08	0.24	1.25	315	17000	43.86
SOC4	7/23/06	TSS	0.78	0.251	0.33	0.5	1.8	1.25	98	3146	35.00
SOC4	7/23/06	$O\text{-}PO_4$	1.17	0.000		0.5	1.8	1.25	98	3146	0.012
SOC4	7/23/06	NH_3	0.48	0.362	0.33	0.5	1.8	1.25	98	3146	0.111
SOC4	7/23/06	NO_3/NO_2	0.43	0.362	0.33	0.5	1.8	1.25	98	3146	0.234
SOC4	7/23/06	TP	0.77	0.137		0.5	1.8	1.25	98	3146	0.054
SOC4	7/23/06	TKN	0.55	0.295	0.33	0.5	1.8	1.25	98	3146	0.494
SOC4	7/23/06	Cr	0.69	0.252	0.33	0.5	1.8	1.25	98	3146	0.001
SOC4	7/23/06	Cu	0.82	0.270	0.33	0.5	1.8	1.25	98	3146	0.005
SOC4	7/23/06	Ti	0.78	0.317	0.33	0.5	1.8	1.25	98	3146	0.133
SOC4	7/23/06	V	0.86	0.294	0.33	0.5	1.8	1.25	98	3146	0.005
SOC4	7/23/06	Zn	0.76	0.334	0.33	0.5	1.8	1.25	98	3146	0.032
SOC4	7/23/06	Ni	0.69	0.328	0.33	0.5	1.8	1.25	98	3146	0.001
SOC4	7/23/06	Pb	0.95	0.250	0.33	0.5	1.8	1.25	98	3146	0.008
SOC3	7/25/06	TSS	0.45	0.354	0.27	0.13	0.36	0.7	290	22490	49.64
SOC3	7/25/06	$O\text{-}PO_4$	1.09	0.000		0.13	0.36	0.7	290	22490	0.060
SOC3	7/25/06	NH_3	0.79	0.104		0.13	0.36	0.7	290	22490	0.250
SOC3	7/25/06	NO_3/NO_2	0.89	0.039		0.13	0.36	0.7	290	22490	0.357
SOC3	7/25/06	TP	0.89	0.054		0.13	0.36	0.7	290	22490	0.140
SOC3	7/25/06	TKN	0.81	0.093		0.13	0.36	0.7	290	22490	1.114
SOC3	7/25/06	Cr	0.58	0.288	0.27	0.13	0.36	0.7	290	22490	0.003
SOC3	7/25/06	Cu	0.57	0.276	0.27	0.13	0.36	0.7	290	22490	0.005
SOC3	7/25/06	Ti	0.51	0.318	0.27	0.13	0.36	0.7	290	22490	0.141
SOC3	7/25/06	V	0.55	0.313	0.27	0.13	0.36	0.7	290	22490	0.006
SOC3	7/25/06	Zn	0.49	0.339	0.27	0.13	0.36	0.7	290	22490	0.033
SOC3	7/25/06	Ni	0.52	0.304	0.27	0.13	0.36	0.7	290	22490	0.001
SOC3	7/25/06	Pb	0.60	0.276	0.27	0.13	0.36	0.7	290	22490	0.009

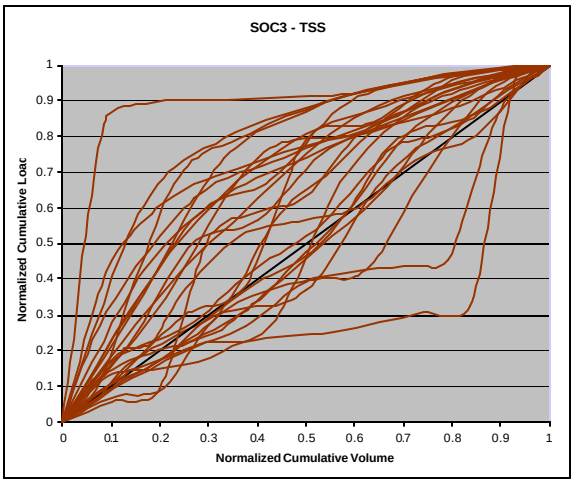
Appendix 1 (con't).

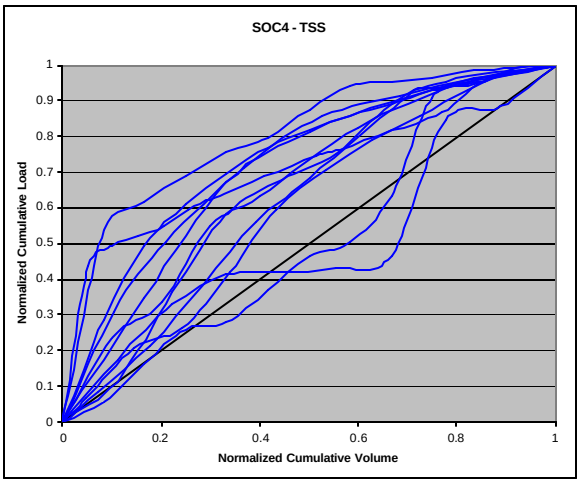
Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC4	7/25/06	TSS	0.46	0.345	0.37	0.6	2.04	0.33	562	6558	51.316
SOC3	7/26/06	TSS	0.63	0.439	0.23	0.6	2.04	0.33	714	28500	328.00
SOC3	7/26/06	$O\text{-}PO_4$	1.52	0.000		0.6	2.04	0.33	714	28500	0.060
SOC3	7/26/06	NH_3	0.87	0.045		0.6	2.04	0.33	714	28500	0.094
SOC3	7/26/06	NO_3/NO_2	1.09	0.003		0.6	2.04	0.33	714	28500	0.251
SOC3	7/26/06	TP	0.94	0.061		0.6	2.04	0.33	714	28500	0.230
SOC3	7/26/06	TKN	0.86	0.113		0.6	2.04	0.33	714	28500	1.359
SOC3	8/20/06	TSS	0.25	0.462	0.33	0.15	1.2	2	492	11400	243.17
SOC3	8/20/06	$O\text{-}PO_4$	1.46	0.000		0.15	1.2	2	492	11400	0.118
SOC3	8/20/06	NH_3	1.21	0.000		0.15	1.2	2	492	11400	0.402
SOC3	8/20/06	NO_3/NO_2	2.11	0.000		0.15	1.2	2	492	11400	0.698
SOC3	8/20/06	TP	0.79	0.078		0.15	1.2	2	492	11400	0.499
SOC3	8/20/06	TKN	0.59	0.195		0.15	1.2	2	492	11400	3.871
SOC3	8/20/06	Cr	0.46	0.273	0.17	0.15	1.2	2	492	11400	0.012
SOC3	8/20/06	Cu	0.49	0.258	0.17	0.15	1.2	2	492	11400	0.017
SOC3	8/20/06	Ti	0.37	0.343	0.17	0.15	1.2	2	492	11400	0.438
SOC3	8/20/06	V	0.49	0.250	0.17	0.15	1.2	2	492	11400	0.024
SOC3	8/20/06	Zn	0.44	0.297	0.33	0.15	1.2	2	492	11400	0.127
SOC3	8/20/06	Ni	0.49	0.252	0.17	0.15	1.2	2	492	11400	0.004
SOC3	8/20/06	Pb	0.47	0.260	0.17	0.15	1.2	2	492	11400	0.027
SOC3	8/30/06	TSS	0.59	0.251	0.60	1.39	1.92	0.5	297	29200	74.00
SOC3	8/30/06	$O\text{-}PO_4$	0.96	0.028		1.39	1.92	0.5	297	29200	0.133
SOC3	8/30/06	NH_3	0.65	0.170		1.39	1.92	0.5	297	29200	0.877
SOC3	8/30/06	NO_3/NO_2	1.02	0.016		1.39	1.92	0.5	297	29200	0.837
SOC3	8/30/06	TP	0.65	0.147		1.39	1.92	0.5	297	29200	0.428
SOC3	8/30/06	TKN	0.75	0.109		1.39	1.92	0.5	297	29200	4.256
SOC3	8/30/06	Cr	0.50	0.276	0.40	1.39	1.92	0.5	297	29200	0.006
SOC3	8/30/06	Cu	0.53	0.245	0.40	1.39	1.92	0.5	297	29200	0.015
SOC3	8/30/06	Ti	0.50	0.324	0.40	1.39	1.92	0.5	297	29200	0.251
SOC3	8/30/06	V	0.58	0.239	0.40	1.39	1.92	0.5	297	29200	0.019
SOC3	8/30/06	Zn	0.57	0.231	0.40	1.39	1.92	0.5	297	29200	0.113
SOC3	8/30/06	Ni	0.59	0.219	0.40	1.39	1.92	0.5	297	29200	0.003
SOC3	8/30/06	Pb	0.56	0.233	0.40	1.39	1.92	0.5	297	29200	0.014

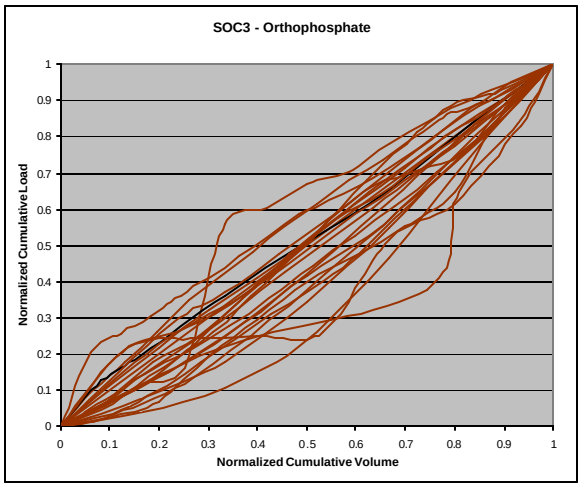
Appendix 1 (con't).

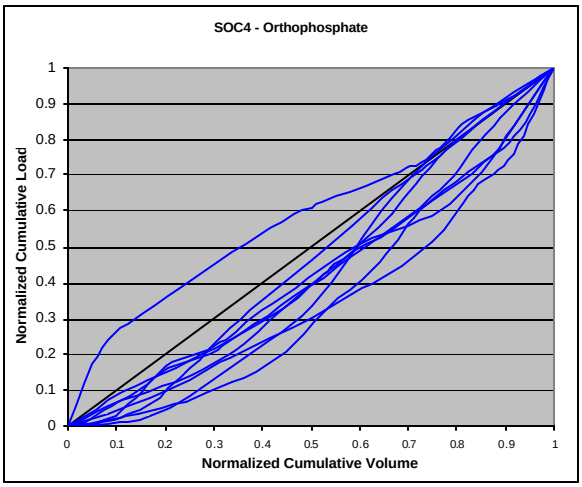
Site	Date	Pollutant	b coeff.	Max L'-V'	V loc.	Rainfall (in)	Max I (in/hr)	ADWP (days)	Peak Q (gpm)	Runoff V (gal)	EMC (mg/L)
SOC3	9/1/06	TSS	1.21	0.033		1.43	0.96	0.5	373	88000	179.14
SOC3	9/1/06	$O\text{-}PO_4$	1.07	0.015		1.43	0.96	0.5	373	88000	0.038
SOC3	9/1/06	NH_3	0.78	0.217	0.56	1.43	0.96	0.5	373	88000	0.083
SOC3	9/1/06	NO_3/NO_2	0.69	0.224	0.28	1.43	0.96	0.5	373	88000	0.142
SOC3	9/1/06	TP	0.94	0.048		1.43	0.96	0.5	373	88000	0.210
SOC3	9/1/06	TKN	0.78	0.122		1.43	0.96	0.5	373	88000	1.316
SOC3	9/1/06	Cr	0.83	0.073		1.43	0.96	0.5	373	88000	0.005
SOC3	9/1/06	Cu	0.87	0.055		1.43	0.96	0.5	373	88000	0.008
SOC3	9/1/06	Ti	0.84	0.075		1.43	0.96	0.5	373	88000	0.290
SOC3	9/1/06	V	0.84	0.076		1.43	0.96	0.5	373	88000	0.013
SOC3	9/1/06	Zn	1.11	0.012		1.43	0.96	0.5	373	88000	0.069
SOC3	9/1/06	Ni	1.22	0.021		1.43	0.96	0.5	373	88000	0.004
SOC3	9/1/06	Pb	0.81	0.080		1.43	0.96	0.5	373	88000	0.015
SOC3	9/5/06	TSS	1.10	0.213	0.30	0.4	1.08	3	551	21000	215.00
SOC3	9/5/06	$O\text{-}PO_4$	1.54	0.000		0.4	1.08	3	551	21000	0.053
SOC3	9/5/06	NH_3	0.73	0.176		0.4	1.08	3	551	21000	0.177
SOC3	9/5/06	NO_3/NO_2	1.09	0.003		0.4	1.08	3	551	21000	0.322
SOC3	9/5/06	TP	0.93	0.053		0.4	1.08	3	551	21000	0.261
SOC3	9/5/06	TKN	0.89	0.065		0.4	1.08	3	551	21000	1.469
SOC3	9/5/06	Cr	0.95	0.120		0.4	1.08	3	551	21000	0.010
SOC3	9/5/06	Cu	0.96	0.054		0.4	1.08	3	551	21000	0.013
SOC3	9/5/06	Ti	1.08	0.106		0.4	1.08	3	551	21000	0.559
SOC3	9/5/06	V	0.98	0.103		0.4	1.08	3	551	21000	0.023
SOC3	9/5/06	Zn	0.88	0.080		0.4	1.08	3	551	21000	0.054
SOC3	9/5/06	As	1.09	0.105		0.4	1.08	3	551	21000	0.001
SOC3	9/5/06	Ni	0.83	0.112		0.4	1.08	3	551	21000	0.005
SOC3	9/5/06	Pb	0.89	0.125		0.4	1.08	3	551	21000	0.021

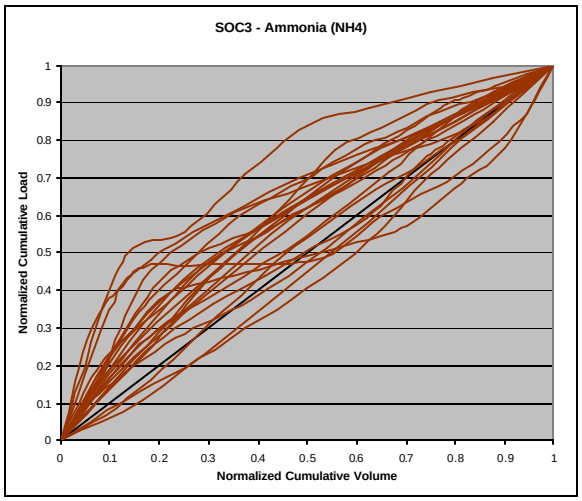
Appendix 2. First Flush Analysis Graphs:
Normalized Cumulative Pollutant Load vs. Normalized Cumulative Storm Volume

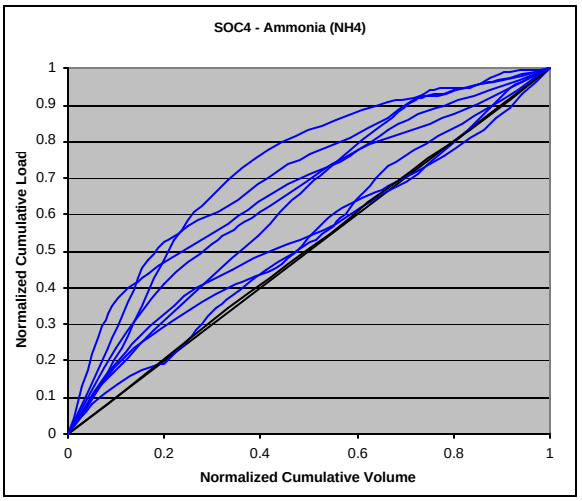


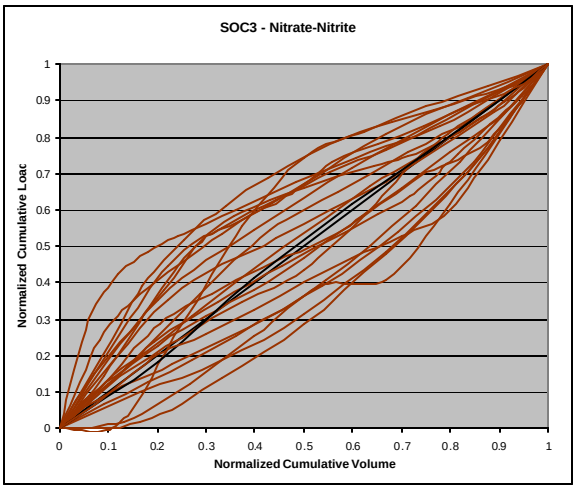


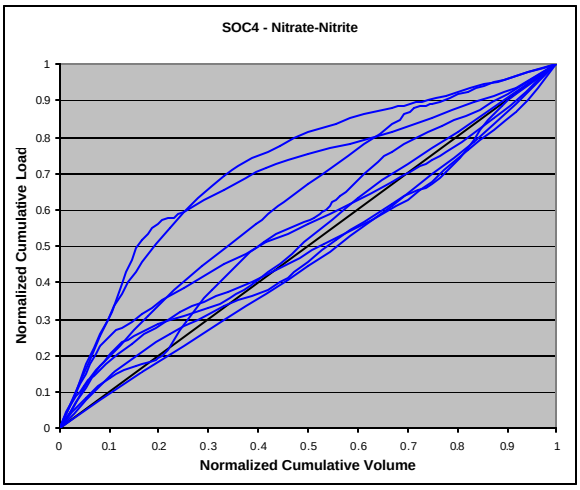


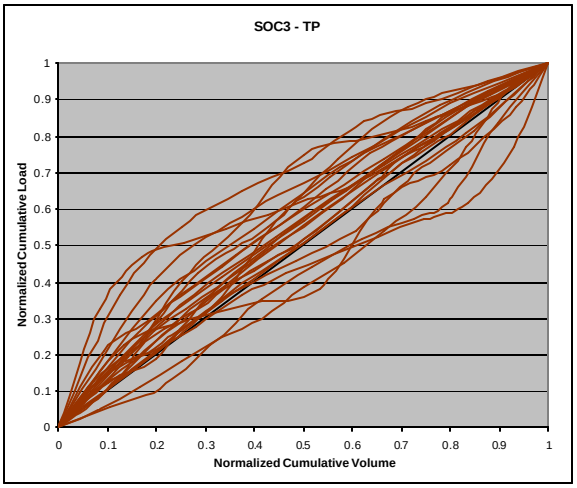


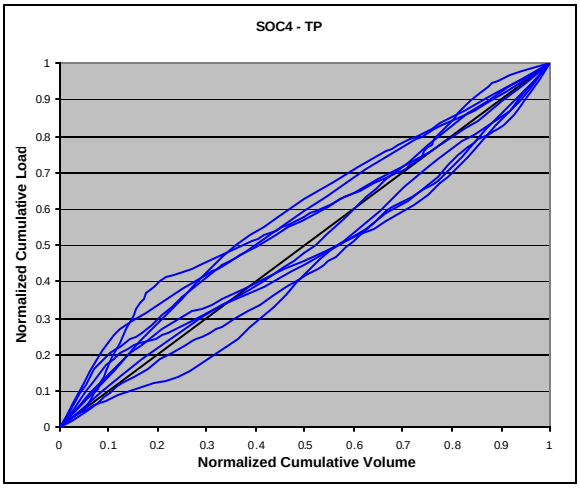


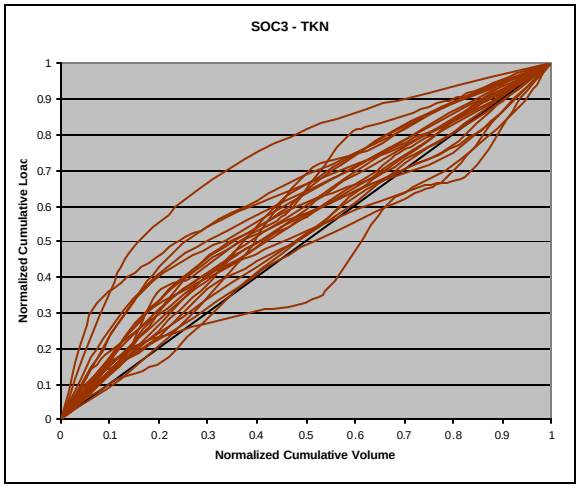


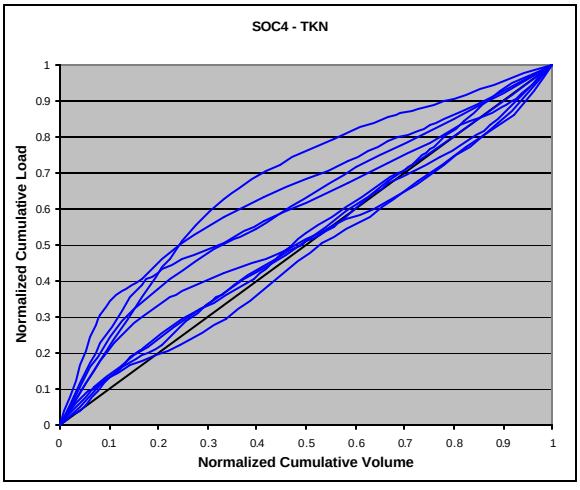

SOC3 - Nitrate-Nitrite
Normalized Cumulative Loac
Normalized Cumulative Volume

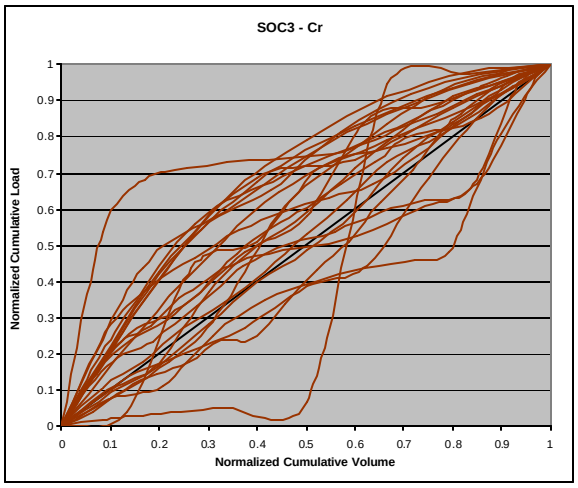

SOC4 - Nitrate-Nitrite
Normalized Cumulative Load
Normalized Cumulative Volume

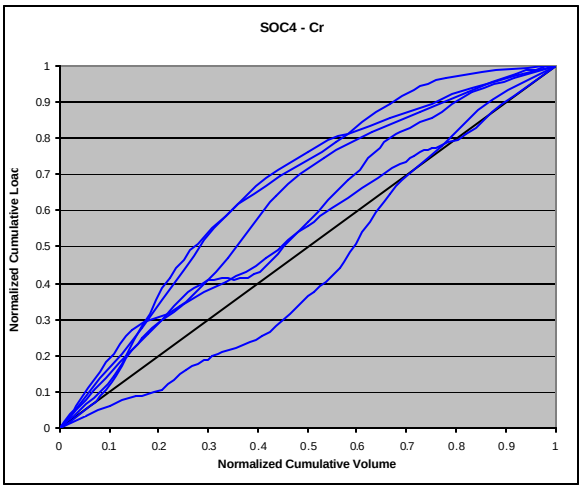

SOC3 - TP
Normalized Cumulative Load
Normalized Cumulative Volume

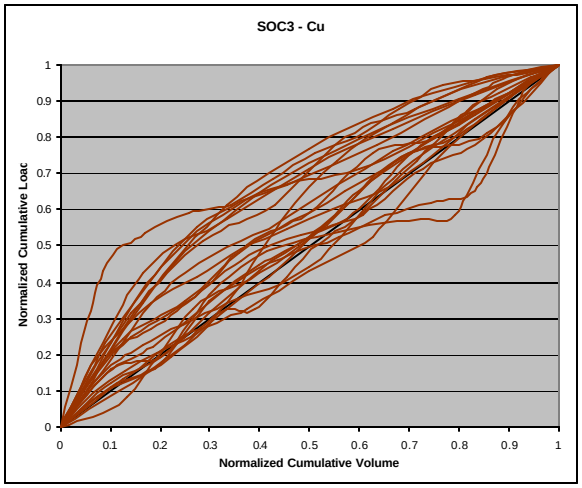

SOC4 - TP
Normalized Cumulative Load
Normalized Cumulative Volume

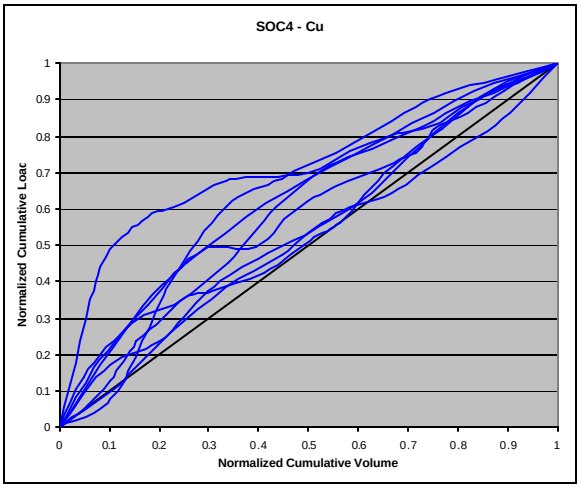

SOC3 - TKN
Normalized Cumulative Loac
Normalized Cumulative Volume

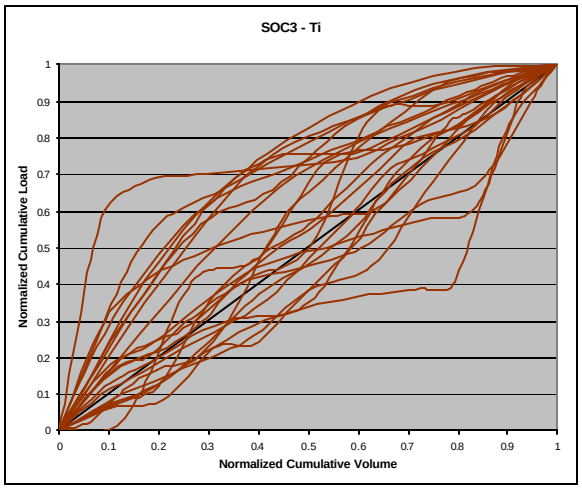

SOC4 - TKN
Normalized Cumulative Load
Normalized Cumulative Volume

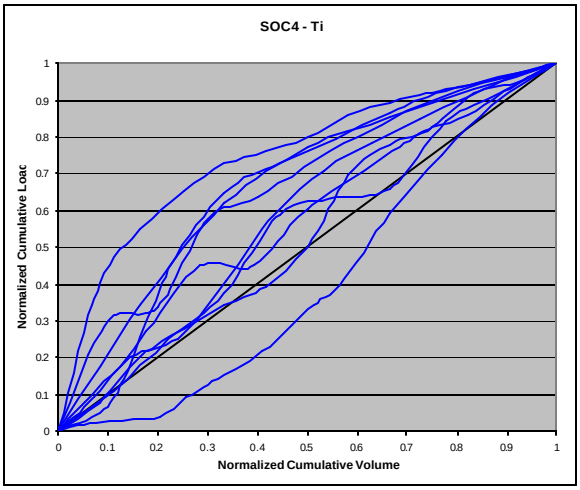

SOC3 - Cr
Normalized Cumulative Load
Normalized Cumulative Volume

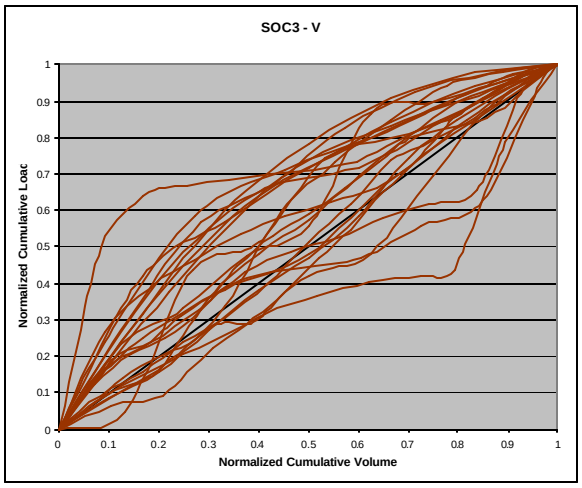

SOC4 - Cr
Normalized Cumulative Loac
Normalized Cumulative Volume

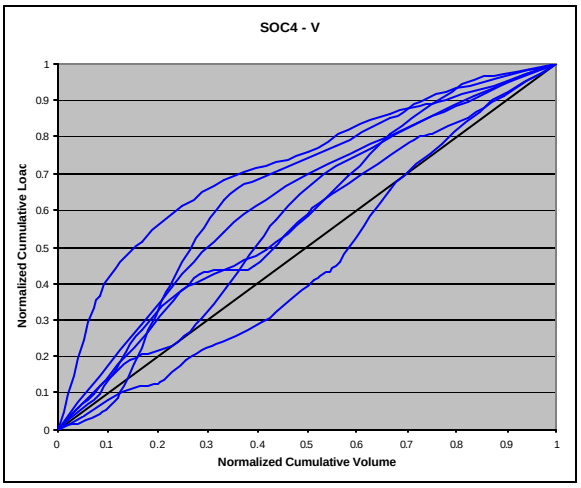

SOC3 - Cu
Normalized Cumulative Loac
Normalized Cumulative Volume

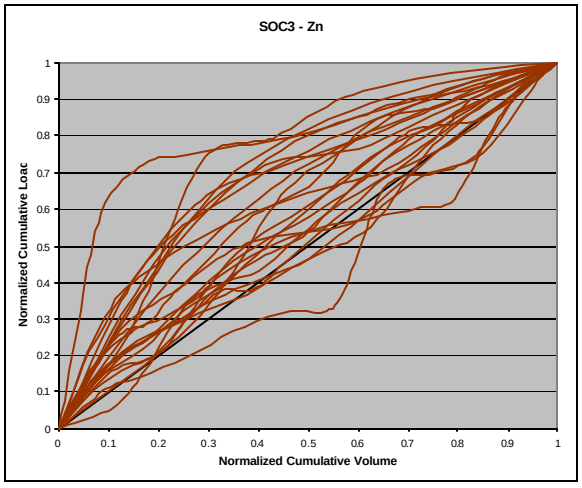

SOC4 - Cu
Normalized Cumulative Loac
Normalized Cumulative Volume

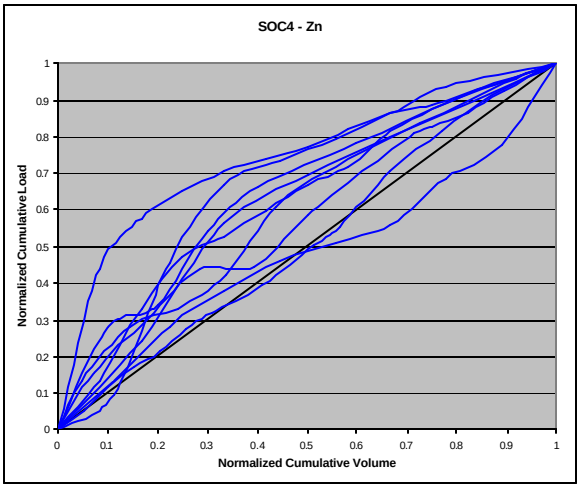

SOC3 - Ti
Normalized Cumulative Load
Normalized Cumulative Volume

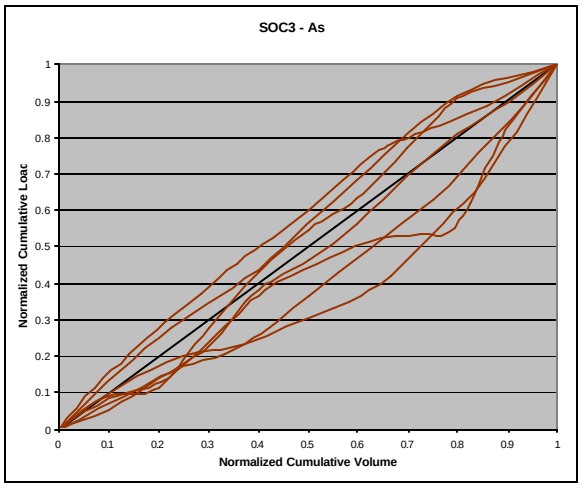

SOC4 - Ti
Normalized Cumulative Loac
Normalized Cumulative Volume

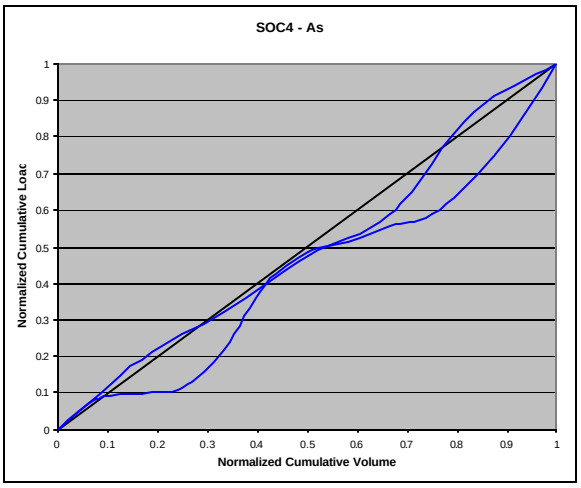

SOC3 - V
Normalized Cumulative Loac
Normalized Cumulative Volume

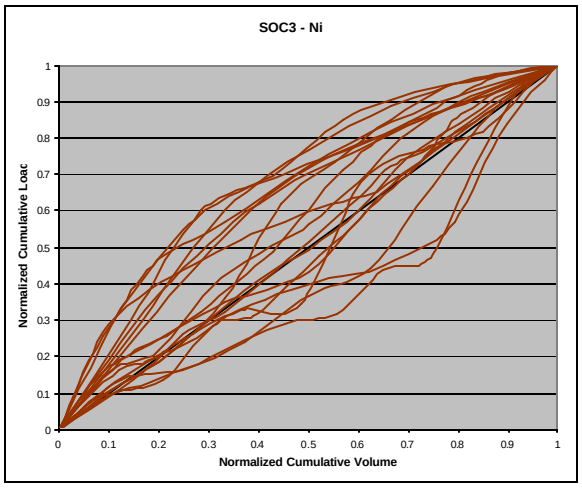

SOC4 - V
Normalized Cumulative Loac
Normalized Cumulative Volume

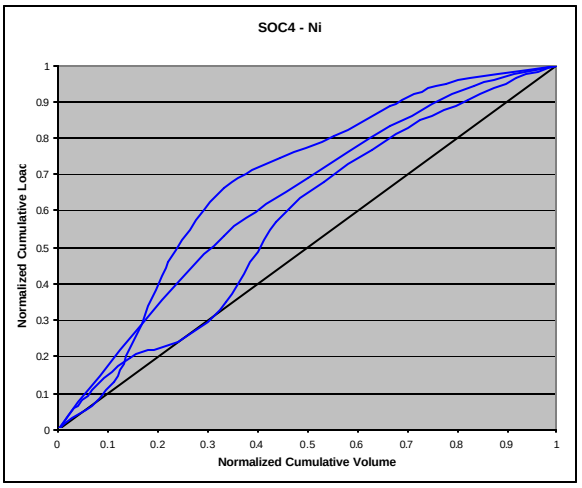

SOC3 - Zn
Normalized Cumulative Loac
Normalized Cumulative Volume

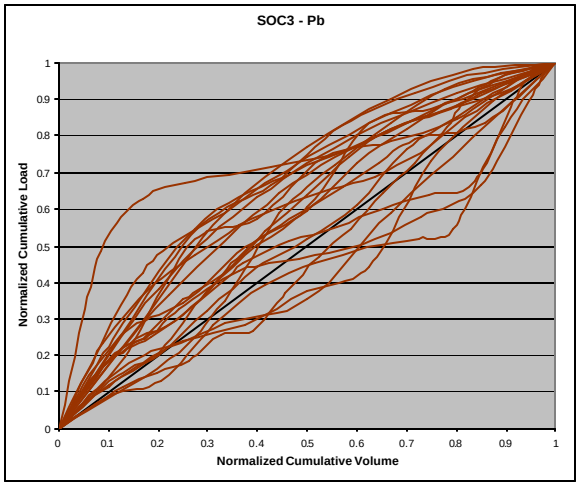

SOC4 - Zn
Normalized Cumulative Load
Normalized Cumulative Volume

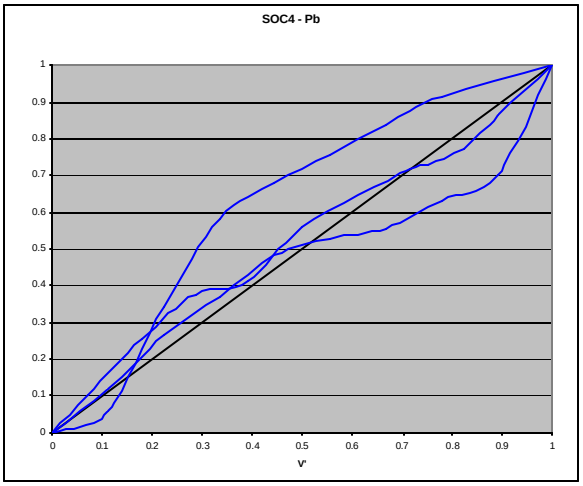

SOC3 - As
Normalized Cumulative Loac
Normalized Cumulative Volume


SOC4 - As
Normalized Cumulative Loac
Normalized Cumulative Volume


SOC3 - Ni
Normalized Cumulative Loac
Normalized Cumulative Volume


SOC4 - Ni
Normalized Cumulative Loac
Normalized Cumulative Volume


SOC3 - Pb
Normalized Cumulative Load
Normalized Cumulative Volume


SOC4 - Pb
v'

Appendix 3. Analysis Results From All Samples Collected (nutrients in mg/L, metals is µg/L)

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	10/6-8/05	10/6/05	1-2	89	95						8.20	21.70	252.3	24.80	88.40	1.00	4.80	9.80
SOC3	10/6-8/05	10/6/05	3-4	43	53						4.70	11.40	149.8	16.80	48.60	<0.9	2.30	6.80
SOC3	10/6-8/05	10/6/05	1-2			0.14	0.68	0.54	0.17	0.92								
SOC3	10/6-8/05	10/6/05	5-8	40	40						4.30	8.20	137.9	11.50	38.60	0.80	2.00	4.90
SOC3	10/6-8/05	10/6/05	3-4			0.08	1.00	0.27	0.10	1.30								
SOC3	10/6-8/05	10/6-7/05	9-12	20	21						2.90	7.20	57.00	8.00	29.20	<0.9	1.40	3.00
SOC3	10/6-8/05	10/6/05	5-8	40	40	0.09	0.33	0.18	0.14	0.69								
SOC3	10/6-8/05	10/7/05	13-16	112	88						182.6	17.60	368.9	17.60	53.50	2.20	3.80	11.10
SOC3	10/6-8/05	10/6-7/05	9-16			0.08	0.16	0.15	0.12	0.39								
SOC3	10/6-8/05	10/7/05	17-20	56	64	0.10	0.16	0.11	0.11	0.42	6.20	12.00	168.1	13.70	55.20	0.90	2.80	9.40
SOC3	10/6-8/05	10/7/05	21-24	50	64	0.09	0.32	0.10	0.15	0.79	5.60	10.90	199.8	12.90	46.80	1.00	2.50	9.40
SOC3	10/6-8/05	10/7/05	1-6	61	52													
SOC3	10/6-8/05	10/8/05	7-12	144	99													
SOC3	10/6-8/05	10/8/05	13-18	172	111													
SOC3	10/6-8/05	10/8/05	19-24	45	36													
SOC4	10/6-8/05	10/7/05	1-5	28	28	0.02	0.21	0.1	0.07	0.55								
SOC4	10/6-8/05	10/7/05	6-8	9	10	0.06	0.18	< 0.1	0.11	0.33	1.70	5.60	36.40	3.40	18.90	<0.9	0.80	2.50
SOC4	10/6-8/05	10/7/05	9-14	6	8	0.1	0.88	0.11	0.16	0.95								
SOC4	10/6-8/05	10/7-8/05	1-5	11	7													
SOC4	10/6-8/05	10/8/05	6-13	8	5													
SOC4	10/6-8/05	10/8/05	14-21	5	5													
SOC4	10/6-8/05	10/8/05	22-24	12	4													
SOC3	11/16/05	11/16/05	1	203	143	0.68	0.25	0.6	1.3	11.3	11.50	27.20	555.4	24.10	143.30	1.80	6.80	13.50
SOC3	11/16/05	11/16/05	2	126	123	0.88	1	0.9	1.2	9.5	12.00	21.70	384.0	18.60	122.40	1.70	5.50	8.70
SOC4	11/16/05	11/16/05	1-2	179	58	0.07	0.79	0.47	0.08	0.79	10.80	32.00	349.1	20.90	343.10	<0.9	6.30	20.50
SOC4	11/16/05	11/16/05	23	162	21	0.25	0.53	0.36	0.28	1.5	5.00	11.40	279.2	10.40	93.90	<0.9	2.70	8.60
SOC4	11/16/05	11/16/05	24	121	24	0.34	0.56	0.45	0.48	1.4	3.30	12.30	166.8	7.00	71.10	<0.9	2.10	7.00
SOC3	11/20-22/05	11/21/05	1-2	71	31	0.29	0.685	0.33	0.39	7.7	3.20	16.65	109.5	12.20	101.30	1.00	3.10	5.50
SOC3	11/20-22/05	11/21/05	3-4	124	77	0.23	0.46	0.25	0.29	3.9	4.80	10.40	360.0	15.70	59.90	0.90	3.10	5.60
SOC3	11/20-22/05	11/21/05	5-6	57	65	0.25	0.43	0.27	0.3	11.6	3.30	8.20	221.0	10.80	43.60	0.80	2.30	4.00

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	11/20-22/05	11/21/05	7-8	26	36	0.25	0.37	0.21	0.24	2.6	2.40	8.30	98.00	7.20	38.20	<0.9	1.60	3.10
SOC3	11/20-22/05	11/21/05	9-10	47	57	0.2	0.35	0.19	0.23	4.4	4.70	12.40	193.0	11.20	56.50	<0.9	2.60	7.20
SOC3	11/20-22/05	11/21/05	11-12	87	85	0.2	0.36	0.17	0.26	4	<0.9	<0.9	<0.5	<2.0	<0.6	<0.9	<0.9	<2.0
SOC3	11/20-22/05	11/21/05	13-14	95	97	0.2	0.34	0.18	0.26	3.5	7.30	16.20	361.0	16.90	64.60	1.10	3.60	10.40
SOC3	11/20-22/05	11/21/05	15-16	95	97	0.19	0.31	0.17	0.25	7.1	7.40	16.10	371.0	17.00	59.50	1.20	3.50	9.50
SOC3	11/20-22/05	11/21/05	17-18	98	93	0.18	0.31	0.16	0.22	7.5	6.20	10.10	360.0	15.70	55.70	1.20	3.30	8.00
SOC3	11/20-22/05	11/21/05	19-20	98	93	0.17	0.29	0.17	0.23	2	8.20	14.50	507.0	20.40	61.00	1.10	4.00	9.50
SOC3	11/20-22/05	11/21/05	21-22	135	102	0.18	0.24	0.17	0.25	1.9	7.00	14.50	445.0	17.30	52.40	1.90	3.20	8.40
SOC3	11/20-22/05	11/21/05	23-24	135	102	0.19	0.3	0.28	0.27	2.1	8.80	16.00	485.0	20.10	68.30	1.90	4.80	9.60
SOC4	11/20-22/05	11/20/05	1	57	25	0.08	0.915	1.295	0.16	2.7	2.60	13.25	56.45	4.55	48.40	<0.9	1.15	5.00
SOC4	11/20-22/05	11/21/05	10-13	31	8	0.02	0.18	0.15	0.03	0.28								
SOC4	11/20-22/05	11/21/05	14-17	12	14	0.11	0.26	0.42	0.17	1.4								
SOC4	11/20-22/05	11/21/05	18-20	10	14	0.18	0.25	0.56	0.19	1.3								
SOC4	11/20-22/05	11/21/05	21-24	7	12	0.19	0.18	0.43	0.24	1.2								
SOC3	11/20-22/05	11/21/05	1	84	75	0.08	0.12	0.29	0.16	1.9	6.50	15.70	175.0	12.60	77.50	1.00	3.30	13.00
SOC3	11/20-22/05	11/22/05	2-3	84	75	0.1	0.17	0.29	0.15	2.4	4.80	8.50	228.0	11.60	42.90	<0.9	2.30	6.30
SOC3	11/20-22/05	11/22/05	4-5	41	68	0.14	0.15	0.27	0.16	2.3	3.30	6.90	210.0	8.70	27.80	2.00	1.90	2.90
SOC3	11/20-22/05	11/22/05	6-7	20	46	0.15	0.15	0.38	0.19	1.7	2.80	8.00	151.0	5.60	24.10	2.00	1.50	1.70
SOC3	11/27-28/05	11/27/05	1								6.00	11.70	262.3	14.00	81.10	<0.9	3.20	11.00
SOC3	11/27-28/05	11/27/05	1-2	210	105	0.08	0.29	0.17	0.16	1.9								
SOC3	11/27-28/05	11/27/05	2								11.10	19.80	938.1	32.00	84.90	0.90	6.80	13.10
SOC3	11/27-28/05	11/27/05	3-4	205	139	0.105	0.245	0.125	0.25	2.9								
SOC3	11/27-28/05	11/27/05	3								13.30	22.05	1158.3	39.35	84.05	0.90	6.50	13.65
SOC3	11/27-28/05	11/27/05	5-6	83	82	0.12	0.23	0.05	0.25	2.2								
SOC3	11/27-28/05	11/27/05	4			0.1	0.21	0.17	0.18	1.7	6.00	9.90	362.1	14.70	40.80	<0.9	2.80	5.90
SOC3	11/27-28/05	11/27/05	5			0.12	0.19	0.16	0.14	3.1	4.90	8.40	261.7	10.20	35.30	0.90	2.10	4.00
SOC3	11/27-28/05	11/27/05	6			0.29	0.48	0.14	0.39	6.6	9.90	19.10	335.3	20.00	96.50	1.10	4.80	21.90
SOC4	11/27-28/05	11/27/05	2	79	24	0.05	0.41	0.35	0.09	0.42								
SOC4	11/27-28/05	11/27/05	3	52	13	0.04	0.23	0.2	0.08	0.42								
SOC4	11/27-28/05	11/27/05	4	33	13	0.06	0.2	0.16	0.06	0.55								
SOC4	11/27-28/05	11/28/05	22	19	25	0.09	0.21	0.17	0.16	0.82	46.33	17.23	155.8	7.80	52.29	0.94	1.75	10.23

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	11/29/05	11/29/05	1-2	138	88	0.04	< 0.1	< 0.1	0.16	2	11.57	17.38	581.4	22.60	103.53	1.56	4.54	24.28
SOC3	11/29/05	11/29/05	3-4	80	87	0.06	0.1	< 0.1	0.2	1.1	7.66	9.81	363.4	15.19	58.07	1.73	3.04	12.81
SOC3	11/29/05	11/29/05	5-6	106	73	0.04	0.1	< 0.1	0.22	1	10.30	15.10	396.0	20.20	80.00	1.60	5.00	15.50
SOC3	11/29/05	11/29/05	7-8	85	80	0.06	< 0.1	< 0.1	0.21	1.1	7.60	18.40	353.8	16.00	54.50	1.00	3.10	11.30
SOC3	11/29/05	11/29/05	9-10	134	104	0.06	< 0.1	< 0.1	0.17	1.4	9.30	15.90	424.0	21.90	82.30	1.30	4.30	16.80
SOC3	11/29/05	11/29/05	11-12	167	129	0.07	< 0.1	< 0.1	0.28	1.6	11.10	19.00	685.3	28.20	72.70	1.50	4.90	15.50
SOC3	11/29/05	11/29/05	13-14	164	109	0.07	0.11	< 0.1	0.21	1.3	10.40	19.70	688.7	24.70	74.60	1.30	4.90	15.00
SOC3	11/29/05	11/29/05	15-16	258	144	0.08	< 0.1	< 0.1	0.29	1.2	11.30	19.10	773.6	29.70	60.40	2.00	5.20	11.70
SOC3	11/29/05	11/29/05	17-18	58	69	0.07	0.12	0.16	0.3	0.99	6.20	12.60	322.0	12.60	36.60	3.30	2.60	6.20
SOC3	11/29/05	11/29/05	19-20	71	74	0.08	0.1	0.27	0.42	1.4	6.80	12.60	374.7	15.10	44.40	3.30	3.40	6.40
SOC3	11/29/05	11/29/05	21-22	140	116	0.09	0.11	0.16	0.52	1.3	8.60	12.60	581.2	20.60	43.70	4.70	3.90	7.80
SOC3	11/29/05	11/29/05	23-24	92	88	0.105	0.12	0.275	0.225	1.5	7.55	12.65	408.7	15.35	41.75	5.20	3.65	6.80
SOC3	12/4-5/05	12/4-5/05	1-3	57	50	0.04	0.13	0.19	0.4	1.4	4.49	8.95	214.3	10.50	62.32	1.58	2.21	7.48
SOC3	12/4-5/05	12/5/05	4-6	31	47	0.04	0.11	0.14	0.74	1.9	2.55	8.09	161.5	7.51	27.74	1.05	<0.9	3.44
SOC3	12/4-5/05	12/5/05	7-9	30	55	0.05	0.13	0.13	0.45	2.3	2.62	5.01	163.2	7.45	21.43	<0.9	1.28	2.06
SOC3	12/4-5/05	12/5/05	10-12	53.7	74	0.06	0.13	0.11	0.54	2.8	3.90	6.97	303.7	11.69	29.14	1.72	2.02	4.13
SOC3	12/4-5/05	12/5/05	13-15	15	35	0.05	0.16	0.2	0.11	0.77	2.18	6.37	139.7	5.41	27.10	1.70	1.27	3.20
SOC3	12/4-5/05	12/5/05	16-18	120	98	0.065	0.22	0.155	0.145	1.25	8.48	13.62	510.7	19.05	67.29	1.78	3.68	13.14
SOC3	12/4-5/05	12/5/05	19-21	98	101	0.07	0.17	0.11	0.24	0.86	7.08	10.42	471.2	17.90	40.39	2.29	3.42	7.53
SOC3	12/4-5/05	12/5/05	22-24	33	67	0.08	0.19	0.28	0.21	0.85	3.94	7.83	230.6	9.09	28.29	2.59	1.95	4.74
SOC3	12/9/05	12/9/05	1-2	35	34													
SOC3	12/9/05	12/9/05	3-4	16	26													
SOC4	12/9/05	12/9/05	1	76	37	0.17	0.99	0.89	0.2	1.3	3.01	11.55	161.2	6.58	79.44	0.92	2.70	4.43
SOC4	12/9/05	12/9/05	2	76	37	0.06	0.72	0.64	0.4	0.89	2.96	8.15	207.5	7.48	51.22	<0.9	2.08	4.30
SOC4	12/9/05	12/9/05	3	103	36	0.05	0.66	0.53	0.11	0.8	2.64	6.98	203.2	7.17	47.16	1.18	1.72	3.50
SOC4	12/9/05	12/9/05	4	103	36	0.05	0.62	0.47	0.1	0.71	<0.9	<0.9	<0.5	<2.0	<0.6	<0.9	<0.9	<2.0
SOC4	12/9/05	12/9/05	5	73	19	0.04	0.68	0.43	0.1	1	2.60	5.99	176.6	6.55	48.35	1.00	1.59	4.16
SOC4	12/9/05	12/9/05	7	73	19	0.03	0.56	0.41	0.1	0.76	1.84	3.06	112.4	4.49	38.64	1.68	<0.9	2.28
SOC4	12/9/05	12/9/05	8	10	12	0.05	0.17	0.18	0.21	0.99	0.93	8.87	93.61	2.58	20.07	<0.9	<0.9	<2.0

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC4	12/9/05	12/9/05	9-10	10	12	0.07	0.16	0.2	0.23	0.96	1.23	3.11	54.12	2.69	20.02	<0.9	<0.9	1.85
SOC4	12/9/05	12/9/05	11	19	22	0.04	0.175	0.125	0.17	0.98	2.27	4.49	115.86	4.25	28.87	1.39	1.12	3.89
SOC4	12/9/05	12/9/05	12	19	22	0.05	0.16	0.16	0.07	0.59	2.07	3.44	86.22	3.84	26.33	<0.9	<0.9	3.83
SOC3	12/15/05	12/15/05	5-6	78	44	0.12	0.56	0.37	0.22	1.8	5.30	12.69	252.16	11.90	89.70	1.05	3.00	8.17
SOC3	12/15/05	12/15/05	7-8	59	54	0.12	0.38	0.33	0.21	1	4.28	7.45	210.77	9.85	58.81	1.68	2.32	6.11
SOC3	12/15/05	12/15/05	9-10	98	72	0.11	0.27	0.25	0.21	1.1	6.53	12.72	413.96	16.19	70.92	1.75	3.35	8.83
SOC3	12/15/05	12/15/05	11-12	81	74	0.1	0.23	0.22	0.19	1	6.60	12.03	479.70	16.08	53.22	3.05	3.23	8.48
SOC3	12/15/05	12/15/05	13-14	58	75	0.11	0.21	0.27	0.2	1.1	4.83	9.73	300.09	12.24	40.97	1.61	2.46	5.38
SOC3	12/15/05	12/15/05	15-16	116	92	0.11	0.19	0.28	0.21	1	5.98	8.10	401.40	16.12	50.67	2.00	3.11	6.79
SOC3	12/15/05	12/15/05	17-18	152	106	0.11	0.19	0.3	0.24	1.3	8.69	15.51	642.82	22.44	66.72	2.56	4.16	10.97
SOC3	12/15/05	12/15/05	19-20	78	85	0.11	0.18	0.3	0.19	0.98	5.61	8.53	363.05	14.53	40.95	2.31	2.78	6.18
SOC3	12/15/05	12/15/05	21-22	55	69	0.1	0.16	0.3	0.19	1.2	5.07	9.42	335.35	12.53	38.01	1.79	2.57	6.06
SOC3	12/15/05	12/15/05	23-24	30	59	0.1	0.18	0.44	0.175	1.04	3.87	7.90	248.66	9.40	34.52	2.02	2.12	4.60
SOC3	12/18/05	12/18/05	1	34	26													
SOC4	12/18/05	12/18/05	1-2	122	38													
SOC4	12/18/05	12/18/05	3-4	18	10													
SOC4	12/18/05	12/18/05	5-6	16	11													
SOC4	12/18/05	12/18/05	7-8	16	8													
SOC4	12/18/05	12/18/05	9-10	9	7													
SOC4	12/18/05	12/18/05	11-12	18	11													
SOC4	12/18/05	12/18/05	13-14	15	11													
SOC4	12/18/05	12/18/05	15-16	2	11													
SOC4	12/18/05	12/18/05	17-18	3	7													
SOC4	12/18/05	12/18/05	19-20	5	7													
SOC4	12/18/05	12/18/05	21-22	1	8													
SOC4	12/18/05	12/18/05	23-24	2	8													
SOC3	1/13-14/06	1/14/06	1	928	174	0.013	0.303	0.325	0.607	2.178	19.03	60.20	555.39	63.37	248.85	2.08	9.95	32.95
SOC3	1/13-14/06	1/14/06	2	821	153	0.029	0.204	0.358	0.723	2.601	15.66	38.68	415.72	52.17	428.72	1.83	10.07	29.75
SOC3	1/13-14/06	1/14/06	3	255	115	0.031	0.213	0.323	0.389	1.279	6.85	19.09	165.23	20.80	62.41	0.93	3.22	12.54

Site	Storm	Date	Bottles	TSS	Turb	$O\text{-}PO_4$	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	1/13-14/06	1/14/06	4	606	136	0.030	0.171	0.202	0.588	1.680	10.08	35.61	294.0	32.20	103.5	1.23	5.16	18.44
SOC3	1/13-14/06	1/14/06	5	213	142	0.044	0.167	0.197	0.442	1.303	6.80	15.30	174.6	19.92	46.97	0.93	2.50	10.34
SOC3	1/13-14/06	1/14/06	6	95	88	0.042	0.117	0.192	0.193	0.904	3.29	16.14	83.51	10.52	28.02	<0.6	1.28	6.11
SOC3	1/13-14/06	1/14/06	7	39	60	0.048	0.132	0.257	0.178	0.867	1.81	7.21	35.72	4.97	13.25	<0.6	1.22	2.84
SOC3	1/18/06	1/18/06	1	2698	128	0.023	0.615	0.552	0.583	2.694	15.81	37.54	395.8	40.80	216.3	1.87	8.37	25.08
SOC3	1/18/06	1/18/06	2	179	73	0.033	0.564	0.577	0.252	1.776	4.17	9.24	67.61	11.62	48.93	0.82	1.94	7.56
SOC3	1/18/06	1/18/06	3	28	27	0.022	0.357	0.381	0.071	1.142	0.87	4.86	14.53	2.49	10.06	<0.5	<0.5	2.28
SOC3	1/18/06	1/18/06	4	13	14	0.026	0.352	0.265	0.067	0.801	0.51	2.04	5.36	1.15	8.63	<0.5	<0.5	1.06
SOC3	1/18/06	1/18/06	5	13	13	0.030	0.230	0.223	0.066	0.731	<0.5	6.00	7.30	1.28	4.37	<0.5	<0.5	1.11
SOC3	1/18/06	1/18/06	6	19	17	0.035	0.196	0.184	0.077	0.625	<0.5	6.22	6.95	1.20	11.57	<0.5	<0.5	1.05
SOC3	1/18/06	1/18/06	7	20	18	0.031	0.234	0.151	0.058	0.713	0.59	3.99	11.98	1.84	12.09	<0.5	<0.5	1.71
SOC3	1/18/06	1/18/06	8	68	34	0.030	0.144	0.104	0.122	0.741	1.46	6.63	36.07	4.73	16.04	<0.5	0.83	3.03
SOC3	1/18/06	1/18/06	9	66	47	0.034	0.178	0.102	0.106	0.649	1.36	5.63	35.96	4.31	9.92	<0.5	0.56	1.81
SOC3	1/18/06	1/18/06	10	64	54	0.039	0.124	0.101	0.136	0.768	1.57	1.71	42.17	5.00	14.65	0.51	0.62	2.88
SOC3	1/18/06	1/18/06	11	40	58	0.040	0.176	0.115	0.131	0.741	1.61	1.48	43.02	5.40	7.17	<0.5	0.49	2.37
SOC3	1/18/06	1/18/06	12	25	51	0.045	0.147	0.190	0.145	0.893	1.11	2.62	23.79	3.14	10.22	<0.5	<0.5	2.53
SOC3	1/22-23/06	1/24/06	1	33	37													
SOC3	1/22-23/06	1/24/06	2	17	29													
SOC3	1/22-23/06	1/24/06	3	81														
SOC3	1/22-23/06	1/24/06	4	17														
SOC3	1/31/06	1/31/06	1	161	60	0.0235	0.9203	0.9059	0.1701	2.5565	3.91	37.97	91.47	12.03	77.94	0.86	2.31	8.17
SOC3	1/31/06	1/31/06	2	97	44	0.0319	0.4754	0.4353	0.1207	1.4312	3.15	16.46	76.62	9.97	45.91	<0.5	1.92	6.19
SOC3	1/31/06	1/31/06	3	42	40	0.0398	0.371	0.4054	0.1092	0.9274	1.56	18.20	39.94	4.61	19.21	<0.5	0.94	3.89
SOC3	1/31/06	1/31/06	4	28	38	0.0416	0.3514	0.4841	0.1023	1.5642	1.33	14.52	30.07	3.32	11.16	<0.5	0.72	2.21
SOC3	1/31/06	1/31/06	5	19	39	0.0336	0.4130	0.6713	0.1038	0.9926	1.89	17.24	28.20	3.99	16.98	<0.5	0.86	3.70
SOC3	2/2/06	2/2/06	1	263	96													
SOC3	2/2/06	2/2/06	2	23	35													

Site	Storm	Date	Bottles	TSS	Turb	$O\text{-}PO_4$	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	2/4/06	2/4/06	1	223	79	0.01827	0.3501	0.27755	0.15021	1.850368	5.93	23.45	145.9	16.62	82.55	0.96	3.32	10.77
SOC3	2/4/06	2/4/06	2	86	55	0.02551	0.32206	0.29533	0.12235	1.111278	2.53	5.88	56.11	7.16	30.89	0.54	1.25	5.26
SOC3	2/4/06	2/4/06	3	623	184	0.02487	0.21655	0.15894	0.30603	2.422015	10.71	26.53	334.6	33.76	101.9	1.33	5.10	18.22
SOC3	2/4/06	2/4/06	4	255	190	0.03682	0.18346	0.14049	0.31966	2.183035	7.22	14.65	187.3	24.65	46.21	1.50	2.48	13.42
SOC3	2/4/06	2/4/06	5	122	106	0.03447	0.18792	0.12261	0.22869	1.383171	3.79	5.99	102.4	12.16	30.88	0.78	1.58	7.25
SOC3	2/4/06	2/4/06	6	75	102	0.04108	0.19322	0.15615	0.19353	1.215597	2.92	4.83	67.26	9.80	15.06	0.72	1.00	5.02
SOC3	2/4/06	2/4/06	7	43	59	0.03447	0.34454	0.29457	0.14881	1.232828	1.88	2.52	37.48	4.80	17.25	<0.5	2.08	2.96
SOC3	2/4/06	2/4/06	8	77	72	0.03109	0.25344	0.22899	0.16146	1.2847	2.55	2.63	56.56	7.23	19.87	<0.5	3.72	4.58
SOC3	2/4/06	2/5/06	9	1333	448	0.00997	0.227225	0.18654	0.552605	3.160624	24.53	39.49	996.7	90.23	131.4	3.05	9.12	34.15
SOC3	2/4/06	2/5/06	10	436	322	0.01955	0.24923	0.192	0.42408	2.48178	14.65	20.73	433.1	55.44	65.86	2.06	5.55	21.21
SOC3	2/4/06	2/5/06	11			0.03729	0.19167	0.21898	0.29387	1.580512	4.93	4.49	106.6	14.90	28.85	0.94	3.63	8.14
SOC4	2/4/06	2/5/06	1	754	88													
SOC4	2/4/06	2/5/06	2	170	43													
SOC4	2/4/06	2/5/06	3	247	65													
SOC3	2/11/06	2/13/06	1	120	47													
SOC3	2/11/06	2/13/06	2	50	42													
SOC3	2/11/06	2/13/06	3	28	41													
SOC3	2/22-23/06	2/23/06	1	155	78	0.17657	2.58944	1.25792	0.57193	5.34342	8.62	27.17	109.5	17.36	142.9	0.85	6.19	17.36
SOC3	2/22-23/06	2/23/06	2	85	69	0.11865	1.38712	0.93856	0.33711	2.83628	5.57	17.82	71.76	11.37	75.21	0.67	5.43	11.41
SOC3	2/22-23/06	2/23/06	3	44	69	0.1125	1.08288	0.97508	0.29882	2.60081	3.14	10.85	36.23	6.48	35.12	0.66	2.71	5.59
SOC3	2/22-23/06	2/23/06	4	66	85	#VALUE!	1.31424	1.05936	0.26264	2.71391	4.70	13.29	65.10	10.93	51.32	0.58	3.77	8.93
SOC3	2/22-23/06	2/23/06	5	107	87	0.0625	0.80356	0.61434	0.31316	2.51932	6.05	17.60	103.5	16.80	94.90	0.61	4.60	13.83
SOC3	2/22-23/06	2/23/06	6	84	74	0.08714	0.7306	0.36915	0.27209	1.927439	4.27	11.40	79.04	11.28	56.82	0.51	4.66	9.52
SOC3	2/22-23/06	2/23/06	7	73	65	0.10986	0.6716	0.28298	0.26119	1.78878	3.32	9.36	59.57	8.41	49.34	0.56	6.38	7.28
SOC3	2/22-23/06	2/23/06	8	105	68	0.17604	0.70324	0.24117	0.34232	2.24156	3.75	10.31	75.07	9.94	55.68	0.61	6.18	7.58
SOC3	2/22-23/06	2/23/06	9	137	67	0.18958	0.72524	0.25486	0.35522	2.3265	3.76	10.40	78.77	10.37	61.40	0.63	4.66	7.96
SOC3	2/22-23/06	2/23/06	10	104	69	0.19962	0.80592	0.22052	0.37167	2.33038	4.08	9.65	82.80	10.25	55.56	<0.6	2.84	8.06
SOC3	2/22-23/06	2/23/06	11-12	32	46	0.15211	0.72508	0.4066	0.26243	1.75991	1.42	4.41	26.24	3.45	15.26	<0.6	1.93	2.81
SOC3	2/22-23/06	2/23/06	13-14	78.5	74.5	0.096545	0.81732	0.63784	0.290915	2.2352825	4.40	17.23	70.35	10.26	60.00	0.53	2.33	10.09
SOC4	2/22-23/06	2/23/06	1	79	38	0.20922	0.98016	0.58204	0.35648	2.51394	1.95	11.64	24.67	3.76	29.94	<0.6	1.12	4.75

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC4	2/22-23/06	2/23/06	2	70	37	0.05934	0.46768	0.38498	0.21672	1.709452	1.92	8.50	27.99	4.04	36.36	<0.6	1.26	4.50
SOC4	2/22-23/06	2/23/06	3	32	18	0.26391	0.02694	0.16264	0.34222	2.29366	1.04	6.63	20.05	2.38	23.26	<0.6	0.84	2.96
SOC4	2/22-23/06	2/23/06	4	27	19	0.14096	0.71492	0.4102	0.21724	1.763706	0.99	6.62	15.75	2.06	17.44	<0.6	0.96	2.61
SOC3	3/6/06	3/7/06	1	42	54													
SOC4	3/6/06	3/7/06	1	59	53													
SOC3	3/11/06	3/13/06	1	85	39													
SOC4	3/11/06	3/13/06	1	40	27													
SOC3	3/14/06	3/14/06	1	308	109													
SOC3	3/14/06	3/14/06	2	31	57													
SOC4	3/14/06	3/14/06	1	17	26													
SOC3	3/20-21/06	3/21/06	1	93	77	0.187795	2.71824	2.59436	0.23817	7.606225	4.72	20.43	57.63	9.94	74.79	0.68	2.75	8.13
SOC3	3/20-21/06	3/21/06	2	79	58	0.047035	1.09158	1.08356	0.08686	2.431503	3.68	13.90	45.34	8.44	61.73	0.58	2.17	7.46
SOC3	3/20-21/06	3/21/06	3	22	27	0.04171	0.65764	0.53994	0.07052	1.465319	1.39	6.14	16.34	3.03	20.23	<0.5	0.79	2.95
SOC3	3/20-21/06	3/21/06	4	113	44	0.05329	0.49042	0.38312	0.13556	1.651846	2.73	9.02	44.14	6.21	51.22	<0.5	1.62	5.33
SOC3	3/20-21/06	3/21/06	5-6	72	36	0.0484	0.39408	0.31455	0.12734	1.06838	1.83	9.89	35.37	4.47	30.50	<0.5	1.29	3.86
SOC3	3/20-21/06	3/21/06	7-8	18	21	0.05265	0.36848	0.32774	0.09768	0.892533	0.64	5.24	12.37	1.40	9.34	<0.5	<0.5	1.22
SOC3	3/20-21/06	3/21/06	9-10	16	16	0.03584	0.3052	0.29967	0.09644	0.86067	0.56	4.28	15.54	1.32	10.40	<0.5	5.06	1.34
SOC3	3/20-21/06	3/21/06	11-12	59	28	0.04939	0.25853	0.26463	0.17928	0.9002	1.33	9.47	35.53	3.94	31.15	<0.5	1.40	2.88
SOC3	3/20-21/06	3/21/06	13-14	29	38	0.05139	0.3229	0.37947	0.13575	1.089341	1.30	6.01	19.78	3.07	17.59	<0.5	0.75	3.19
SOC3	3/20-21/06	3/21/06	15-16	78	98	0.03972	0.4052	0.32175	0.17354	1.370749	5.10	12.89	77.24	15.08	57.65	0.84	2.44	10.60
SOC3	3/20-21/06	3/21/06	17	27	80	0.05178	0.42112	0.57418	0.15942	1.294481	2.80	10.75	54.55	6.82	33.64	0.67	1.30	6.50
SOC4	3/20-21/06	3/21/06	1	33	23	0.0209	0.37756	0.36487	0.1186	1.158297	0.80	5.26	10.79	1.99	15.95	<0.5	<0.5	2.10
SOC4	3/20-21/06	3/21/06	2	29	11	0.01569	0.21026	0.25106	0.04697	0.631378	0.85	7.30	13.27	2.13	18.03	<0.5	0.63	2.59
SOC4	3/20-21/06	3/21/06	3	16	8	0.01664	0.16754	0.17804	0.04576	0.342748	0.60	6.17	12.10	1.40	11.41	<0.5	<0.5	1.94
SOC4	3/20-21/06	3/21/06	4	1	6	0.02023	0.12098	0.16087	0.04491	0.304458	0.51	4.36	20.79	1.36	10.00	<0.5	0.55	1.97
SOC4	3/20-21/06	3/21/06	5	2	8	0.02515	0.266	0.27813	0.05242	0.367919	<0.5	5.53	4.24	<0.5	5.90	<0.5	<0.5	0.83

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC4	3/20-21/06	3/21/06	6	7	5	0.0236	0.13361	0.22679	0.04796	0.335834	<0.5	2.65	2.57	<0.5	5.66	<0.5	<0.5	<0.5
SOC4	3/20-21/06	3/21/06	7	72	7	0.02727	0.15541	0.20851	0.06418	0.508002	0.54	5.02	17.43	1.55	15.29	<0.5	0.59	1.35
SOC4	3/20-21/06	3/21/06	8	7	10	0.04082	0.19248	0.43912	0.10062	0.594596	<0.5	4.91	7.72	<0.5	10.73	<0.5	<0.5	1.18
SOC4	3/20-21/06	3/21/06	9	22	26	0.03084	0.258515	0.26691	0.107375	0.8313105	1.93	7.51	27.04	4.54	26.77	<0.5	1.10	5.36
SOC3	4/3/06	4/3/06	1-2	237	98	0.07446	0.57956	1.45204	0.40739	3.79312	5.43	18.55	87.92	16.06	82.31	0.76	3.60	10.44
SOC3	4/3/06	4/3/06	3	322	140	0.04735	0.55662	0.70064	0.45162	4.093818	9.34	28.34	164.2	26.44	122.2	1.08	5.28	18.20
SOC3	4/3/06	4/3/06	4	636	208	0.05725	0.38178	0.4952	0.73741	4.657144	15.01	43.45	336.5	44.00	174.1	1.84	8.82	27.00
SOC3	4/3/06	4/3/06	5	315	171	0.05932	0.29079	0.48156	0.43087	2.699212	8.15	31.20	173.0	23.50	80.43	0.91	4.13	14.69
SOC3	4/3/06	4/3/06	6	355	110	0.05956	0.35768	0.39517	0.36547	2.47543	6.77	19.82	148.1	19.62	73.92	0.61	4.02	12.84
SOC3	4/3/06	4/3/06	7	258	128	0.0634	0.30912	0.42258	0.32566	2.125511	5.86	14.85	128.3	16.43	55.59	0.82	3.07	10.69
SOC3	4/3/06	4/3/06	8	71	89	0.0566	0.28279	0.54066	0.23442	1.848099	2.62	8.59	38.16	6.39	31.52	<0.6	1.24	4.69
SOC3	4/3/06	4/3/06	9	37	69	0.037665	0.269995	0.56154	0.1698	1.4756855	1.52	7.29	21.38	3.70	20.82	<0.6	0.82	3.13
SOC4	4/3/06	4/3/06	1	252	88													
SOC4	4/3/06	4/3/06	2	37	17													
SOC3	4/3/06	4/4/06	10	65	61													
SOC4	4/3/06	4/4/06	1	52	37													
SOC3	4/8-9/2006	4/10/06	1	60	68													
SOC3	4/8-9/2006	4/10/06	2	60	53													
SOC3	4/8-9/2006	4/10/06	3	31	34													
SOC3	4/8-9/2006	4/10/06	4	27	32													
SOC4	4/8-9/2006	4/10/06	1	28	39													
SOC3	4/17/06	4/18/06	1	382	142													
SOC3	4/17/06	4/18/06	2	59	62													
SOC4	4/17/06	4/18/06	1	122	44													
SOC4	4/17/06	4/18/06	2	27	27													
SOC3	4/22/06	4/24/06	1	291	101													
SOC3	4/22/06	4/24/06	2	325	147													
SOC3	4/22/06	4/24/06	3	217	84													

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC4	4/25-26/06	4/26/06	1	451	36													
SOC4	4/25-26/06	4/26/06	2	342	28													
SOC4	4/25-26/06	4/26/06	4	810	101													
SOC4	4/26-27/06	4/27/06	1	296	14	0.012545	0.237435	0.360945	0.06415	0.7470	0.88	2.02	42.53	1.55	13.44	0.71	<0.6	1.17
SOC4	4/26-27/06	4/27/06	2	38	19	0.02604	0.17779	0.24032	0.09123	0.9650	0.80	2.65	12.48	1.90	16.93	<0.6	<0.6	1.60
SOC4	4/26-27/06	4/27/06	3	17	15	0.02278	0.10064	0.13547	0.06815	0.6683	0.63	3.93	16.38	1.48	13.48	<0.6	<0.6	<1.1
SOC4	4/26-27/06	4/27/06	4	19	10	0.02957	0.07658	0.11218	0.07092	0.5204	0.52	2.26	8.65	<1.1	10.16	<0.6	<0.6	<1.1
SOC4	4/26-27/06	4/27/06	5	33	17	0.01322	0.21169	0.41386	0.06696	0.8238	1.43	2.20	104.6	2.65	15.91	<0.6	0.73	1.40
SOC4	4/26-27/06	4/27/06	6	21	8	0.0173	0.2175	0.3717	0.05432	0.7042	0.96	0.71	89.43	1.63	11.00	1.20	<0.6	<1.1
SOC4	4/26-27/06	4/27/06	7-8	20	11	0.02621	0.15826	0.27709	0.06081	0.6213	0.76	0.89	78.90	1.44	9.69	1.07	<0.6	<1.1
SOC4	4/26-27/06	4/27/06	9-10	20	14	0.02839	0.12654	0.14393	0.06854	0.4954	1.63	1.78	127.8	2.45	13.60	0.74	0.69	2.17
SOC4	4/26-27/06	4/27/06	11	14	19	0.03149	0.16538	0.24763	0.07055	0.5539	1.71	1.54	106.3	2.30	13.43	<0.6	0.66	2.06
SOC4	4/26-27/06	4/27/06	12-13	17	19	0.02368	0.2153	0.26295	0.09666	0.7031	2.70	2.80	194.7	4.23	19.81	0.81	1.05	4.20
SOC4	4/26-27/06	4/27/06	14-15	17	14	0.02744	0.12205	0.1475	0.06711	0.4746	1.76	1.95	158.7	2.69	13.48	<0.6	0.82	1.61
SOC4	4/26-27/06	4/27/06	16-17	35	14	0.02995	0.11277	0.13562	0.11487	0.5564	1.69	1.98	136.8	2.56	12.16	<0.6	0.65	1.84
SOC4	4/26-27/06	4/27/06	18-20	8	10	0.05531	0.133265	0.17987	0.11258	0.8836	1.00	1.01	88.30	1.72	9.03	0.59	0.62	1.38
SOC4	5/7/06	5/8/06	1-2	22	15	0.01031	0.5296	0.78304	0.11739	1.9447	1.45	2.32	119.6	2.49	19.68	<0.6	0.81	<1.1
SOC4	5/7/06	5/8/06	3-4	43	22	0.01479	0.55136	0.82224	0.10229	1.4016	2.64	2.69	187.1	4.42	28.72	<0.6	1.17	1.32
SOC4	5/7/06	5/8/06	5-6	41	12	0.01588	0.21003	0.23524	0.07237	0.6182	1.46	2.19	109.9	2.73	20.32	<0.6	0.75	<1.1
SOC4	5/7/06	5/8/06	7-8	8	7	0.01958	0.12658	0.19645	0.04694	0.3886	1.05	<0.6	100.1	1.40	8.35	<0.6	<0.6	<1.1
SOC4	5/7/06	5/8/06	9-10	36	6	0.01733	0.17882	0.17881	0.05291	0.5088	1.04	1.08	74.59	1.45	10.38	<0.6	0.76	<1.1
SOC4	5/7/06	5/8/06	11-12	39	6	0.01733	0.14763	0.11252	0.05084	0.4469	1.65	<0.6	163.6	2.29	10.44	<0.6	0.60	<1.1
SOC4	5/7/06	5/8/06	13-14	16	6	0.02132	0.10023	0.09967	0.04826	0.4684	1.84	<0.6	294.0	2.79	7.18	0.75	0.67	<1.1
SOC4	5/7/06	5/8/06	15-16	52	10	0.01893	0.13103	0.09747	0.07455	0.4510	1.87	1.42	126.1	2.92	14.43	0.89	0.89	<1.1
SOC4	5/7/06	5/8/06	17-18	113	13	0.02609	0.16019	0.1183	0.0763	0.4723	0.96	<0.6	69.73	2.03	8.04	<0.6	<0.6	<1.1
SOC4	5/7/06	5/8/06	19-20	15	11	0.04559	0.02621	0.12581	0.10222	0.5525	1.11	<0.6	139.7	1.73	7.27	0.56	<0.6	<1.1
SOC4	5/7/06	5/8/06	21-22	15	9	0.03201	0.09632	0.13332	0.07024	0.4482	0.59	<0.6	41.15	<1.1	5.71	<0.6	<0.6	<1.1
SOC4	5/7/06	5/8/06	23-24	7	11	0.07511	0.020325	0.1953	0.14949	0.8908	0.62	<0.6	77.65	<1.1	5.46	<0.6	<0.6	<1.1

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	5/11/06	5/12/06	1	536	127													
SOC3	5/11/06	5/12/06	2	86	68													
SOC4	5/11/06	5/12/06	1	16	18													
SOC4	5/14/06	5/15/06	1	118	25	0.00742	0.46276	0.4920	0.14262	1.8900	4.12	7.80	267.2	8.43	57.01	<0.5	2.01	4.35
SOC4	5/14/06	5/15/06	2-3	122	23	0.01693	0.39836	0.2454	0.09218	0.9349	3.86	4.14	241.2	7.16	30.94	0.74	1.51	1.71
SOC4	5/14/06	5/15/06	4-5	48	15	0.01977	0.27266	0.1757	0.05868	0.6225	1.42	1.67	98.92	2.93	10.26	<0.5	0.59	<1.1
SOC4	5/14/06	5/15/06	6-7	138	44	0.03021	0.17253	0.1241	0.12684	0.8577	2.95	2.97	293.5	8.96	19.30	<0.5	1.33	<1.1
SOC4	5/14/06	5/15/06	8-9	155	53	0.04301	0.14386	0.1266	0.17697	1.1609	3.74	4.15	342.8	11.33	38.42	<0.5	2.86	<1.1
SOC4	5/14/06	5/15/06	10-11	98	51	0.07459	0.12219	0.1488	0.20623	1.1418	2.26	3.09	220.0	7.52	19.39	<0.5	1.41	<1.1
SOC4	5/14/06	5/15/06	12-13	75	33	0.06613	0.18001	0.1399	0.16308	0.8742	1.55	1.51	137.5	4.42	14.72	<0.5	1.17	<1.1
SOC4	5/14/06	5/15/06	14-15	57	34	0.09039	0.18536	0.1669	0.19519	1.0904	1.27	1.66	119.2	4.23	13.69	<0.5	1.00	<1.1
SOC4	5/14/06	5/15/06	16-17	64	23	0.06153	0.25887	0.2361	0.15225	1.0745	1.20	1.91	114.4	3.28	13.10	<0.5	0.72	<1.1
SOC4	5/14/06	5/15/06	18-19	53	28	0.001062	0.001516	0.1103	0.00386	0.0127	1.06	1.52	110.3	3.86	12.73	<0.5	0.81	<1.1
SOC4	5/14/06	5/15/06	20-21	8	25	0.13348	0.15432	0.3208	0.24545	1.8760	0.63	1.70	67.89	2.85	10.33	<0.5	0.52	<1.1
SOC3	5/14/06	5/15/06		81	50													
SOC3	5/14/06	5/15/06		692	210													
SOC3	5/14/06	5/15/06		919	442													
SOC3	5/14/06	5/15/06		231	223													
SOC4	5/18/06	5/19/06	1	112	23	0.00692	0.44848	0.31832	0.11439	1.3355	2.62	2.93	201.3	5.06	23.20	2.27	1.23	<0.9
SOC4	5/18/06	5/19/06	2	104	19	0.03322	0.45984	0.30274	0.09057	0.9601	2.91	1.81	160.8	4.46	30.47	1.55	1.05	<0.9
SOC4	5/18/06	5/19/06	3	46	18	0.04197	0.42256	0.29956	0.08678	0.9122	1.68	1.33	89.59	2.75	12.48	1.84	0.68	<0.9
SOC4	5/18/06	5/19/06	4	27	13	0.073235	0.44516	0.349515	0.12409	1.0259	0.86	1.05	47.18	1.86	9.80	1.39	0.61	<0.9
SOC4	5/18/06	5/19/06	5	21	13	0.05306	0.4106	0.36414	0.11	0.9953	0.80	1.06	44.99	1.88	9.37	3.33	0.47	<0.9
SOC4	5/18/06	5/19/06	6	12	13	0.0359	0.4466	0.4341	0.08388	1.0395	0.59	0.68	40.41	1.56	9.94	1.58	<0.5	<0.9
SOC3	5/26/06	5/30/06	2	178	64													
SOC3	5/26/06	5/30/06	3	77	58													
SOC3	5/26/06	5/30/06	4	25	19													
SOC4	5/26/06	5/30/06	1	97	8													

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	6/2/06	6/3/06	4	249	87													
SOC3	6/2/06	6/3/06	5	950	181													
SOC3	6/2/06	6/3/06	6	139	84													
SOC3	6/2/06	6/3/06	7	280	135													
SOC3	6/2/06	6/3/06	8	74	83													
SOC4	6/2/06	6/3/06	1-2	136	28	0.00777	0.76252	0.64512	0.20743	2.88456	5.54	9.40	405.6	11.94	72.67	1.43	2.45	10.35
SOC4	6/2/06	6/3/06	3-4	98	15	0.02174	0.2531	0.25608	0.09678	0.94855	2.00	2.72	149.4	4.78	22.37	<0.5	1.09	4.42
SOC4	6/2/06	6/3/06	5-6	55	16	0.04971	0.17284	0.20018	0.1126	0.93440	0.65	1.07	103.8	3.03	12.01	<0.5	0.71	1.79
SOC4	6/2/06	6/3/06	7-8	41	13	0.05613	0.15447	0.18578	0.10286	0.64903	<0.5	1.27	76.13	2.43	8.88	1.76	0.54	1.44
SOC4	6/2/06	6/3/06	9-10	34	11	0.04704	0.17252	0.17213	0.08602	0.54585	<0.5	<0.5	32.53	1.27	5.55	3.03	<0.5	<1.1
SOC4	6/2/06	6/3/06	11-12	22	7	0.04664	0.13821	0.15546	0.0887	0.43908	<0.5	<0.5	39.80	1.14	5.53	1.49	<0.5	<1.1
SOC4	6/2/06	6/3/06	13-14	21	7	0.04804	0.11748	0.1552	0.08941	0.46755	0.90	1.24	62.55	2.03	8.06	0.48	<0.5	1.52
SOC4	6/2/06	6/3/06	15-16	15	6	0.04721	0.16332	0.16723	0.08591	0.52109	0.55	0.94	34.70	1.42	6.79	0.76	<0.5	1.41
SOC4	6/2/06	6/3/06	17-18	17	5	0.04046	0.12483	0.17217	0.0737	0.41605	<0.5	0.59	25.77	0.89	4.27	0.53	<0.5	<1.1
SOC4	6/2/06	6/3/06	19-21	12	5	0.0455	0.08854	0.22206	0.06868	0.49651	<0.5	1.42	23.61	1.10	6.01	1.79	<0.5	1.02
SOC4	6/2/06	6/3/06	22-24	11	7	0.04068	0.09183	0.27874	0.081245	0.56669	<0.5	0.99	29.41	1.22	6.32	2.87	<0.5	1.01
SOC3	6/4-5/06	6/5/06	2	64	27													
SOC3	6/4-5/06	6/5/06	3	32	21													
SOC3	6/4-5/06	6/5/06	4	16	17													
SOC3	6/4-5/06	6/5/06	5	14	7													
SOC3	6/4-5/06	6/5/06	6	14	13													
SOC3	6/4-5/06	6/5/06	7	11	10													
SOC3	6/4-5/06	6/5/06	8	94	68													
SOC3	6/4-5/06	6/5/06	9	20	16													
SOC3	6/8/06	6/9/06	1	158	69													
SOC3	6/8/06	6/9/06	2	20	17													
SOC3	6/11-12/06	6/12/06	3-4	57	30													
SOC3	6/11-12/06	6/12/06	5	74	27													

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	6/11-12/06	6/12/06	6-7	42	34													
SOC3	6/11-12/06	6/12/06	8-9	121	73													
SOC3	6/11-12/06	6/12/06	10	39	60													
SOC3	6/14/06	6/15/06	1	62	34													
SOC3	6/14/06	6/15/06	2	43	33													
SOC3	6/14/06	6/15/06	3	177	104													
SOC3	6/14/06	6/15/06	4	631	149													
SOC3	6/14/06	6/15/06	5	208	81													
SOC3	6/14/06	6/15/06	6	21	46													
SOC3	6/14/06	6/15/06	7	12	41													
SOC3	6/23/06	6/24/06	1	81	48	0.02509	1.11544	1.05296	0.31953	3.326064	4.12	9.07	182.1	9.71	51.23	1.49	1.95	7.51
SOC3	6/23/06	6/24/06	2	104	37	0.01873	0.38472	0.55492	0.151145	1.466105	2.50	4.23	107.4	5.71	26.50	1.12	1.02	4.92
SOC3	6/23/06	6/24/06	3	16	20	0.03094	0.38256	0.51484	0.11052	1.031265	0.49	1.39	12.06	1.62	6.07	1.47	<0.5	<1.1
SOC3	6/23/06	6/24/06	4	31	23	0.02235	0.35648	0.42878	0.11717	1.074676	1.37	2.75	49.92	3.53	13.18	1.37	0.58	2.91
SOC3	6/23/06	6/24/06	5	17	21	0.01828	0.39792	0.4106	0.0864	0.882435	1.17	3.22	44.38	3.18	12.44	0.52	0.56	2.54
SOC4	6/23/06	6/24/06	1	39	16													
SOC4	6/23/06	6/24/06	2	8	6													
SOC4	6/23/06	6/24/06	3	10	6													
SOC4	6/23/06	6/24/06	4	8	4													
SOC3	6/25-26/06	6/26/06	1-2	100	54	0.66607	3.7904	0.01691	1.35932	9.07146	0.56	2.23	26.07	1.45	10.31	<0.5	<0.5	<1.1
SOC3	6/25-26/06	6/26/06	3-4	137	66	0.08236	0.3134	0.08281	0.40811	3.321102	5.31	6.54	275.0	12.12	32.81	<0.5	2.35	7.80
SOC3	6/25-26/06	6/26/06	5-6	32	26	0.02824	0.06767	0.10445	0.26613	2.306546	0.98	2.56	50.10	2.42	9.61	<0.5	0.50	1.73
SOC3	6/25-26/06	6/26/06	7-8	88	47	0.03108	0.15588	0.10939	0.24828	2.276706	2.76	3.60	194.2	7.20	18.73	0.90	1.24	4.18
SOC3	6/25-26/06	6/26/06	9-10	38	33	0.78969	1.06892	0.01330	1.44444	11.89605	0.64	4.57	28.68	1.76	13.89	0.63	0.66	1.11
SOC3	6/25-26/06	6/26/06	11-12	23	21	0.30428	0.84432	0.16787	0.55832	5.46013	0.91	1.98	46.15	1.98	11.16	<0.5	<0.5	1.59
SOC3	6/25-26/06	6/26/06	13-14	38	31	0.66913	1.3288	0.20856	0.94524	7.87653	1.76	3.72	104.2	3.76	18.03	0.59	0.84	3.04
SOC3	6/25-26/06	6/26/06	15	40	36	1.03801	2.57568	0.19446	1.43833	11.68252	0.88	2.98	38.61	1.23	14.81	0.61	0.49	1.63
SOC4	6/25-26/06	6/26/06	1	60	16	0.00517	0.6164	0.26603	0.15125	1.645143	1.99	4.62	134.0	3.89	22.85	<0.5	0.86	4.68
SOC4	6/25-26/06	6/26/06	2	25	6	0.02199	0.45892	0.10842	0.06549	0.878897	<0.5	1.72	17.67	1.16	4.97	<0.5	<0.5	<1.1

Site	Storm	Date	Bottles	TSS	Turb	$O\text{-}PO_4$	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC4	6/25-26/06	6/26/06	3	55	10	0.00907	0.28862	0.05549	0.05417	0.680719	1.43	3.79	107.8	3.00	16.55	0.49	0.60	3.02
SOC4	6/25-26/06	6/26/06	4	21	4	0.01601	0.22978	0.1001	0.05077	0.449993	0.48	2.37	27.20	<1.1	10.01	0.70	<0.5	<1.1
SOC4	6/25-26/06	6/26/06	5-6	25	8	0.01498	0.22138	0.14674	0.04827	0.55830	<0.5	2.04	36.59	1.04	4.73	1.74	<0.5	<1.1
SOC4	6/25-26/06	6/26/06	7-8	15	5	0.01056	0.13017	0.11964	0.04767	0.452613	<0.5	3.34	27.59	1.07	5.01	1.61	<0.5	<1.1
SOC4	6/25-26/06	6/26/06	9-10	7	5	0.02958	0.16501	0.12007	0.06619	0.510072	<0.5	1.80	16.83	<1.1	4.00	<0.5	<0.5	<1.1
SOC3	7/6/06	7/6/06	1	108	72	0.06783	1.29628	0.03869	0.87490	6.89476	7.05	10.63	338.1	15.89	61.95	0.56	2.73	15.75
SOC3	7/6/06	7/6/06	2	75	58	0.02031	0.20417	0.64004	0.45164	2.93835	2.79	4.39	140.2	6.98	27.89	0.86	1.33	5.60
SOC3	7/6/06	7/6/06	3	86	54	0.03118	0.41368	0.6402	0.23363	1.894595	4.40	6.81	230.5	9.72	39.61	0.90	2.04	9.51
SOC3	7/6/06	7/6/06	4	44	55	0.04647	0.35728	0.44964	0.18394	1.332739	2.98	3.80	148.6	5.87	21.67	0.81	1.17	6.72
SOC3	7/6/06	7/6/06	5	220	105	0.04417	0.11954	0.16571	0.26995	0.96399	7.93	7.09	612.2	21.23	40.00	1.09	3.35	14.35
SOC3	7/6/06	7/6/06	6	22	38	0.04135	0.12213	0.16383	0.1233	0.695483	1.07	1.86	53.09	2.04	8.72	<0.5	<0.5	2.48
SOC3	7/6/06	7/6/06	7	49	46	0.03615	0.09783	0.12984	0.14708	0.682255	1.71	5.72	101.0	3.73	14.54	0.52	0.72	3.93
SOC3	7/6/06	7/6/06	8	25	43	0.03844	0.09619	0.14304	0.11444	0.650165	1.69	3.01	92.96	3.48	13.59	<0.5	0.71	3.92
SOC3	7/6/06	7/6/06	9	16	44	0.04042	0.10742	0.21646	0.13631	0.780882	1.71	2.69	81.48	2.71	14.08	<0.5	<0.5	3.98
SOC4	7/6/06	7/6/06	1-2															
SOC4	7/6/06	7/6/06	3-4															
SOC4	7/6/06	7/6/06	5-6															
SOC4	7/6/06	7/6/06	7-8															
SOC3	7/19/06	7/19/06	1	495	106	0.07305	0.8376	1.2434	0.73984	5.297904	16.03	27.25	1144	33.90	246.05	1.06	7.10	33.92
SOC3	7/19/06	7/19/06	2	190	64	0.08816	1.12432	1.05876	0.28078	3.533346	8.00	14.84	465.4	16.20	107.32	0.74	3.18	21.30
SOC3	7/19/06	7/19/06	3	95	54	0.12797	1.39288	1.15772	0.33471	3.480604	4.89	9.41	226.7	9.68	58.77	<0.5	1.97	12.91
SOC3	7/19/06	7/19/06	4	57	50	0.14365	1.41632	1.2162	0.30054	3.652918	4.65	9.26	184.6	8.86	51.70	<0.5	1.68	12.03
SOC3	7/19/06	7/19/06	5	52	49	0.14431	1.31928	1.31788	0.29431	3.942144	3.19	6.94	131.9	6.21	36.18	0.61	1.34	8.30
SOC3	7/19/06	7/19/06	6	40	47	0.13864	1.05512	1.45656	0.33563	4.323414	2.50	6.75	98.16	5.49	35.54	0.48	1.26	5.92
SOC3	7/19/06	7/19/06	7	26	38	0.11693	1.06184	1.74128	0.34562	4.48963	2.16	5.62	85.09	4.55	26.99	0.62	1.04	5.28
SOC3	7/19/06	7/19/06	8	57	86	0.05903	0.82368	2.01816	0.23029	3.165758	4.85	10.21	426.5	11.19	59.37	<0.5	2.30	9.57
SOC3	7/19/06	7/19/06	9	60	105	0.05876	0.94864	2.2004	0.20412	3.211068	6.36	12.62	497.9	13.31	70.71	0.53	2.68	13.53
SOC3	7/19/06	7/19/06	10	60	97	0.1849	1.09976	2.43376	0.15648	3.528562	4.85	10.75	313.2	10.03	59.30	0.66	2.27	10.98
SOC3	7/19/06	7/19/06	11	43	91	0.12009	1.2136	2.47832	0.271375	4.10937	4.49	10.17	277.0	9.24	55.56	0.57	2.03	10.83

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	7/22/06	7/23/06	2	335	70	0.0096	0.78572	0.42436	0.38888	3.4031	11.90	17.82	623.4	20.95	153.5	0.54	4.07	25.09
SOC3	7/22/06	7/23/06	3	353	52	0.01621	0.43364	0.38332	0.26209	3.4531	9.86	13.75	494.5	18.73	119.7	0.68	4.07	24.65
SOC3	7/22/06	7/23/06	4	121	61	0.03133	0.41832	0.55776	0.22826	2.3961	5.76	8.03	277.9	12.08	56.58	0.73	2.27	15.49
SOC3	7/22/06	7/23/06	5	67	50	0.05491	0.51428	0.727	0.20713	2.2922	4.08	5.78	179.0	8.09	35.74	0.46	1.62	11.23
SOC3	7/22/06	7/23/06	6	34	35	0.06765	0.5418	0.95552	0.21607	2.1021	2.38	4.00	92.40	4.76	22.08	<0.5	0.98	6.52
SOC3	7/22/06	7/23/06	7	18	25	0.060785	0.31087	1.2754	0.16585	1.6995	0.75	2.26	18.48	1.50	14.90	<0.5	0.54	1.62
SOC4	7/22/06	7/23/06	1-3	78	16													
SOC4	7/23/06	7/24/06	4	36	21	0.00792	0.23443	0.70972	0.07611	1.0608	1.29	3.07	87.78	2.56	18.75	<0.5	1.04	2.69
SOC4	7/23/06	7/24/06	5	78	25	0.00506	0.2966	0.45602	0.07592	1.0030	2.35	4.20	215.83	5.02	30.70	<0.5	1.07	5.70
SOC4	7/23/06	7/24/06	6	70	11	0.0084	0.16388	0.3021	0.07535	0.7318	1.47	2.14	97.24	2.88	18.01	<0.5	0.69	4.18
SOC4	7/23/06	7/24/06	7	30	7	0.01399	0.10117	0.17767	0.05278	0.4215	0.96	1.53	72.70	2.20	13.75	<0.5	0.52	2.80
SOC4	7/23/06	7/24/06	8	23	6	0.0128	0.05948	0.12547	0.04575	0.3046	0.79	1.03	49.09	1.32	9.59	<0.5	<0.5	2.10
SOC4	7/23/06	7/24/06	9	44	6	0.0145	0.05292	0.08454	0.04077	0.2796	0.93	1.27	74.17	1.96	10.88	<0.5	<0.5	2.52
SOC4	7/23/06	7/24/06	10	20	5	0.01915	0.02373	0.07577	0.03762	0.1886	0.62	1.79	45.43	1.26	7.55	<0.5	<0.5	2.34
SOC4	7/23/06	7/24/06	11-12	7	4	0.012105	0.033895	0.08924	0.03974	0.2289	0.15	0.80	10.74	<1.1	3.08	<0.5	<0.5	<1.1
SOC3	7/23/06	7/24/06	8	37	33													
SOC3	7/23/06	7/24/06	9	30	30													
SOC3	7/23/06	7/24/06	10	16	19													
SOC3	7/23/06	7/24/06	12	123	60													
SOC3	7/23/06	7/24/06	13	61	31													
SOC3	7/23/06	7/24/06	14	28	22													
SOC3	7/23/06	7/24/06	15	12	15													
SOC3	7/23/06	7/24/06	16	183	39													
SOC3	7/23/06	7/24/06	17-18	94	33													
SOC3	7/23/06	7/24/06	19-20	261	53													
SOC3	7/23/06	7/24/06	21-22	221	80													
SOC3	7/23/06	7/24/06	23-24	274	114													
SOC3	7/25/06	7/25/06	1	55	31	0.33616	0.29908	0.35307	0.45232	2.3029	1.84	3.60	111.2	3.53	26.88	<0.5	1.34	4.15

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	7/25/06	7/25/06	2	168	56	0.04939	0.40412	0.4765	0.18317	1.7404	8.27	12.58	415.6	15.46	103.3	<0.5	3.38	21.19
SOC3	7/25/06	7/25/06	3-4	87	57	0.05437	0.29572	0.36882	0.14915	1.3699	6.31	8.47	251.5	11.35	59.92	<0.5	2.09	17.68
SOC3	7/25/06	7/25/06	5-6	32	44	0.06175	0.26924	0.3628	0.15088	1.0055	2.44	3.27	95.24	4.09	19.65	<0.5	0.84	7.27
SOC3	7/25/06	7/25/06	7-8	25	39	0.05969	0.23196	0.33666	0.13452	0.9389	1.96	2.95	77.98	3.01	16.26	<0.5	0.63	5.50
SOC3	7/25/06	7/25/06	9-10	26	44	0.0645	0.20276	0.29603	0.12308	1.0409	2.16	3.52	85.88	3.73	19.98	<0.5	0.85	6.08
SOC3	7/25/06	7/25/06	11	21	45	0.06347	0.18848	0.31268	0.11656	0.8993	2.04	3.13	73.50	3.50	20.55	<0.5	0.67	5.75
SOC3	7/25/06	7/25/06	12	17	47	0.068575	0.15368	0.40926	0.12564	0.9089	1.23	1.65	43.35	1.85	9.13	<0.5	<0.5	3.07
SOC4	7/25/06	7/26/06	4-5	151	23													
SOC4	7/25/06	7/26/06	6-7	95	14													
SOC4	7/25/06	7/26/06	8-10	68	15													
SOC4	7/25/06	7/26/06	11-13	46	14													
SOC4	7/25/06	7/26/06	14-16	19	12													
SOC4	7/25/06	7/26/06	17-19	16	10													
SOC4	7/25/06	7/26/06	20-22	12	8													
SOC3	7/25/06	7/26/06	1	488	71	0.01526	0.1494	0.26142	0.23694	1.6593								
SOC3	7/25/06	7/26/06	2-3	1184	222	0.03334	0.09242	0.1564	0.29528	2.2074								
SOC3	7/25/06	7/26/06	4-5	296	150	0.05772	0.06275	0.16781	0.25001	1.0988								
SOC3	7/25/06	7/26/06	6-7	184	102	0.06491	0.08618	0.18718	0.21273	1.4498								
SOC3	7/25/06	7/26/06	8-9	114	95	0.07113	0.09744	0.23949	0.24794	1.1446								
SOC3	7/25/06	7/26/06	10-11	75	100	0.07868	0.10967	0.31539	0.20607	1.0655								
SOC3	7/25/06	7/26/06	12-13	35	76	0.07507	0.09079	0.43472	0.16151	1.0369								
SOC3	8/11/06	8/14/06	1	218	104													
SOC3	8/11/06	8/14/06	2	76	70													
SOC3	8/11/06	8/14/06	3	74	64													
SOC3	8/18/06	8/18/06	2-4	111	72													
SOC3	8/20/06	8/21/06	5	887	147	0.0558	0.2632	0.0695	0.7300	8.3959	31.63	43.97	1338	61.22	335.4	2.20	10.71	69.13
SOC3	8/20/06	8/21/06	6	274	79	0.0722	0.3933	0.5228	0.5006	3.2674	10.80	15.26	401.8	22.35	146.0	0.66	3.80	26.66
SOC3	8/20/06	8/21/06	7	125	61	0.1167	0.4281	0.6022	0.4744	3.0787	11.44	14.58	331.2	21.49	100.5	0.87	4.04	24.20
SOC3	8/20/06	8/21/06	8	88	57	0.1447	0.4315	0.8136	0.4688	2.8655	8.19	11.25	278.4	18.70	76.78	0.74	2.98	19.78

Site	Storm	Date	Bottles	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	8/20/06	8/21/06	9	54	51	0.1598	0.4772	0.9356	0.4608	2.8613	5.99	9.90	184.3	14.30	59.85	<0.5	2.31	14.16
SOC3	8/20/06	8/21/06	10	31	33	0.1587	0.4180	1.2452	0.3583	2.7583	3.83	8.54	92.92	8.77	45.15	<0.5	1.75	8.04
SOC3	8/23/06	8/21/06	1-2	50	35													
SOC3	8/23/06	8/21/06	3-4	37	41													
SOC3	8/30/06	8/31/06	1	131	67	0.1522	1.4914	0.7733	0.7425	6.5828	12.09	30.62	500.2	34.44	209.6	<0.5	5.13	27.33
SOC3	8/30/06	8/31/06	2	101	47	0.1070	1.0076	0.9662	0.4237	4.0268	7.39	17.47	409.7	24.93	145.3	<0.5	3.48	17.99
SOC3	8/30/06	8/31/06	3	83	34	0.1308	0.7574	0.8410	0.4051	3.0822	4.36	11.34	162.3	13.14	93.70	<0.5	2.03	12.23
SOC3	8/30/06	8/31/06	4	36	22	0.1274	0.5569	0.7940	0.2822	2.2856	3.11	8.11	120.7	12.04	59.93	<0.5	1.79	8.07
SOC3	8/30/06	8/31/06	5	19	14	0.1495	0.5706	0.8115	0.2845	5.3048	1.87	7.06	63.34	8.44	54.25	<0.5	1.49	5.98
SOC3	8/31-9/1/06	9/1/06	1	243	92	0.02919	0.11556	0.22394	0.3177	2.286	9.11	13.29	524.6	22.93	77.18	<0.5	3.66	27.36
SOC3	8/31-9/1/06	9/1/06	2	42	48	0.04291	0.11023	0.29442	0.1470	2.072	3.86	6.76	212.1	9.29	35.36	<0.5	1.80	12.21
SOC3	8/31-9/1/06	9/1/06	3	40	54	0.0306	0.13513	0.24999	0.1590	1.048	5.37	8.82	314.1	12.35	45.34	<0.5	2.13	14.84
SOC3	8/31-9/1/06	9/1/06	4	102	52	0.04173	0.1059	0.10517	0.1915	0.952	5.92	8.72	278.9	13.70	49.83	0.62	2.63	17.30
SOC3	8/31-9/1/06	9/1/06	5	38	33	0.04897	0.10989	0.09895	0.1357	0.768	3.49	5.38	161.0	8.17	29.03	<0.5	2.10	9.63
SOC3	8/31-9/1/06	9/1/06	6	22	25	0.04058	0.11853	0.14705	0.1209	0.814	1.89	3.83	95.48	4.79	19.48	<0.5	1.02	5.84
SOC3	8/31-9/1/06	9/1/06	7	49	24	0.02814	0.05305	0.07371	0.1131	0.747	2.82	5.41	131.4	7.32	232.1	<0.5	4.94	8.08
SOC3	8/31-9/1/06	9/1/06	8	54	19	0.04067	0.05588	0.0788	0.1024	0.602	1.88	3.37	97.67	5.43	28.20	<0.5	1.52	5.90
SOC3	8/31-9/1/06	9/1/06	9	39	16	0.03448	0.02908	0.0796	0.1047	0.571	1.77	3.69	93.66	5.00	39.47	<0.5	10.88	5.84
SOC3	8/31-9/1/06	9/1/06	10	1224	133	0.03834	0.02066	0.07743	0.3520	2.7158	15.45	23.53	976.5	37.88	143.3	1.99	9.17	41.16
SOC3	8/31-9/1/06	9/1/06	11	97	49	0.04308	0.05797	0.13277	0.6818	2.102	4.52	8.98	313.0	12.17	57.44	0.83	2.72	13.75
SOC3	9/4-5/06	9/5/06	1	124	66	0.01336	0.3611	0.29624	0.3224	1.88095	10.04	13.82	407.6	21.92	86.24	1.17	7.55	25.20
SOC3	9/4-5/06	9/5/06	2	74	55	0.0236	0.30466	0.35736	0.1763	1.5518	7.31	8.32	279.0	14.95	48.09	<0.5	2.65	18.80
SOC3	9/4-5/06	9/5/06	3	906	170	0.0658	0.08342	0.18012	0.4208	1.92628	19.71	21.39	1279	44.58	99.46	2.06	7.94	35.79
SOC3	9/4-5/06	9/5/06	4	155	114	0.05173	0.05914	0.21452	0.2104	1.16318	12.51	12.74	686.4	27.85	61.53	1.90	4.79	26.56
SOC3	9/4-5/06	9/5/06	5	98	97	0.05591	0.06527	0.24236	0.2144	1.0628	9.15	9.67	490.2	20.75	48.93	1.51	3.78	20.03
SOC3	9/4-5/06	9/5/06	6	347	78	0.03674	0.0617	0.21876	0.2761	1.6184	12.31	16.07	760.9	27.56	91.14	1.05	5.63	27.37
SOC3	9/4-5/06	9/5/06	7	164	94	0.04373	0.07669	0.19612	0.2673	1.12968	10.44	12.62	605.2	24.89	60.55	1.74	6.28	20.65
SOC3	9/4-5/06	9/5/06	8	191	97	0.05114	0.18055	0.22284	0.2126	0.99456	8.95	10.82	493.0	21.06	49.17	1.71	4.06	17.33
SOC3	9/4-5/06	9/5/06	9	58	41	0.1201	0.18671	0.61932	0.2782	1.8452	4.32	10.43	357.5	12.68	53.85	0.60	2.60	10.33
SOC3	9/4-5/06	9/5/06	10	33	34	0.06406	0.39117	0.6707	0.2301	1.52021	4.65	9.68	236.0	10.95	41.05	0.60	2.30	10.09

Appendix 4. Summary of First Flush Literature Review

Author	Year	Site/Events	Def. utilized	FF Findings
Droste and Hartt	1975	Homogenous residential area (12 ha)		% of constituent loading = $2.83P_v^{0.78}$ (Pv = % of total annual runoff)
Helsel et al.	1979		**L'(t)>=V'(t)**	
Geiger	1984	540 ha mixed- use urban area (comined sewer)		FF depended on time of day FF not dependent upon ADWP
Geiger	1987		**max L'(t)-V'(t)**	
Stahre and Urbonas	1990		**Defined 20/80 FF**	
Hewitt and Rashed	1992	1 km length of rural road	high C in early part of event	FF effect for dissolved metals (Pb, Cu, Cd) Particulate bound metals and PAHs follow TSS behavior Correlation b/t removal rates of Pb and dissolved Cu and ADWP
Wanielista and Yousef	1993		**Defined 25/50 FF**	
Saget et al.	1996	7 separate systems 7 combined systems 197 total events	**$L'=V'^b$** **Defined 30/80 FF**	High variability in b values No relationships with basin characterisitics (max P, max I, ADWP) 65% of storms have b values 0.185 and 0.862 for storm sewers
Gupta and Saul	1996	2 sites, 79 storms	Site-specific relationships to predict FF load of TSS in combined sewer flow Used Geiger (1987)	No statistically significant relationships b/t EMC and Emflow, and b/t TSS load, inflow, and EMC and EMflow No correlation between FF EMC, Emflow and ADWP EMC of FF TSS load not related to rainfall I_{max}, Iavg, Qpeak,
Sansalone and Buchberger	1997	20m x 15m highway	L'(t)>V'(t)	Metal elements in lateral pavement sheet flow predominately dissolved Pronounce FF occurred in all events for dissolved Zn and Cu but not for particulate bound metals (Pb) Mostly dissolved (Zn, Cd, Cu), mostly particulate bound (Pb, Al, Fe) 60% of TSS load delivered in first 50% of the storm for impervious site
Deletic	1998	2 small urban areas	**Defined 20/40 FF** used L'V' curves	Site specific FF regression curves not reliable, FF is complex and site specific strong FF effect not observed Imax and time to Imax most important for predicting FF load for TSS High volumes yields high FF solute loads FF at end of drainage system not caused by pollution input

Bertrand-Krajewski	1998	12 separate and combined sewer systems (197 events)	Proposed 30/80 FF	80% of load transported in first 74% of volume for 50% of events for separate systems L'V' curves depend on pollutant, site, rainfall event and functioning of sewer system No multi-regression relationships can explain L'V' curve shape
Lee and Bang	2000	9 watersheds of various land use and characteristics	L'(t)>V'(t)	Peak conc. preceded peak flowrate in area < 100 ha and impervious > 80%, as well as watershed with area > 100 ha and impervious < 50%. Relative strength of FF is COD>n-hexane extracts>SS>PO_4-P>NO_3-N>Pb
Lee et al.	2002	13 urban watersheds 38 events	$L'=V'^{b}$ Max L'-V' Cum. Curve Ratio	No correlation b/t FF and ADWP, FF greater for smaller watersheds than large ones Strength of FF for b value: TKN>PO_4-P>TP>COD>Fe>HEM>SS Max L'-V' rank: SS>HEM>Fe>PO_4-P>TKN>COD>TP>Pb (residential), PO4-P>SS>Pb>Fe>COD>TP>TKN (indust.) FF strength proportional to Imax, % imper., inversely related to watershed area b value rank: TKN>PO4-P>TP>COD>Fe>HEM>SS for both watersheds CCR rank: TKN>COD>PO4-P>TP>SS>Fe>Pb>runoff (residential area)
Cristina and Buchberger	2002			Mass delivery of particulate matter coincides with the hydrograph
Cristina and Sansalone	2003	9 events	L'V'vsT', L'>T'	Mass limited events transported 80% of particle mass in the first 60% of the storms duration (T') Flow limited events exhibited partial FF, 80% of PND not expressed until storm completion Entire event requires capture and treatment due to particle separation
Lee et al.	2003	92 ha, 68% imperv.	CCR used 3rd degree polynomials	watershed area proportional and rainfall intensity inversely proportional to L'V' curve
Sansalone and Cristina	2004	2 small urban transportation areas 8 events		
Taebi and Droste	2004			
Soller et al.	2005	25 sites, 8 events in mixed-use watershed		No consistent FF for detected constituents (total and dissolved metals and anions) Suggest slight relationship b/t ADWP and dissolved metal concentrations, but not with storm size
Lee et al.	2005	20m x 14m roadway, 5 events	$L'vsV'$, $L'=V'^{b}$	30% & 80% V: 34-43% and 82-88% of the pollutants, 50% V: 60% SS, 59% Cu, 58% Ni, 57% Cd/Pb, 55% Zn, 54% Zn
Han et al.	2006	3 highway sites 18, 21 and 23 events	MFF_{20} (mass FF ratio)	No correlation b/t MFF20 and storm characteristics, TSS well correlated to particulate metals Greatest MFF20 ratios for TSS, COD, DOC, TKN, and NH3-N, lowest for NO2-N, dissolved Cd/Cr, total Cr/Pb

CHAPTER 2 EVALUATION OF POLLUTANT REMOVAL EFFICIENCIES AND FIRST FLUSH TREATMENT BY AN UNDERSIZED CONSTRUCTED WETLAND

Abstract

The impairment of surface waters and degradation of streams and waterways typically begins in the developed areas at the headwaters of a watershed. Among all the stormwater BMPs currently utilized to reduce peak runoff volumes and remove contaminants from urban runoff, constructed wetlands have emerged as an optimal choice because of their high performance of water quality improvement and ecological benefits. Due to a stormwater wetland's high land requirement, however, they are often difficult to size properly in urban environments. This study attempted to evaluate the pollutant removal efficiencies of a newly constructed flow-through stormwater wetland that is sized to only capture 20% of runoff generated by the recommended design storm in N.C. (first 2.5 cm of rainfall). The wetland was constructed in December 2006 as a retrofit to a failing level-spreader in order to repair a rapidly eroding head-cut between two stormwater outfall channels and the receiving stream. Following addition of the extended detention function, the undersized wetland has initially removed, on average, 71% of the TSS load, between 39% and 60% of the nutrient load, and 60% of the heavy metal load. For all the pollutants except TP and TKN, lower removal efficiencies were observed for the storms with flow bypass (5 out of 9 events after extended detention was added) on average as compared to the smaller events without bypass. When evaluated for all the sampled storms, event mean concentrations proved to be statistically lower at the outlet for all pollutants except Ti and V. For most pollutants, higher influent EMCs were observed for the storms with higher removal efficiencies. It is important to note, however, that these initial results are skewed by a small number of storms with low rainfall depths (median = 0.46 cm). With that considered, the average removal efficiencies are actually higher than predicted for the 1.3 cm design storm BMP. Undersized wetlands with "flow through" design might provide effective and efficient pollutant removals if designed to safely pass the larger storms. Longer term research will provide a more definitive evaluation.

1. Introduction

In this era of rapid growth and development, increasing importance is placed upon stormwater managers and practice designers to protect our natural resources from the adverse of effects from excessive surface runoff. Especially in North Carolina, where a significant influx of urban growth has occurred during the past 20 plus years, the impacts from stormwater runoff consist of, but are not limited to, flooding, erosion, sedimentation, wetland loss, nutrient enrichment and eutrophication, fish kills from algal blooms and dissolved oxygen depletion, temperature rise, toxicity, reduced biodiversity and the degradation to usable water supplies. These impacts further lead to revenue losses and increased burdens to taxpayers (e.g. shellfish bed and beach closures). Although sediment remains the major pollutant of concern in North Carolina, other pollutants that impact ecosystem health include nutrients (particularly nitrogen and phosphorus), organics, heavy metals, and pathogens. These pollutants derive from a variety of urban non-point sources, such as construction, in-stream erosion, atmospheric deposition, fertilizer from lawns and gardens, automobiles, pet and wildlife waste, and leaky sewers.

New regulatory guidelines and Best Management Practices (BMPs) are being implemented to reduce peak runoff amounts and treat and remove the contaminants present in urban stormwater runoff. Constructed wetlands (wetlands intentionally created from nonwetland sites for water quality improvement) have gained popularity as stormwater BMPs during the past two decades for their ability to transform and store organic matter and nutrients (Brix, 1994). Due to high land area requirements (often more than other BMPs), stormwater wetlands can be expensive or unfeasible in dense urban areas if sized to capture and treat the majority of storm events. Long term research on the overall pollutant removal of stormwater wetlands is still lacking. Even more lacking is research on the performance of conventionally undersized stormwater wetlands. This study attempted to evaluate the pollutant removal efficiencies of a newly constructed flow-through stormwater wetland that is sized to only capture 20% of runoff generated by the recommended design storm in N.C. (first 2.5 cm of rainfall). The wetland was constructed as a retrofit to a failing level spreader

in order to repair a rapidly eroding head-cut between two stormwater outfall channels and the receiving stream.

2. Literature Review

Constructed wetlands are increasingly being used for the treatment of urban runoff, both for their high performance of water quality improvement and ecological benefits (Schulz and Peall, 2001). Constructed wetlands represent an innovative and sustainable approach to stormwater management, turning storm or wastewater into an urban aquatic ecosystem or natural open space within a city (Smith et al., 1993). Previous researchers have found that constructed wetlands designed specifically as BMPs typically performed slightly better and with less variability than natural wetlands at removing various constituents from stormwater (Strecker et al., 1992). In addition, using constructed stormwater wetlands as a buffer between urban areas and receiving waters helps preserve and protect natural wetlands from polluted runoff.

Calculation of Pollutant Removal

Wetland performance in treating stormwater is generally related to inflow (hydraulic loading rate) and detention time, which are related to storm intensity, runoff volume, and wetland size (Scherger and Davis, 1982; Carleton et al., 2001). Inflow rate is known to affect pollutant retention by influencing the degree of bottom scouring and re-suspension of settled solids, and thus the overall retention of solids and pollutants adsorbed to solid particles. Other factors that affect the detention time and thus the pollutant removal performance of stormwater wetlands include variations in the hydrograph and pollutograph, hydraulic characteristics of the outlet structure, the storage-elevation relationship, and the size of the permanent pool in the wetland (Somes et al., 2000). The volume of the wetland determines how much of the runoff event is captured for treatment (Woodward-Clyde, 1986).

A mathematical approach that assumes steady-state, plug-flow reactor conditions has been developed for predicting the removal performance of wastewater treatment wetlands (Kadlec and Knight, 1996). Compared to the intermittent and unpredictable nature of stormwater

runoff, wastewater treatment wetlands are typically operated at rather constant hydraulic and pollutant loading rates and, thus, the steady-state assumptions are a reasonable approximation of flow conditions. The steady-state pollutant concentration (C) at the outlet of the wetland is represented by the following exponential equation:

$$\frac{\left(C - C^*\right)}{\left(C_i - C^*\right)} = e^{-k_a/q} \quad (1)$$

where C_i is the inlet concentration, C^* is the irreducible background concentration of a particular pollutant, q is the hydraulic loading rate (e.g. m/yr), and k_a is the "areal" rate constant (expressed in units of length over time). According to Kadlec and Knight (1996), C^* can be considered zero for pollutants such as total phosphorus (TP), ammonia (NH_3) and nitrate (NO_3^{2-}), and equation (1) can therefore be expressed as:

$$\frac{C}{C_i} = e^{-k_a/q} \quad (2)$$

Substituting the equivalent removal efficiencies (RE) as percentages for the concentration terms in the above equation will yield the form:

$$1 - \frac{RE}{100} = e^{-k_a/q} \quad (3)$$

The previous equations can also be expressed in terms of a "volumetric" rate constant (k_v), with units of inverse time, and detention time (t). The equations remain the same except the "$-k_a/q$" term is replaced by "$-k_v t$".

These equations can be utilized in several ways for design applications. If C_i, C^*, k, and the fraction of stormwater runoff that can be captured for treatment are known, then the wetland area required to treat a pollutant to a given RE can be calculated. Alternatively, the first-order rate constants (k_a or k_v) can be calculated if estimates of removal percentages for pollutants with negligible background concentrations and values of either q or t are known.

Although the former technique requires estimates of first-order rate constants (k) for stormwater wetlands, Carleton et al. (2001) showed that for pollutants like TP, NH_3, and

NO_3, the areal removal rate constants calculated for stormwater wetlands were generally consistent with the values published in the literature for wastewater treatment wetlands.

Removal Mechanisms and Performance

The reason wetlands so effectively treat storm or wastewater is because they employ a combination of chemical, biological, and physical removal mechanisms. These various pollutant removal mechanisms within stormwater wetlands include sedimentation, adsorption to sediments/detritus/vegetation, physical filtration, microbial uptake/transformation (e.g. nitrification/denitrification), plant and algae uptake, and extra detention and retention (Schueler, 1992).

According to Schueler (1992), the typical long-term pollutant removal rates for stormwater wetlands in the Mid-Atlantic Region are as follows:

- TSS 75%
- Total Phosphorus 45%
- Total Nitrogen 25%
- Organic Carbon 15%
- Lead 75%
- Zinc 50%
- Bacteria 2 log reduction

Wetland systems that include a pool can reach phosphorus and nitrogen removal efficiencies of 65% and 40%, respectively (per Schueler, 1992).

Although studies have shown that sedimentation is the primary process for removing heavy metals from stormwater, Walker and Hurl (2002) attempted to demonstrate the contribution of other processes like biological assimilation and chemical transformation, and define an overall areal rate constant for these other processes. They found that Zn, Pb and Cu concentrations on sediment decreased 57%, 71%, and 48%, respectively, through the wetland, while the concentration of Cr remained constant and that of As actually increased by 150%. The results also showed that is was possible to assign an areal decay rate constant

to the sedimentation process and a separate decay rate to the sum of the other process (biological and chemical) that were acting to remove heavy metal concentrations.

Critical Design Factors

When designing a stormwater treatment wetland, several techniques can be implemented to improve pollutant removal efficiencies. As reported by Schueler (1992), these design techniques include:

1. *Increase the volume of runoff treatment* – Naturally, the larger the wetland the more stormwater can be captured and potentially treated.

2. *Increase the surface area to volume ratio* - Wetland systems containing heterogeneous internal elevations and complex geometries can increase the surface area to volume ratio without increasing the footprint area and thus improve pollutant removal by providing greater areas for adsorptive and filtering removal pathways.

3. *Increase the effective flow path through the wetland* – Systems with longer flow paths (3:1 or greater according to Horner et al., 1990) significantly improve performance by increasing retention time. Flow depths between 0 and 15 cm (6 in) are also an important design requirement since this is where wetland vegetation thrives (Strecker et al., 1992).

4. *Provide pre-treatment and energy dissipation* – Forebays help improve the performance of ED wetlands by limiting the scour and re-suspension of pollutants deposited by prior storms.

5. *Utilize redundant pollutant removal pathways* – Wetland systems containing a combination of extended detention, shallow marsh, shallow land, and deep pools can increase pollutant removal by creating longer retention times and a wider variety of plants and animals.

Carleton et al. (2001) concluded that approximate long-term performance of a constructed wetland for removing common stormwater pollutants could be predicted using the ratio of wetland surface area to watershed area.

As research revealed the importance of proper sizing of treatment wetlands, the initial design guideline for the wetland surface area to be at least 3% of the drainage area was recommended by the state of Maryland (MDE, 1987). Strecker et al. (1992) later suggested that the ratio of runoff volume to storage volume may be more important than the area ratio. Schueler (1992) recommended a minimum area ratio of 2% (1% for extended detention wetlands), and a treatment volume large enough to capture 90% of the storm events. In piedmont North Carolina, approximately 90% of the historical record of storm events fall are 2.6 cm (1 in.) of rainfall or less (US EPA, 1992).

In the North Carolina Coastal Plain, a study by Bass (2000) on a small in-stream constructed wetland revealed concentration reductions for NO_3-N, NH_4-N, and TKN of 60%, 30%, and 9.5%, respectively. Over the evaluation period, however, phosphorus levels increased 55% between the inlet and outlet. The wetland was built to intercept drainage waters from both agriculture and urban land uses and had a wetland:watershed area ratio of 0.004:1, much less than the recommened 0.02:1 ratio suggested by Schueler (2002). This study also showed that monthly nutrient reductions were generally associated with temperature changes, with higher temperatures resulting in greater reductions in NO_3-N and NH_4-N concentrations and higher concentrations of TKN and phosphorus.

The major drawback to stormwater wetlands is their relatively high land requirement, so not all stormwater wetlands can be sized in accordance with recent guidelines (particularly stormwater wetlands implemented as retrofits). The first flush study conducted on the contributing watersheds prior to construction of the wetland system revealed that although the overall first flush effect for most pollutants analyzed was weak, a “most efficient” capture volume (contains the most pollutant load per volume of water) is approximately the first 40% of runoff. This 40% of runoff closely corresponds to the first 1.3 cm of rainfall if 2.6 cm of rainfall is used as the water quality design volume. As a result, more research is needed to

understand how effectively flow-through BMPs like an extended detention wetland that are undersized relative to the 2.6 cm of rainfall design standard in N.C. (but sized around the "most efficient" volume) can treat stormwater runoff.

3. Research Objectives

The primary purpose of this study was to evaluate the pollutant removal abilities of a recently constructed stormwater wetland that is undersized by the N.C. design standard, which is 2.5 cm of rainfall in 1 hour (US EPA, 1992). The purpose of this innovative BMP retrofit is to improve the water quality of North Creek by reducing urban pollutants delivered to the stream through stormwater runoff, stabilize a heavily eroding stormwater conveyance channel, reduce erosion along North Creek through peak flow reduction, and incorporate biological habitat and ecological function where possible for both stream macroinvertebrates and riparian aquatic vertebrates. Depending on the flashboard riser outlet configuration, the extended detention part of the wetland can store approximately 20% of the runoff volume from a 2.6 cm storm event. In a follow-up to the first flush phenomenon study performed for the two watersheds discharging to the wetland, the partitioning of total pollutant load with respect to the inflow and outflow runoff volumes was also examined for events with sufficient samples.

4. Site Description

4.1 North Creek

North Creek is a small urban stream that flows through the center of Centennial Campus, NCSU. The stream is a tributary to Lake Raleigh and is included on the 303(d) list for impaired waters as a backwater of Lake Raleigh and Walnut Creek (Category 6). Figure 4.1 depicts the watershed drainage area for North Creek. This stream is included on the 303(d) list based on impaired biological integrity caused by urban runoff and storm sewers. Due to rapid growth of Centennial Campus over the past decade, construction activities and expansion of impervious surfaces within the 1,320 hectare watershed have drastically increased stormwater runoff volumes to North Creek. Several stormwater outfalls are located in the riparian areas of the stream; some have eroding conveyance channels that cause instability of the streambanks and stormwater conveyance channels.

The stormwater reaching North Creek carries an assortment of urban pollutants. Between 2002 and 2004, preliminary water quality and biological assessments were made as part of a USDA grant to establish an outdoor field laboratory along the stream corridor. Preliminary water quality sampling along the stream found elevated nutrients, metals, and toxic organic compounds (PAHs) (Carter, 2005). Suspended sediment and turbidity have been monitored extensively within the past two years, with average stormflow TSS concentrations around 500 mg/L. The predominant non-point source pollutant in North Creek is sediment derived from the watershed runoff and bank erosion.

Stream macroinvertebrate sampling indicated reduced taxa richness and relative abundance. Throughout the course of the two years, fewer than 10 EPT organisms were found, including the more tolerant caddisfly and mayfly species. The dominant species include chironomid midge larvae and mosquito larvae that are very tolerant to impaired water quality. Some salamanders have been captured throughout the study, but have since retreated to the riparian areas along the corridor. Biological integrity has been lost due to water quality and habitat degradation.

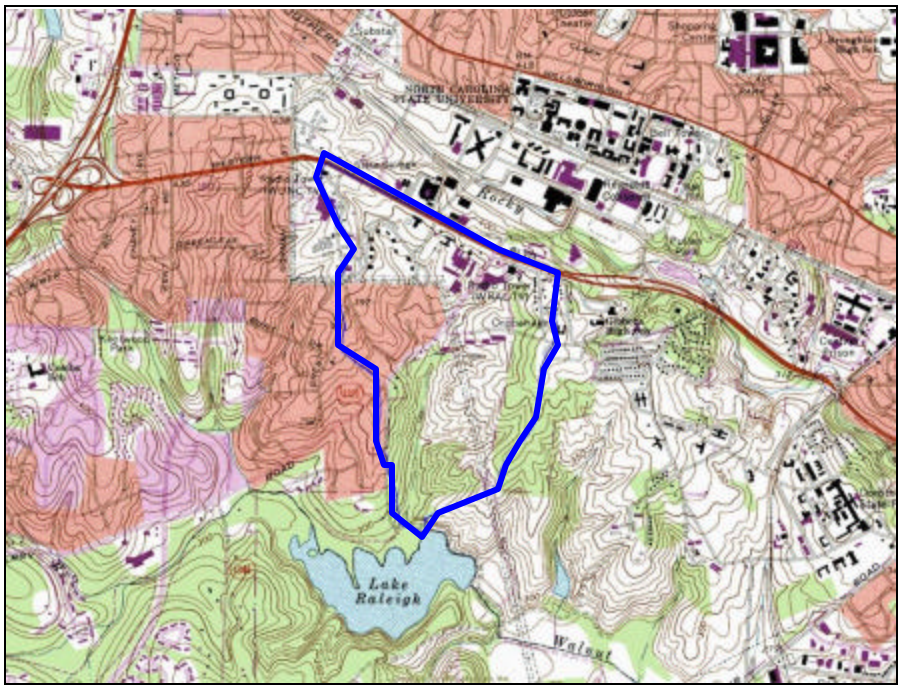


Figure 4.1: Watershed drainage area for North Creek.

4.2 Impaired Stormwater Conveyance Channel

The site for the implemented BMP was one of the heavily eroding stormwater conveyance channels discharging to North Creek, located at the corner of Varsity Drive and Capability Drive (see Figure 4.2). Adjacent to North Creek, the eroding channel was encroaching the wing-wall to the North Creek culvert under Varsity Drive. The erosion was due to a steep hydraulic gradient between the storm sewer outfalls and the deeply incised North Creek. The culverts from the two watersheds are named stormwater outfall channel 3 (SOC 3) and stormwater outfall channel 4 (SOC 4) since SOC1 and SOC2 were assigned to two other eroding stormwater outfall channels located upstream of North Creek (see Figure 4.2). SOC 3, which is 0.91 meters (3 ft) in diameter, collects stormwater runoff from an approximately 1.94 hectare watershed of 66% impervious roadway (Curve Number = 86). The watershed draining to SOC 4, which drains to a 0.61 meter (2 ft) diameter culvert, is 2.26 hectares and 87% wooded with the remaining land area being roadway and dense lawn (Curve Number = 69). A BMP consisting of two boulder plunge-pools, a vegetated waterway, and a constructed wetland was built on the current channel in December of 2006 (see Figure 4.3 for design schematic). The goals of this BMP were to reduce erosion and sediment both in the

channel and in North Creek and Lake Raleigh, treat the stormwater for urban pollutants, such as sediment, nutrients, and heavy metals, and improve biological habitat.

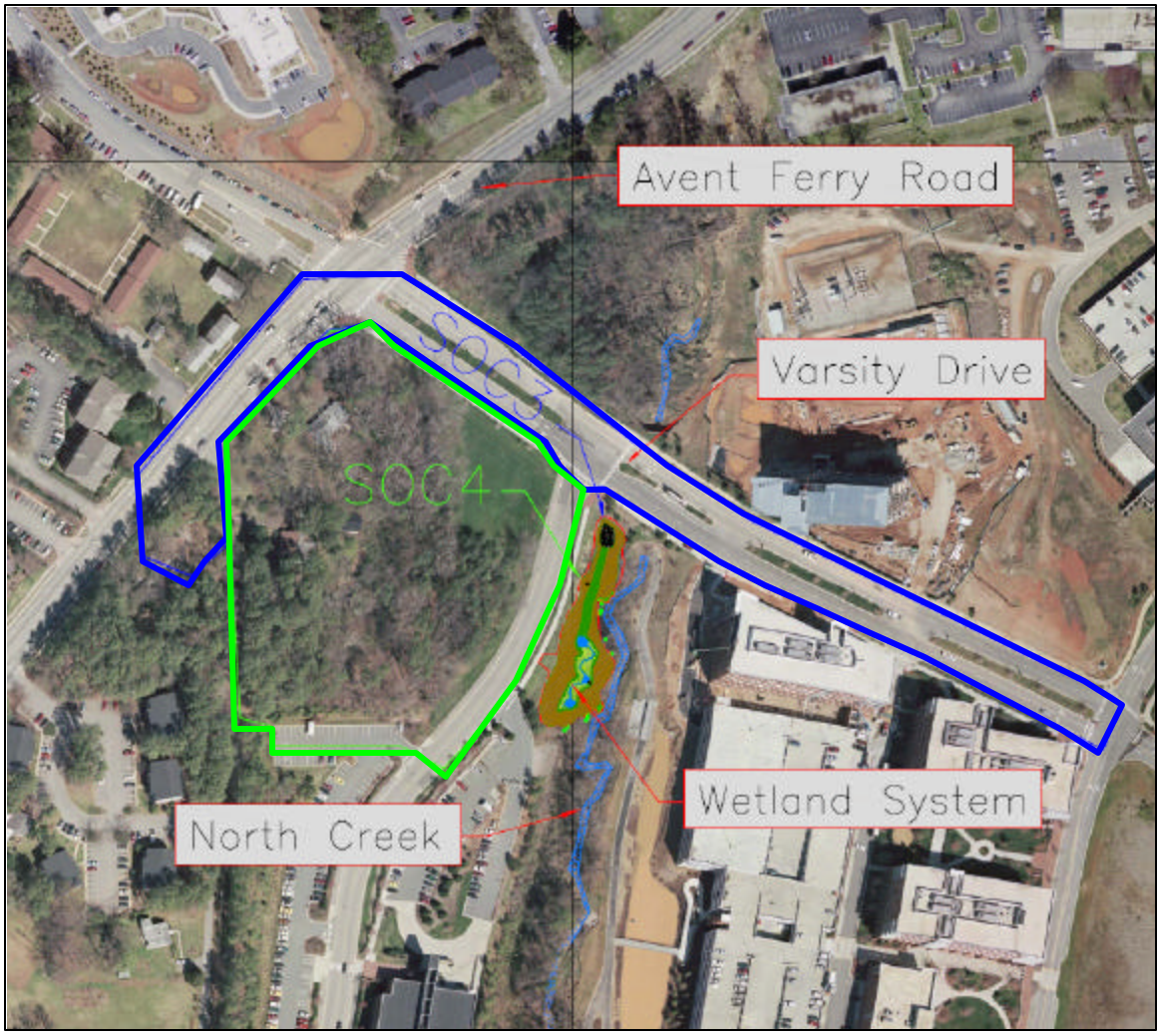


Figure 4.2: Drainage areas and locations of SOC 3 and SOC 4

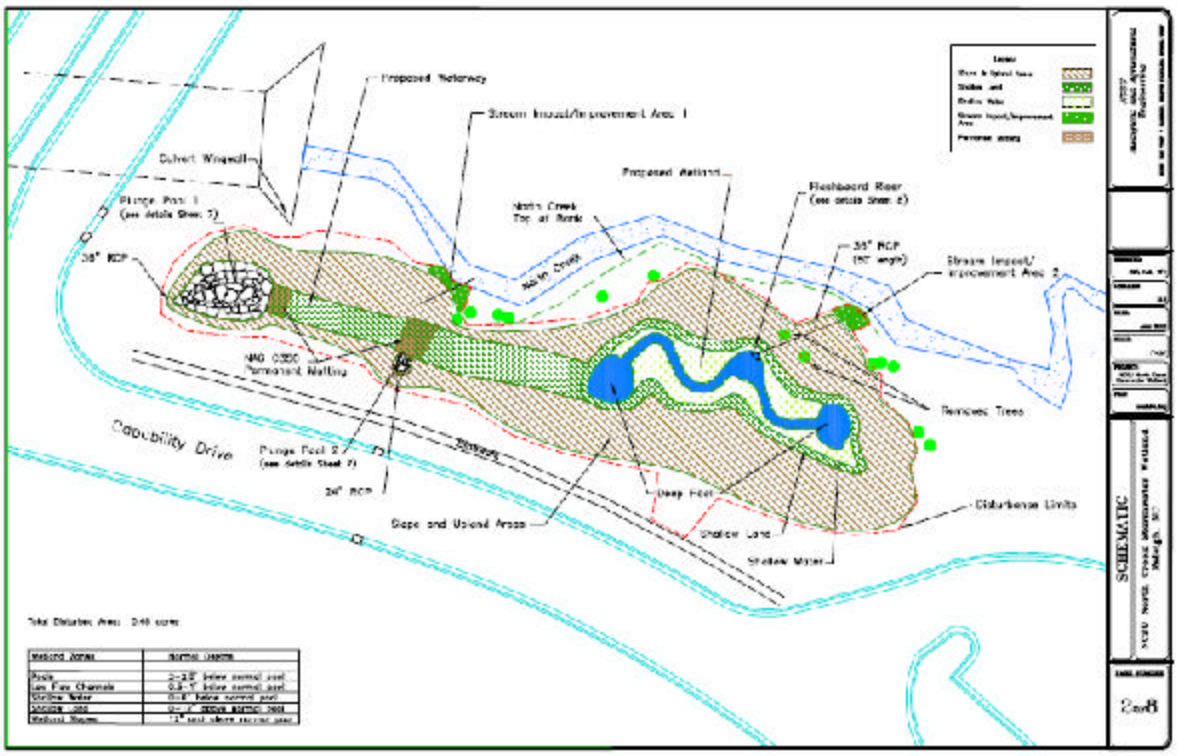


Figure 4.3: Schematic of constructed wetland system

5. Design of the Constructed Wetland System

The constructed wetland system consists of several major components:

- 2 boulder plunge pools at each culvert outlet
- vegetated waterway
- extended detention wetland
- flashboard-riser and barrel outlet structure
- emergency spillway

The previously eroded conveyance channel to North Creek was filled in to stabilize the streambanks and avoid storm flow exposure for the Research Drive culvert wingwall. Stormwater was rerouted down the abandoned floodplain terrace via the vegetated waterway to the constructed wetland for temporary storage, treatment and energy dissipation before entering North Creek. The existing plunge pools required expansion and reinforcement with

large boulders at both culverts in order to better accommodate greater storm flows from future development. These plunge pools serve to reduce energy and remove the coarser suspended sediment before emptying into the vegetated waterway that is lined with semi-permanent erosion control matting. The vegetated waterway (Dimensions: 31m L, 3.7m - 4.9m W, 0.46m - 0.61m H) runs from the SOC3 plunge pool, parallel to Capability Drive, down slope to the constructed wetland entrance. The waterway is intersected midway by a second smaller boulder plunge pool that receives drainage from SOC4. Figure 5.1 shows the locations of the two plunge pools and vegetated waterway shortly following construction.

Figure 5.1: Constructed wetland system filling in from first storm after construction

Storage Capacity

Due to the limited area for construction on the site, the stormwater wetland could not be sized to capture the recommended water quality volume (first 2.6 cm of rainfall). As a result, the wetland was designed and built as large as possible given the site constraints. With a 22.9 cm (9 in.) extended detention depth, the wetland can store approximately 65 m^3 (2,300

ft^3) of stormwater. Based on the runoff volume estimation using a discrete NRCS Curve Number Method, this storage volume is approximately equal to runoff from the first 0.52 cm of rainfall (20% of the runoff from the 2.6 cm design storm). Considering the first-flush nature of pollutant runoff during storm events, this stormwater wetland system is expected to capture and treat a larger proportion of the pollutants in the runoff compared to the fraction of runoff volume.

Outlet Structure

A modified flashboard riser system controls the water level in the wetland. The flashboard riser consists of two 0.73 meter (2.4 ft) rectangular weirs inserted into a 1.52 meter (5 ft) diameter aluminum riser that connects to a 0.91 meter (3 ft) diameter aluminum culvert (see Appendix 1 for details). A 3.18 cm (1.25 in.) diameter drawdown orifice is located 22.9 cm below the top of the weir (centerline location). This outlet structure configuration provides several benefits: the weir component allows safe bypass and accurate flow measurements for storm events that exceed 0.52 cm, the drawdown orifice allows the water level to fluctuate regularly with each storm promoting a wider operating depth range and vegetation diversity (Somes et al., 2000), and the permanent pool and extended detention levels can easily be adjusted using the moveable weir boards. The outlet structure is designed to safely route the 25-yr, 24-hr storm with minimum disturbance to the stream and floodplain. An emergency overflow spillway was also constructed to safely pass larger storms.

Design Features

To improve stormwater treatment and biological habitat, the wetland was constructed with various features and heterogeneous internal elevations, including shallow water, shallow land, deeper pools, and upland areas. Native vegetation was planted within the entire floodplain site, with riparian buffer enhancements and diverse wetland vegetation in appropriate areas. A complete list of the native vegetation plantings is included in Appendix 2.

An innovative erosion control and native seeding component was utilized for the BMP system. A Hydromulch Treatment System (HMTS), designed by USEPS for erosion control

and vegetation establishment using a slow-release fertilizer system, was applied to the disturbed area surrounding the wetland immediately following construction. The HMTS system included:

- GeoSkin Cotton Hydromulch
- BIOSOL organic fertilizer
- H_2OLD mineral soil amendment and fertilizer
- 10-10-10 soluble fertilizer
- Site-specific polyacrylamide (PAM)
- Native warm season grass seed species
- Annual rye

Detailed construction drawings for SOC3 and SOC4 plunge pool/swale/wetland system are in Appendix 1.

In-situ soil tests by GeoTechnologies, Inc., revealed permeabilities greater than the recommended 1 times 10^{-6} cm/second to prevent leakage in the wetland (see Appendix 3). As a result, a 4% volume content of bentonite was applied to the upper 15 cm of the wetland bottom. The mixture was then compacted and covered with 10 cm of topsoil.

6. Sampling Materials and Methods

6.1 Sampling Sites

The two inlet sampling locations were the interior inverts of the stormwater culverts discharging onto the site. The outlet samples were collected immediately upstream of the flashboard riser.

6.2 Instrumentation

The culvert outlets were monitored using ISCO automated water samplers (3700 series). Following construction of the wetland, stormwater from SOC3 was no longer outlet controlled (culvert tailwater during storm events) and conditions were thus unsuitable for the ISCO area-velocity meter used in the previous study. Instead, a 0.61 meter rectangular

aluminum weir was installed inside the culvert to measure flow using an ISCO 4230 bubble flow meter (see Figures 6.1 and 6.2). The bubble flow meter measured depth and calculated flow using a weir and orifice equation in junction. To help prevent sediment from covering the bubble tube during large storm events, a 5 cm diameter orifice was inserted below the weir to allow sediment to pass. At SOC4, a 120° v-notch weir was installed inside the culvert for an additional ISCO 4230 flow meter to calculate flow rates (see Figure 6.3). Since flow through this culvert was less than flow through SOC 3 (on average 4% of total flow through SOC3), the weir proved satisfactory and recorded flow from the majority of the storm events within its measurable range.

Figure 6.1: Rectangular weir and orifice (SOC3)

Figure 6.2: ISCO 3700 sampler and 4230 FM

Figure 6.3: V-notch weir (SOC 4)

6.3 Sampling Methods

Both flow meters were programmed to collect flow-paced composite stormwater samples from the culverts. Flow-based sampling captures samples after a specified volume of water has passed through the pipe or channel. Automated sampling on a flow-basis allows for variable sampling frequency that follows the hydrograph. This is important for targeting pollutant load variations instead of concentration variations throughout an event.

Each automated sampler contained 24 plastic, 1 liter ISCO sampler bottles. Depending on the size of the anticipated storm event, the flow-pacing was adjusted to sufficiently capture the entire storm within 24 bottles. The samplers were typically programmed to composite 4 individual flow-weighted samples in each bottle (see Table 6.1 for typical sampler programming details). Contingent upon the size of the storm, the sampler bottles were further combined up to a total of 4-5 bottles per site to help quantify variations in pollutant concentrations throughout the hydrograph.

Table 6.1: Typical automated sampler details

Site	Pacing	Freq.	Sample Vol.	Samples Per Bottle
SOC 3	Flow	4000 gal	250 ml	4
SOC 4	Flow	300 gal	250 ml	4
Outlet	Flow	5000 gal	250 ml	4

6.4 Analysis Protocol

The stormwater samples were analyzed for the following contaminants:

- Total suspended solids (TSS)
- Turbidity
- Ammonia (NH_3-N)
- Nitrate/nitrite (NO_3/NO_2-N)
- Total Kjeldahl nitrogen (TKN)
- Ortho-phosphates (O-PO_4)
- Total phosphorus (TP)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Nickel (Ni)
- Titanium (Ti)
- Vanadium (V)
- Zinc (Zn)
- Arsenic (As)

Beryllium, antimony and selenium were initially included in the analysis but early results yielded concentrations below the detectable limits and these metals received no further analysis.

After collection in the field, the sampler bottles were separated into pre-labeled analysis bottles for each pollutant. The sample for metals analyses were combined into one bottle and the nitrate/nitrite and TKN analysis were also combined into one bottle. Table 6.2 lists the analysis bottle details used for each pollutant.

Table 6.2: Analysis bottle details

Pollutant	Container Type	Container Size	Acid Preservative?	Preservation
NH_3	Glass	30-mL	No	On ice, 1-4° C
TKN/NO_3-NO_2	Polyethylene plastic	125-mL	Yes	H_2SO_4, pH<2, On ice, 1-4° C
O-PO_4	Brown Glass	60-mL	No	On ice, 1-4° C
TP	Brown Glass	60-mL	No	On ice, 1-4° C
Heavy metals	HDPE plastic	125-mL	No	On ice, 1-4° C

The nitrate/nitrite and TKN analysis bottle was preserved with 2-mLs of sulfuric acid (H_2SO_4).

To help prevent contamination, latex gloves were worn during collection of the sampler bottles from the automated samplers and during the partitioning into the analysis bottles. A clean 90-mL syringe was used for partitioning the ammonia and OP bottles. The O-PO_4 samples were pre-filtered with a 0.45-µm glass fiber and nylon membrane syringe filter prior injection into the analysis bottle. All analysis bottles were then stored between 1-4° C before delivery to the lab.

Table 6.3 lists the analysis methods utilized for each pollutant. The methods were from either the APHA Standard Methods (APHA, 1995) or from EPA Methods (US EPA, 1983). Also included in the table are the detection limits and maximum holding times for each pollutant analysis.

Table 6.3: Lab analysis methods

Parameter	Method	Analytical Method	Detection Limit	Maximum Holding Time
TP	S.M. 4500 P E	Lachat 31-115-01-4-A	10 µg/L	28 days
O-PO_4	S.M. 4500 P F	Lachat 31-115-01-1-H	6 µg/L	48 hours
TKN	EPA 351.1	Traacs 786-86T	140 µg/L	28 days
NH_3-N	S.M. 4500 NH_3 H	Traacs 780-86T	7 µg/L	28 days
NO_3/NO_2	S.M. 4500 NO_3 F	Traacs 781-86T	5.6 µg/L	28 days
Metals (total)	See below	NA	5-10 µg/L	6 months
Residue, TSS	S.M. 2540 D	NA	1 mg/L	7 days
Turbidity	S.M.	NA	0.1 NTU	48 hours

Metals Analysis Protocol - Acid Extraction with a Hot Block:

The steps are essentially these:

1. *Settle the solids*.

   A specific type of polyacrylamide known to work with the mineralogy of the samples was added to flocculate the suspended sediment. Inherent in this step is the assumption that all the metals are associated with the solid phase. This assumption was made based on the metals of interest and the nature of the runoff (i.e. rainfall pH and composition).

   The only element with some doubt was arsenic since this one might be more associated with organic matter, but the flocculent settled the organic matter as well.

   Note: Filtering the medium would yield the same result, but it would take longer and be more difficult.

2. Decant off liquid.

   The bottles treated with flocculent were let stand for several days in the refrigerator at (4°C). Excess liquid in bottle was siphoned out until the solution was down to about 1/4 of original volume. A rubber policeman was then used to re-suspend the solids from the bottom of the bottle and the side walls. Suspension then transferred into 125 mL Teflon bottles with minimal DI water to keep volume of water low. Then frozen and then freeze-dried to remove all the water and further concentrate solids.

3. Acid Reflux.

To the freeze dried Teflon bottles, 2.5 mL of Ultra Pure Grade HNO3 and 1 mL of Ultra Pure Grade HCl were added. Also added was about 0.25 mL of concentrated HF. These mixtures were allowed to stand overnight and then heated on sand bath to reflux the acid mixture for 30 to 45 minutes. The caps were kept on the Teflon bottle during this procedure but not tight to avoid pressure buildup. The refluxing is not designed to dissolve all the solids. A little HF acid was added to promote dissolution of the Ti present which is most likely as TiO2. This compound does not dissolve in acids and requires HF to promote dissolution.

4. Spectrometer Analysis

After samples allowed to stand and cool they were transferred to 15 mL screw cap centrifuge tubes. A little DI was first added and swirled, then sample transferred to the tubes. More DI then added, then tube is capped and shaken well to rinse twice. Thereafter, the total volume in the centrifuge tubes were increased to 14 mL, then capped and mixed well for spectrometer analysis. Since this digestate was pretty acidic, a Meinhart C nebulizer was used to over come acid strength effects when using the ICP Emission Spectrometer.

Note: One could use microwave digestion for this procedure but it would be an enormous amount of effort given the small sediment size in the samples. When the intra-element correlations within the data are considered, it is obvious there is good dissolution and mobilizing of most metals except perhaps for those within the clay mineral lattice.

Analysis Labs

Every storm water sample was analyzed for TSS and turbidity, while nutrient and metals analyses were only performed for storm events with sufficient samples for a first flush analysis. TSS and turbidity analyses were conducted in a department lab. The NCSU Soil Analysis Laboratory performed total metals analyses and NCSU's Applied Aquatic Ecology (AAE) Lab, which is North Carolina state-certified to quantify key nutrients, analyzed the samples for nutrients and cleaned the ISCO sampler and lab analysis bottles.

Cleaning

After each use, the ISCO sampler bottles and caps were cleaned with phosphate-free soap (LiquiNox), rinsed five times with deionized water, washed with a 10% solution of hydrochloric acid (HCl), rinsed eight times with deionized water and three more times with Milli-Q water. The plastic TKN/NO3-NO2 analysis bottles and caps were washed according to the same procedure as the ISCO sampler bottles. The glass TP and O-PO_4 bottles and caps cleaning procedure were similar except the bottles were acid-washed with a 100% solution of H_2SO_4. The glass NH_3 serum bottles were first soaked in deionized water overnight. The next day, the bottles were filled with 10% HCl solution and the caps were placed in a beaker of 10% HCl solution and both soaked again overnight. Thereafter, the bottles and caps were rinsed eight times with deionized water and rinsed three times with Milli-Q water. After rinsing, the bottles with filled with Milli-Q water and capped for storage.

Quality Control

Approximately 10% of the samples collected in the field for analysis were duplicated. A field blank was also sent to the lab for every 10 samples. Within the lab, 10% of the samples were duplicated for analysis and a blank was analyzed for every 10 samples per analysis. In addition, 20% of the samples were spiked per analysis and they were expected to fall within 90-110% recovery.

6.5 Performance Calculations

Percent Pollutant Load Removal

The following equation was used to calculate the percent removal of the wetland system for each storm event. $SOC3_{in}$ and $SOC4_{in}$ are the influent loads (kg) from the culverts and $Outlet_{out}$ is the effluent load (kg) leaving the wetland system through the flashboard riser.

$$\% \text{ Pollutant Load Removal} = \frac{\left(SOC3_{in} + SOC4_{in} - Outlet_{out}\right)}{\left(SOC3_{in} + SOC4_{in}\right)} * 100 \qquad (1)$$

Effluent Concentration Reduction

Since pollutant concentrations can vary by orders of magnitude during a runoff event, an event mean concentration (EMC) was used to characterize storm event concentrations at both the inlets and the outlet. The EMC represents a flow average concentration computed as the total pollutant load (mass) divided by the total runoff volume for an event of duration *t*, as shown by the following equation:

$$\text{EMC} = \frac{M}{V} = \frac{\int_0^t c(t)q(t)dt}{\int_0^t q(t)dt} \qquad (2)$$

where M = total pollutant mass over entire storm event (dimensional units of mass, M), V = total volume over storm event (dimensional units of length cubed, L^3), c(t) = time variable pollutant concentration (M/L^3), t = time (dimensional units of time, T), and q(t) = time variable flow (L^3/T).

The EMCs from the two inlets were combined into one weighted value using a similar equation:

$$EMC_{in} = (EMC_{SOC3}*Q_{SOC3} + EMC_{SOC4}*Q_{SOC4})/(Q_{SOC4}+Q_{SOC3}) \qquad (3)$$

where Q represents the total event runoff volume from each inlet. This calculation provides two paired groups of flow weighted concentrations for statistical comparison of EMC differences.

A paired *t*-test (2-tailed) was utilized to help evaluate the effectiveness of the wetland system at reducing effluent concentrations. The paired t-test computed the differences (d_i) between the inlet and outlet EMCs for each storm event and calculated the sample mean ($\bar{d}$) and standard deviation of the differences. The paired t-test evaluates the null hypothesis that the mean difference of the population (μ_d) is equal to zero (no reduction in pollutant concentration between inlet and outlet) against the alternative hypothesis that μ_d is not equal to zero. If the paired differences are calculated by subtracting the inlet EMC from the outlet EMC, then a negative mean difference value indicates reductions in effluent concentrations.

7. Initial Results

This section includes the initial removal efficiencies and EMCs following construction of the wetland system in December 2006. To date, 17 storm events have been sampled, although one of those events (5/12/07) was only analyzed for TSS and the complete nutrient and heavy metal results have not yet been received from the lab for the last three events (7/27, 7/28, and 7/30/07). All of the received lab results and calculated EMCs are included in Appendices 5 and 6. As shown in the rainfall/runoff relationship graph (Figure 7.1), storm events with rainfall depths ranging between 0.18 cm and 5.30 cm and total inflow runoff volumes between 45 m^3 and 1,680 m^3 were collected and analyzed.

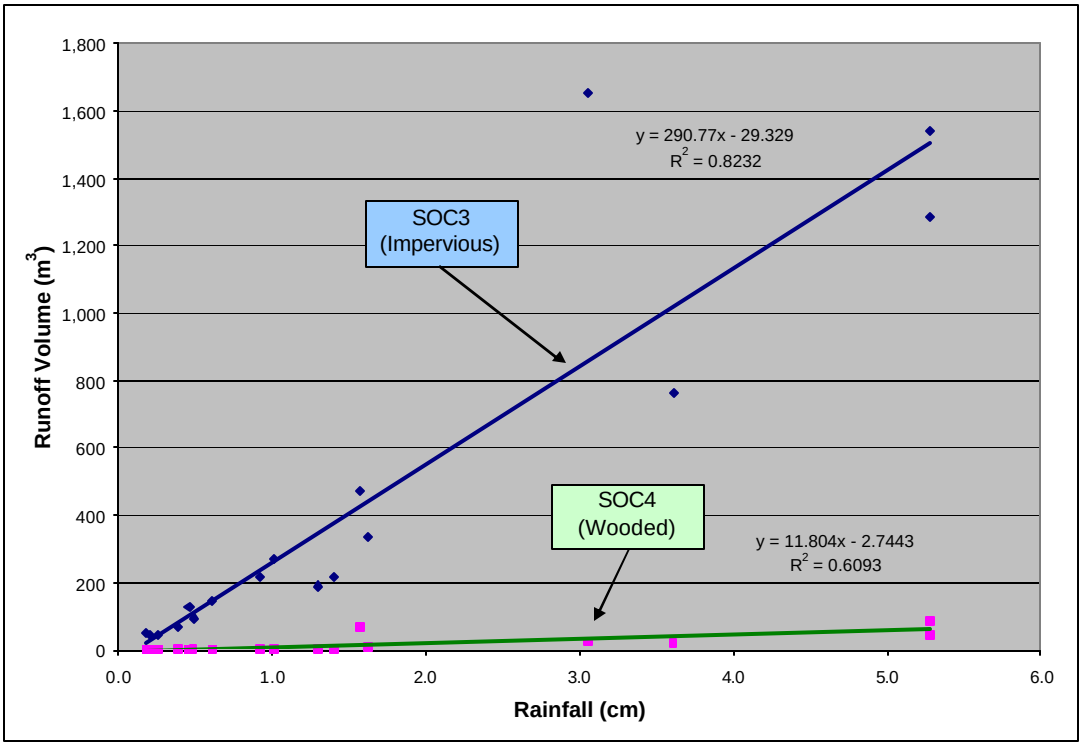


Figure 7.1: Rainfall/runoff relationships on SOC3 and SOC4

Upland shrubs and trees were planted in January 2007, but the majority of the aquatic vegetation was not planted until April 13, 2007. Prior to planting, weir boards were removed in the flashboard riser to drop the water level just below normal pool for plant survival and establishment. The remaining weir boards and drawdown orifice were installed at the end of

May 2007 to provide the 22.9 cm extended detention depth. Prior to this date, the wetland system did not contain an extended detention component, and the majority of the flow flowed through the system through the lowered outlet weir. Most of the sediment removal was likely performed by the plunge pools, and as shown by Figure 7.2.

Figure 7.2: Sediment deposited in SOC3 plunge pool

Percent Pollutant Load Removal

Tables 7.1 and 7.2 list the initial pollutant removal efficiencies of the establishing wetland system for all the pollutants analyzed. Of the analyzed storm events, only the past events since 6/2/07 (up to 9 for TSS) occurred with the wetland outlet structure functioning with its extended detention design. As shown by the following tables, pollutant removal efficiencies are high compared to the events collected prior to the extended detention treatment. Due to the small number of events collected with the extended detention, however, the initial removal efficiencies of the wetland are likely skewed by the size of the storms and the quality of the influent water. Both of these influencing factors were examined.

Table7.1: Percent pollutant load removal for TSS and nutrients

Storm Date	Rain (cm)	TSS	O-PO_4	NH_3	NO_3/NO_2	TP	TKN	
3/1-2/07	1.57	34	22	21	-9	22	11	
3/16/07[1]	5.28	-4	-17	-16	-48	-24	-13	
3/29/07	0.48	92	99	97	97	95	95	
4/12/07	1.63	77	53	36	37	29	47	
4/15/07	3.61	-1	19	16	36	13	-5	
4/27/07	1.40	0	32	-1	7	20	-23	
5/9/07	0.91	70	Missing	41	48	51	53	Extended detention added
5/12/07	5.28	-59	Not Analyzed					
6/2-3/07	3.05	38	Missing	53	66	50	49	
6/6/07	0.38	82	Missing	33	36	7	9	
6/9/07	0.61	82	-45	11	43	36	27	
6/13/07	1.02	77	65	46	50	59	48	
6/19/07	0.18	95	59	29	90	80	73	
6/20/07	0.20	58	82	75	74	25	31	
7/27/07	0.25	91	63	Lab Results Pending				
7/28/07	0.46	77	55					
7/30/07	1.30	40						

[1] Does not include load from SOC4 due to equipment failure

Table 7.2: Percent pollutant load removal for heavy metals

Storm Date	Rain (in)	Cr	Cu	Ti	V	Zn	As	Ni	Pb	
3/1-2/07	1.57	29	40	13	19	46		31	29	
3/16/07[1]	5.28	-9	12	-44	-20	43	-21	4	-4	
3/29/07	0.48	90	96	82	90	95		92	92	
4/12/07	1.63	44	51	37	44	59	23		50	
4/15/07	3.61	-28	-4	-44	-39	14			3	
4/27/07	1.40	-9	-4	-36	-21	-1	-44	-6	2	
5/9/07	0.91	52	50	48	51	60			59	Extended detention added
5/12/07	Not Analyzed									
6/2-3/07	3.05	36	55	24	-1	56			43	
6/6/07	0.38	30	26	30		28			30	
6/9/07	0.61	63	54	64		59		76	63	
6/13/07	1.02	47	47	46	47	13	55		17	
6/19/07	0.18	77	83	86	93	91		85	82	
6/20/07	0.20	65	54	79	47	58	80		66	
7/27/07	0.25	Lab Results Pending								
7/28/07	0.46									
7/30/07	1.30									

[1] Does not include load from SOC4 due to equipment failure

Influence of Flow Bypass

Out of 9 total events sampled with the extended detention functioning in the wetland, 5 of these events had a portion of the flow overtop the weir and bypass further treatment. Table 7.3 lists the average removal efficiencies separated by events with or without flow bypass for the 9 storms. Except for TP, TKN, and Cu, pollutant removal is noticeably less for storms where a portion of the total event runoff bypassed extended detention treatment. Even with partial flow bypass, the undersized wetland system has initially removed 63% of the TSS and on average, 41% of the nutrients and 48% of the heavy metals from the incoming stormwater, although the storm sizes were small (median equals 0.46 cm of rainfall).

Table 7.3: Pollutant removal efficiencies separated by bypass

Pollutant	No Bypass	Bypass
TSS	81	63
O-PO_4	68	25
NH_3	46	37
NO_3/NO_2	67	53
TP	37	48
TKN	37	41
Cr	57	49
Cu	54	52
Ti	65	45
V	70	23
Zn	59	43
As	80	55
Ni	85	76
Pb	60	41

Influence of Influent Concentration

It is often assumed that higher removal percentages are more easily attained with more polluted influent. In order to help examine the influence of influent EMC on pollutant removal, comparative graphs of removal efficiencies and influent and effluent EMC concentrations were developed. Figures 7.3 and 7.4 are examples for TSS. Considering just the events occurring after the extended detention, it does not appear from visual observation that higher TSS EMCs are correlated with higher removal efficiency. Appendix 7 includes the comparative graphs of removal efficiencies and EMCs for all the other pollutants.

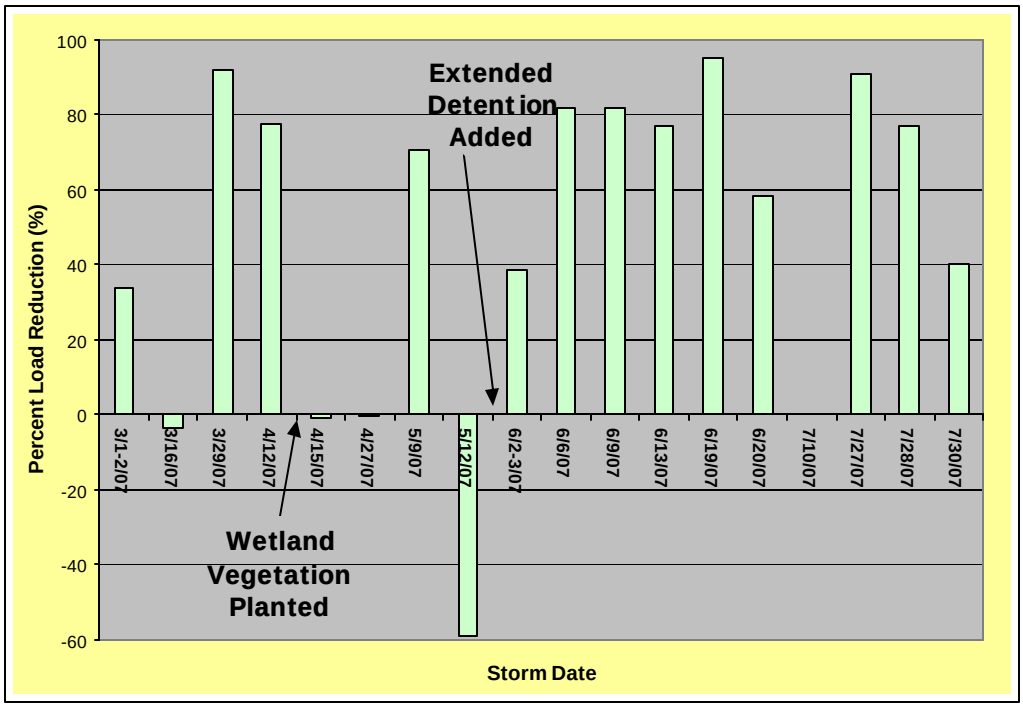


Figure 7.3: Removal efficiencies for TSS

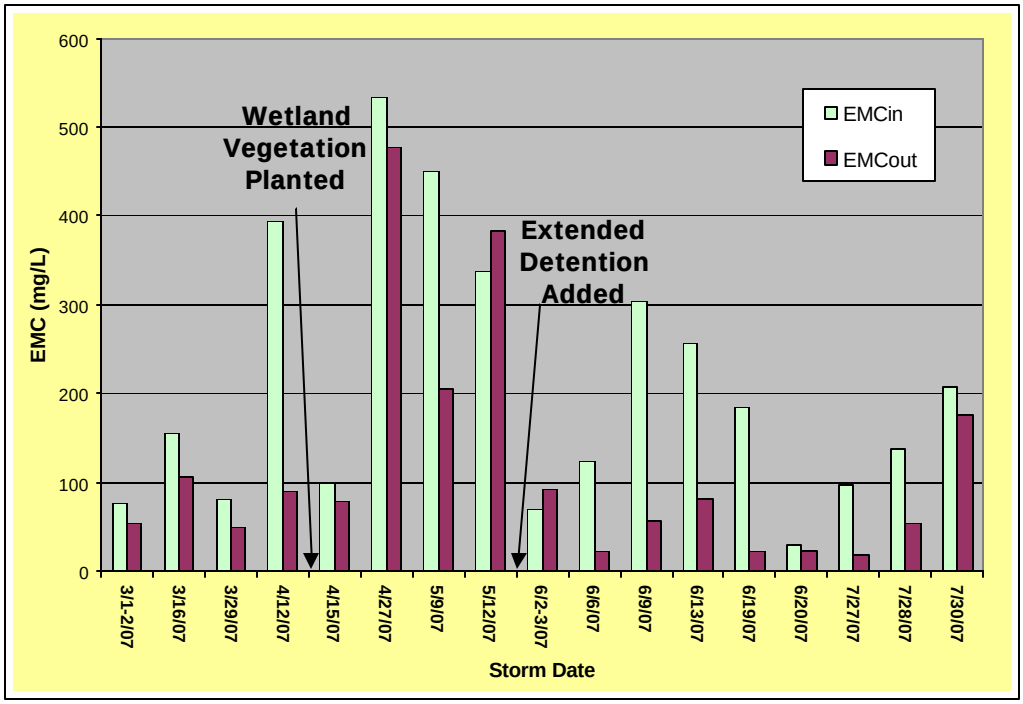


Figure 7.4: TSS EMCs for inlet and outlet (mg/L)

A more quantitative way of examining the effect of influent EMCs on pollutant removal efficiency in the wetland system was to divide the extended detention events in half by rank

of removal efficiencies. As shown by Table 7.4, TSS and most of the nutrients (except NH_3) had on average higher influent EMCs associated with the events yielding higher removal efficiencies. The contrary was true, however, for the heavy metals (except Cu). Note that these results should be considered with limited statistical validity due to the quite small sample size and small event size.

Table 7.4: Mean EMCs for high and low removal efficiency events

(TSS & nutrients in mg/L, metals in µg/L)

POLLUTANT	N	HIGH RE	LOW RE
TSS	9	184	102
$O\text{-}PO_4$	7	0.028	0.012
NH_3	6	0.39	0.42
NO_3/NO_2	6	0.62	0.49
TP	6	0.31	0.24
TKN	6	2.35	2.08
Cr	6	8	12
Cu	6	40	11
Ti	6	360	647
Zn	6	92	130
Pb	6	11	16

Pre-Extended Detention Erosion

Overall, the initial results exhibit high variability in removal efficiency. As a result of the lowered normal pool in the wetland (to allow for aquatic vegetation establishment) and the failure of vegetation to establish in the vegetated waterways, several large storm events (3/16, 4/15 and 5/12/07) caused significant erosion within the channels and thus caused net sediment loading from the system. Repairs were made with addition turf matting, *Juncus effusus* and *Sparganium americanum* transplants, and seeding of brown-top millet (*Panicum ramosum*). The channels are currently stabilized and densely vegetated (see Figures 7.5 and 7.6).

Figure 7.5: Vegetation established in upper channel

Figure 7.6: Vegetation established in second channel

Effluent Concentration Reduction

The mean concentrations for each pollutant and sampling location are included in Table 7.5. Note that the turbidity units are in NTUs, TSS and nutrient concentrations are in mg/L and the heavy metal concentrations are in µg/L. The results from the paired t-test, which used the log-transformed EMCs for comparative analysis, are included below in Table 7.6. The p-value for the calculated test statistic and the mean difference among all the influent and

effluent EMC pairings is included. Nickel and arsenic were excluded from the analysis due to insufficient sample sizes.

Table 7.5: Mean concentrations (TSS/nutrients in mg/L, metals in ug/L)

Pollutant	SOC3	SOC4	Outlet
TSS	200	107	120
Turbidity	96	40	91
$O\text{-}PO_4$	0.07	0.08	0.05
NH_3	0.49	0.33	0.43
NO_3/NO_2	0.53	0.31	0.38
TP	0.32	0.18	0.24
TKN	2.39	1.18	1.91
Cr	27	5	25.5
Cu	46	11	40
Ti	1665	270	2074
V	53	7	63
Zn	253	62	183
As	4	1	5
Ni	13	2	14
Pb	38	9	29

Table 7.6: Results from 2-sample t-test

Pollutant	n	p-value	d (mg/L)	Statistical Difference?
TSS	17	0.0005	-90.8	Yes
$O\text{-}PO_4$	12	0.0354	-0.028	Yes
NH_3	13	0.0412	-0.152	Yes
NO_3/NO_2	13	0.0008	-0.267	Yes
TP	13	0.0022	-0.104	Yes
TKN	13	0.0202	-0.679	Yes
Cr[1]	13	0.0035	-0.004	Yes
Cu[1]	13	0.0006	-0.010	Yes
Ti[1]	13	0.1185	0.026	No
V[1]	12	0.0853	-0.004	No
Zn[1]	13	0.0002	-0.076	Yes
Pb[1]	13	0.0003	-0.010	Yes

[1] d in ug/L

Among all the pollutants, only Ti and Zn did not show a significant reduction in EMC between the inlet and outlet of the wetland system. Since the paired t-test included the earlier

storm events that exhibited internal erosion and net pollutant loading, the results are likely skewed. The last six storm events analyzed for Ti and V show lower EMCs at the outlet compared to the weighted inlet EMC.

8. Discussion/Conclusions

Although the wetland vegetation is still within its first growing season, the initial removal results are promising. Disregarding the relatively large events that caused internal erosion and net sediment loading, the wetland system removed on average 68% of the TSS prior to the addition of the extended detention function of the wetland. Following channel stabilization/repair and addition of the extended detention in the wetland, overall pollutant removals were high. On average, pollutant removals following addition of the extended detention are 71% for TSS, between 39% and 60% for nutrients, and 60% for heavy metals. Five of the 9 events collected after extended detention was added had flows overtop the weir and bypass further treatment in the wetland, which will be a regular occurrence due to the undersized storage. For all the pollutants except TP and TKN, lower removal efficiencies were observed for the storms with flow bypass on average as compared to the smaller events without bypass. The phenomenon with TP and TKN might be due to the small sample size and will be further explored as more storms are collected. When evaluated for all the sampled storms, event mean concentrations proved to be statistically lower at the outlet for all pollutants except Ti and V. For most pollutants, higher influent EMCs were observed for the storms with higher removal efficiencies, indicating that more polluted influent was easier to treat.

As wetland vegetation continues to establish, pollutant removal is expected to be greater (particularly for nutrients). Continued monitoring should be performed through the growing season and into the winter to determine the performance of this BMP during plant dormancy. In addition, more events are needed to better account for the variability of storm size and influent concentrations on the removal performance of the wetland.

The ability of the undersized wetland system to safely route storm events greater than the 25-year, 24-hour event was recently tested by an intense summer storm that overtopped the emergency spillway. No visible damage to the wetland system occurred, but unfortunately the event was not sampled due to equipment failure. Since undersized wetlands are vulnerable to "pollutant flushing" and net positive loading during the extreme events, added importance will be placed in the future to accurately sample and analyze the performance of this system during these large events.

The initial performance evaluation of the wetland system concurs with the removal percentages estimated for an undersized stormwater wetland by the TAPL study in the previous chapter. The estimated removal credits, which were based on the preceding first flush study and the BMP removal efficiencies designated by NC DENR, indicate that a stormwater wetland designed to capture runoff from 1.3 cm of rainfall could potentially treat 61% of the TSS, 27% of the TN and 23% of the TP. These estimates assume that flows exceeding the storage volume in the wetland are diverted and do not pass through the BMP and primary outlet. The undersized wetland system evaluated in this study, which can store runoff from approximately 1.0 cm of rainfall, passes all the flow through the plunge pools and out the flashboard riser positioned in the center of the wetland. Taking note of the small number of storms and rainfall depths for the events sampled to date, the average removal efficiencies are actually higher than predicted for the 1.3 cm design storm BMP. These initial results indicated that undersized wetlands with "flow through" design might provide effective and efficient pollutant removals if designed to safely pass the larger storms. Longer term research will provide a more definitive evaluation when a large range of storm events can be analyzed.

9. References

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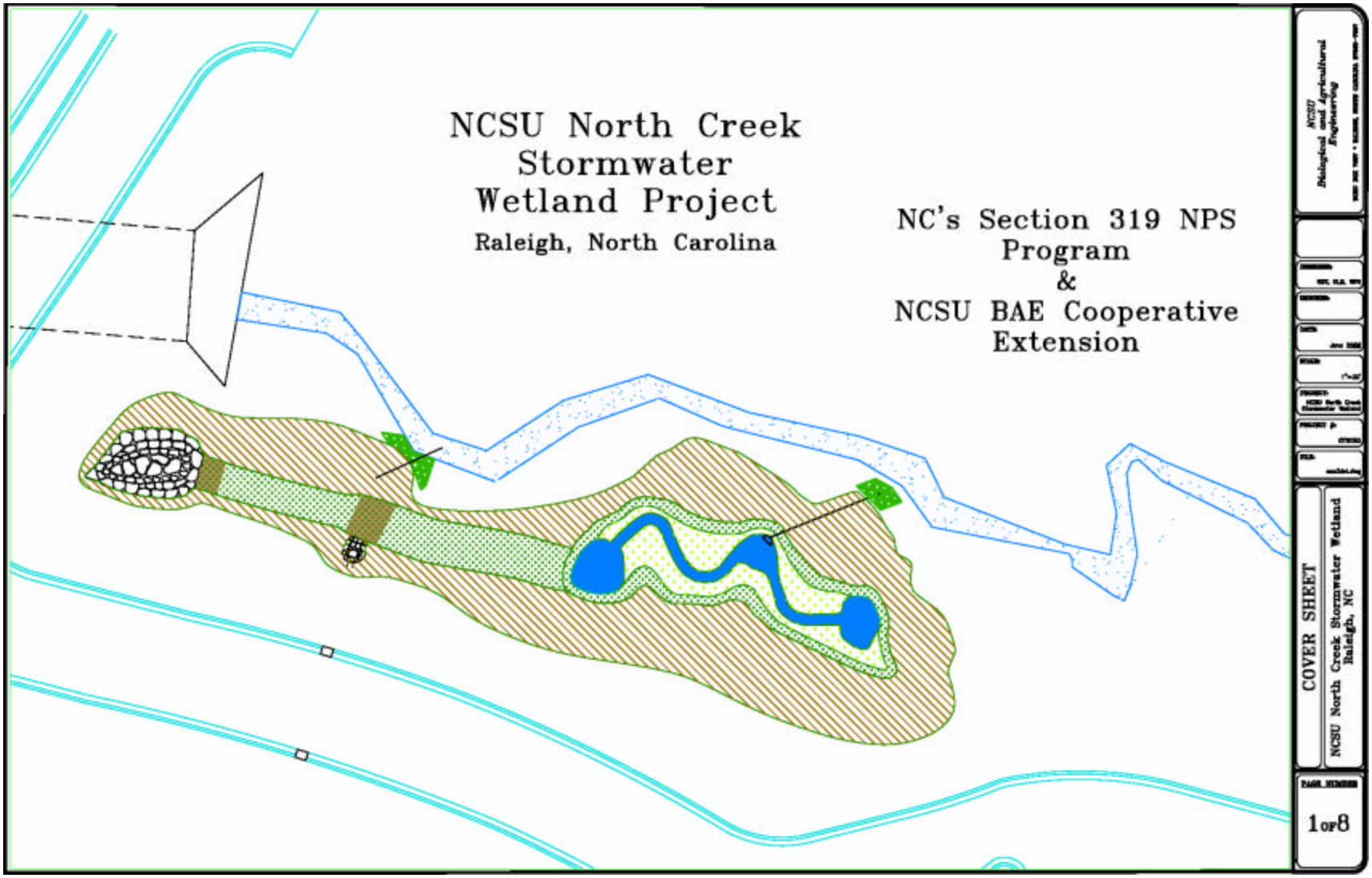
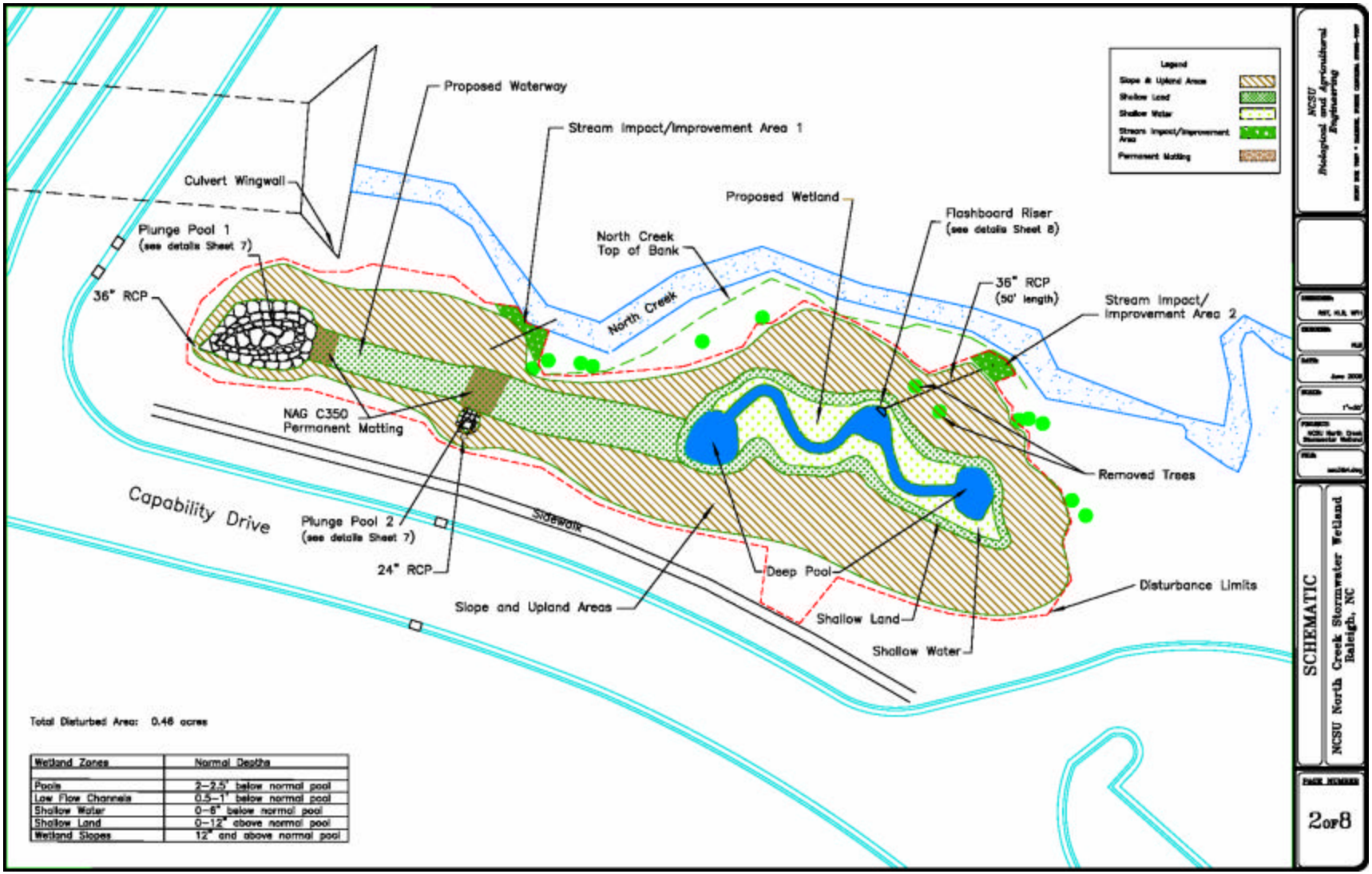
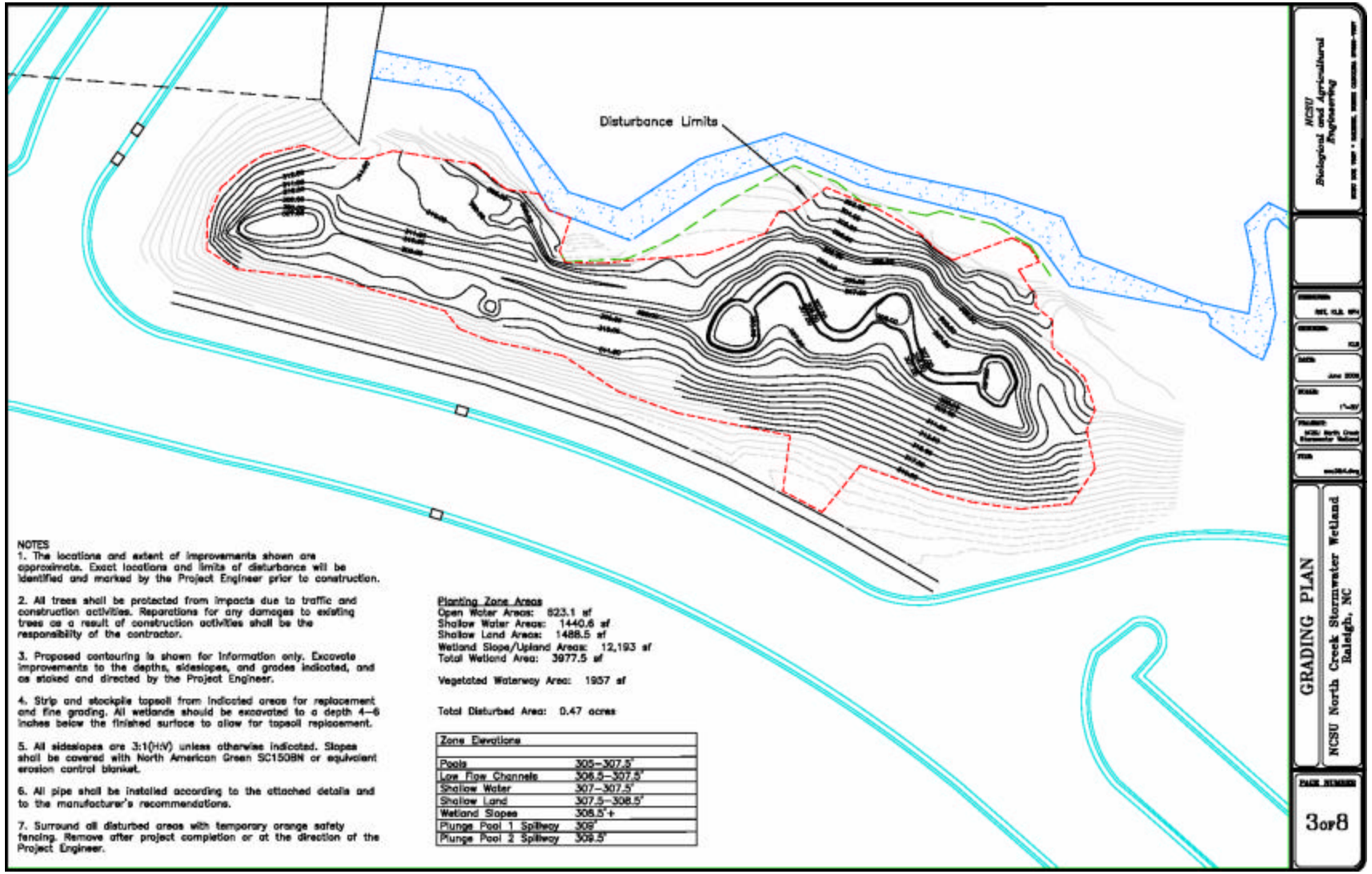
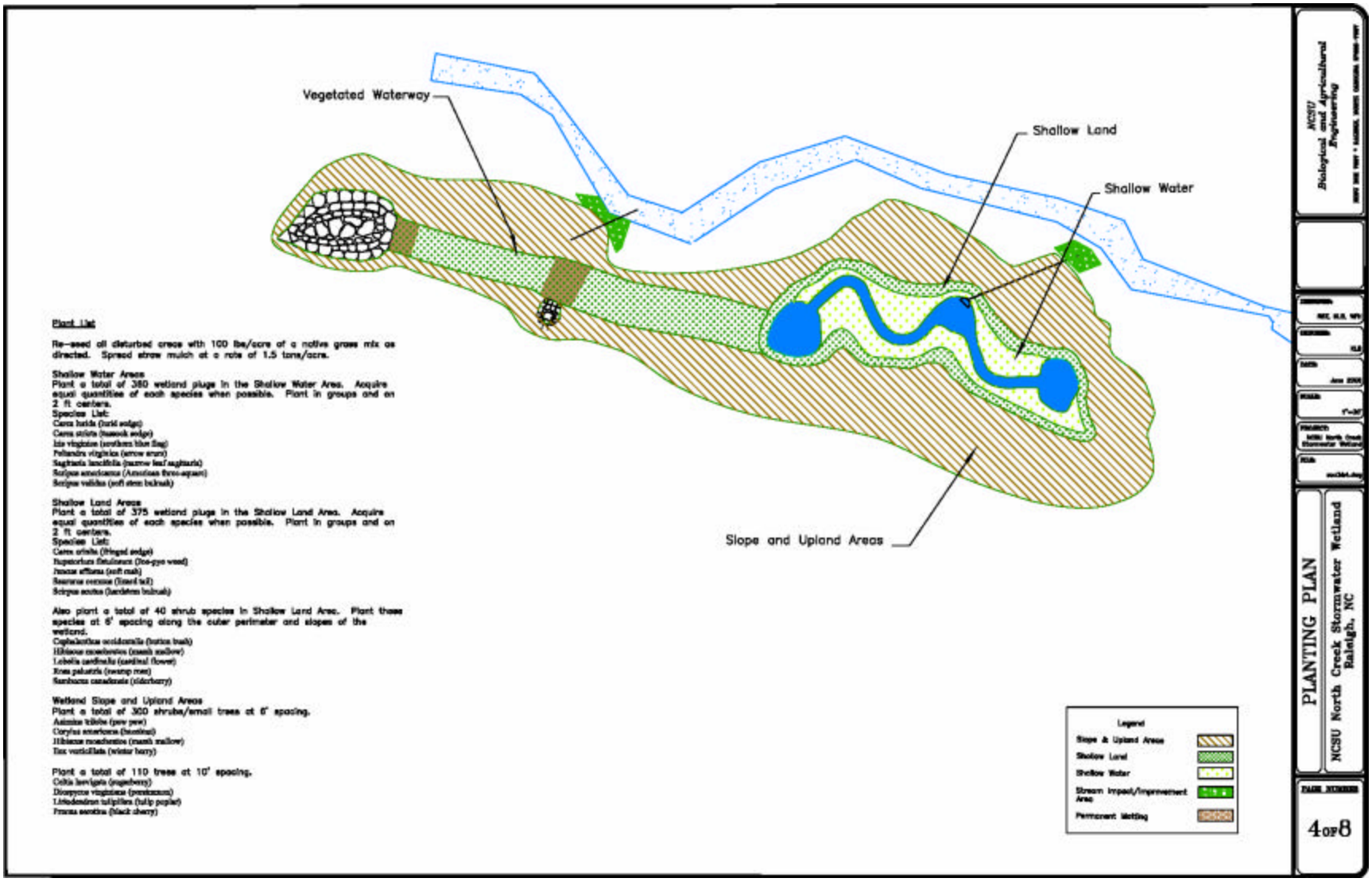
Appendices

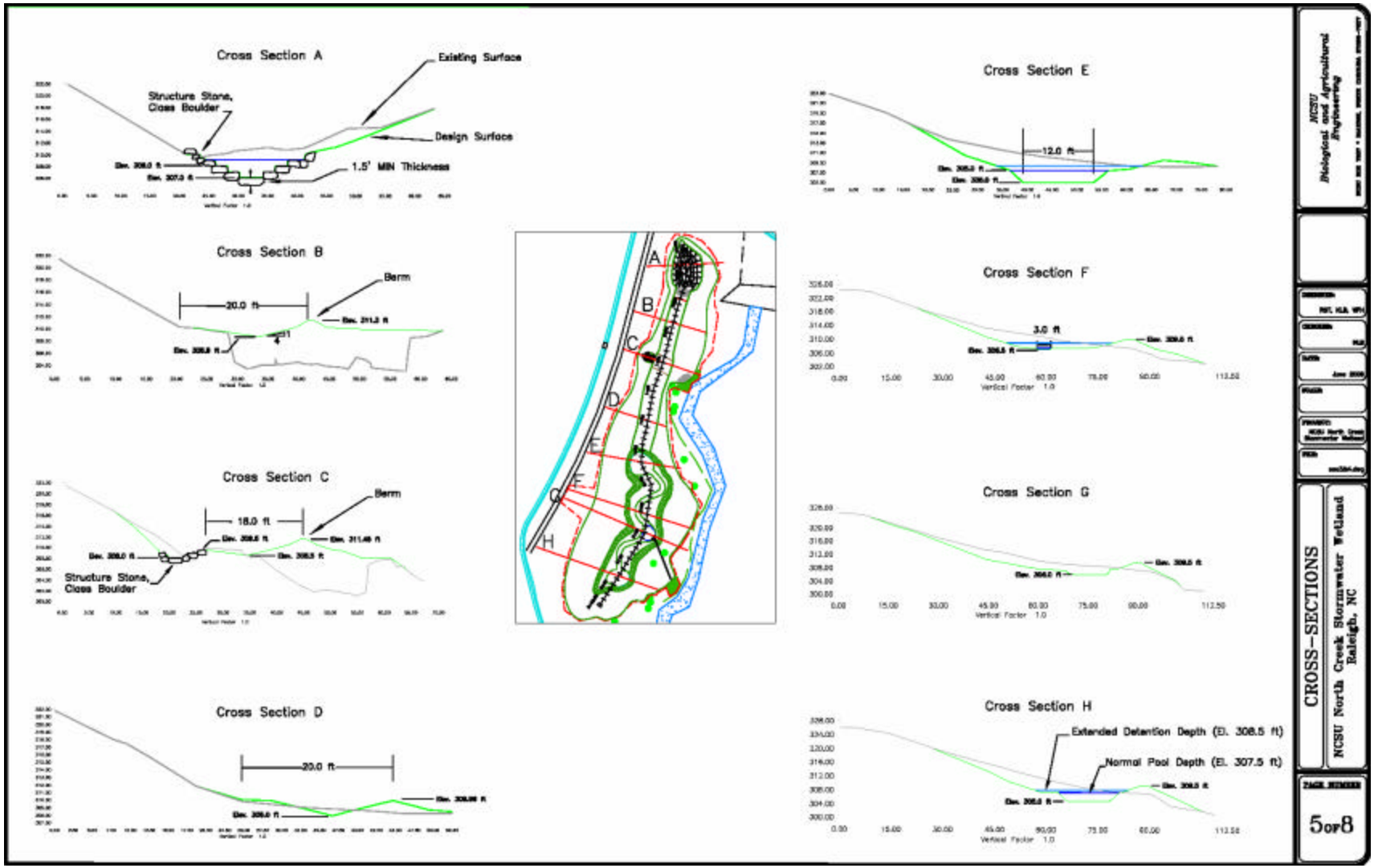
Appendix 1: Construction Drawings

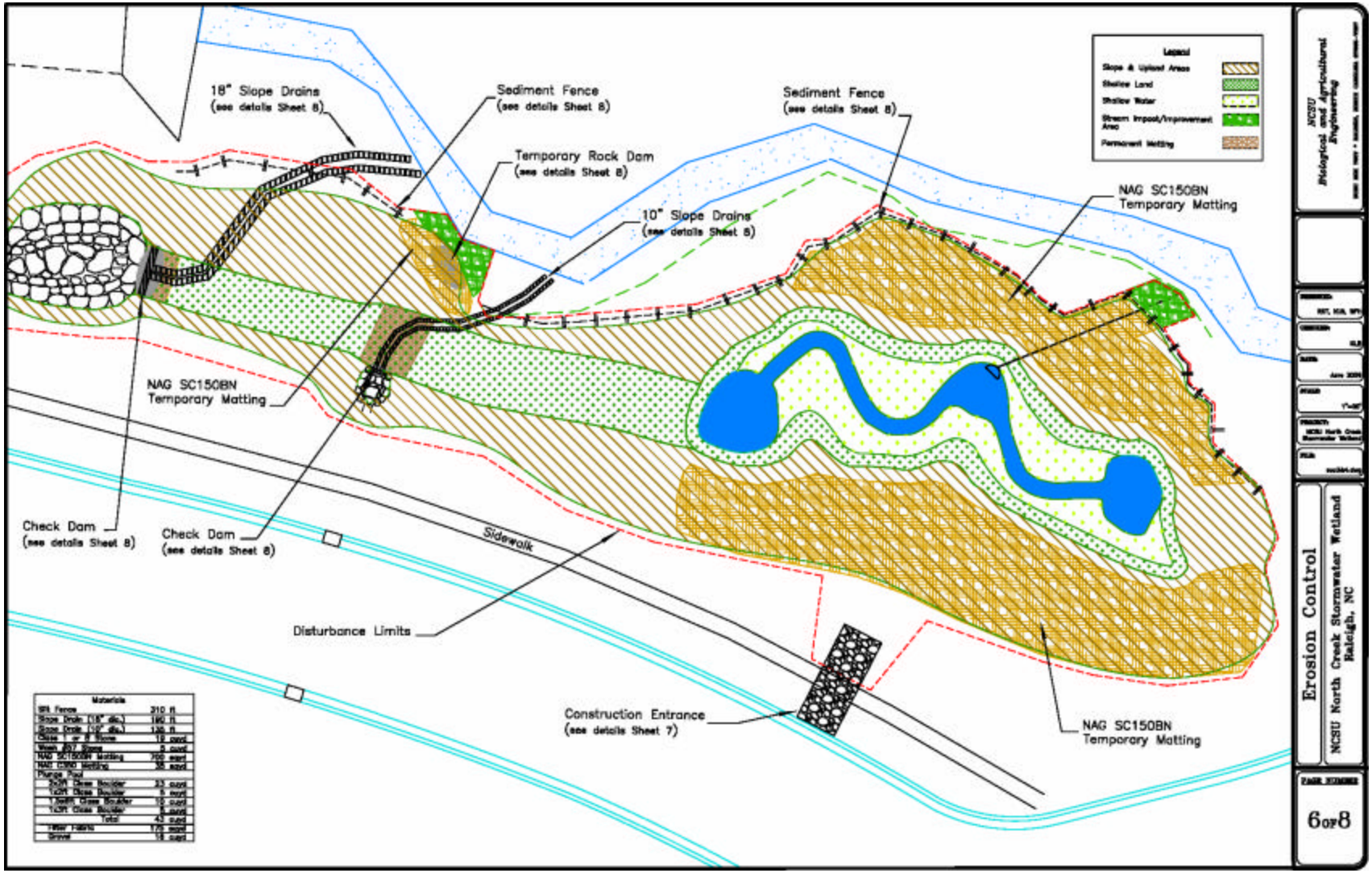

NCSU North Creek
Stormwater
Wetland Project
Raleigh, North Carolina
NC's Section 319 NPS
Program
&
NCSU BAE Cooperative
Extension
COVER SHEET
NCSU North Creek Stormwater Wetland
Raleigh, NC
1 OF 8


Proposed Waterway
Stream Impact/Improvement Area 1
Culvert Wingwall
Plunge Pool 1
(see details Sheet 7)
36" RCP
Proposed Wetland
North Creek
Top of Bank
North Creek
Flashboard Riser
(see details Sheet 8)
36" RCP
(50' length)
Stream Impact/
Improvement Area 2
NAG C350
Permanent Matting
Removed Trees
Capability Drive
Plunge Pool 2
(see details Sheet 7)
Sidewalk
24" RCP
Deep Pool
Disturbance Limits
Slope and Upland Areas
Shallow Land
Shallow Water
Legend
Slope & Upland Areas
Shallow Land
Shallow Water
Stream Impact/Improvement Area
Permanent Matting
Total Disturbed Area: 0.46 acres
Wetland Zones
Normal Depths
Pools
2–2.5' below normal pool
Low Flow Channels
0.5–1' below normal pool
Shallow Water
0–6" below normal pool
Shallow Land
0–12" above normal pool
Wetland Slopes
12" and above normal pool
SCHEMATIC
NCSU North Creek Stormwater Wetland
Raleigh, NC
2 OF 8


Disturbance Limits
NOTES
1. The locations and extent of improvements shown are approximate. Exact locations and limits of disturbance will be identified and marked by the Project Engineer prior to construction.
2. All trees shall be protected from impacts due to traffic and construction activities. Reparations for any damages to existing trees as a result of construction activities shall be the responsibility of the contractor.
3. Proposed contouring is shown for information only. Excavate improvements to the depths, sideslopes, and grades indicated, and as staked and directed by the Project Engineer.
4. Strip and stockpile topsoil from indicated areas for replacement and fine grading. All wetlands should be excavated to a depth 4–6 inches below the finished surface to allow for topsoil replacement.
5. All sideslopes are 3:1(H:V) unless otherwise indicated. Slopes shall be covered with North American Green SC150BN or equivalent erosion control blanket.
6. All pipe shall be installed according to the attached details and to the manufacturer's recommendations.
7. Surround all disturbed areas with temporary orange safety fencing. Remove after project completion or at the direction of the Project Engineer.
Planting Zone Areas
Open Water Areas: 823.1 sf
Shallow Water Areas: 1440.6 sf
Shallow Land Areas: 1488.5 sf
Wetland Slope/Upland Areas: 12,193 sf
Total Wetland Area: 3977.5 sf
Vegetated Waterway Area: 1957 sf
Total Disturbed Area: 0.47 acres
Zone Elevations
Pools 305–307.5'
Low Flow Channels 306.5–307.5'
Shallow Water 307–307.5'
Shallow Land 307.5–308.5'
Wetland Slopes 308.5'+
Plunge Pool 1 Spillway 309'
Plunge Pool 2 Spillway 309.5'
NCSU Biological and Agricultural Engineering
GRADING PLAN
NCSU North Creek Stormwater Wetland
Raleigh, NC
3 OF 8


Vegetated Waterway
Shallow Land
Shallow Water
Slope and Upland Areas
Legend
Slope & Upland Areas
Shallow Land
Shallow Water
Stream Impact/Improvement Area
Permanent Wetting
Plant List
Re-seed all disturbed areas with 100 lbs/acre of a native grass mix as directed. Spread straw mulch at a rate of 1.5 tons/acre.
Shallow Water Areas
Plant a total of 380 wetland plugs in the Shallow Water Area. Acquire equal quantities of each species when possible. Plant in groups and on 2 ft centers.
Species List:
Carex lurida (lurid sedge)
Carex stricta (tussock sedge)
Iris virginica (southern blue flag)
Peltandra virginica (arrow arum)
Sagittaria lancifolia (narrow leaf sagittaria)
Scirpus americanus (American three-square)
Scirpus validus (soft stem bulrush)
Shallow Land Areas
Plant a total of 375 wetland plugs in the Shallow Land Area. Acquire equal quantities of each species when possible. Plant in groups and on 2 ft centers.
Species List:
Carex crinita (fringed sedge)
Eupatorium fistulosum (Joe-pye weed)
Juncus effusus (soft rush)
Saururus cernuus (lizard tail)
Scirpus cyperinus (woolgrass bulrush)
Also plant a total of 40 shrub species in Shallow Land Area. Plant these species at 6' spacing along the outer perimeter and slopes of the wetland.
Cephalanthus occidentalis (button bush)
Hibiscus moscheutos (swamp mallow)
Lobelia cardinalis (cardinal flower)
Rosa palustris (swamp rose)
Sambucus canadensis (elderberry)
Wetland Slope and Upland Areas
Plant a total of 300 shrubs/small trees at 6' spacing.
Asimina triloba (paw paw)
Corylus americana (hazelnut)
Hibiscus moscheutos (swamp mallow)
Ilex verticillata (winter berry)
Plant a total of 110 trees at 10' spacing.
Celtis laevigata (sugarberry)
Diospyros virginiana (persimmon)
Liriodendron tulipifera (tulip poplar)
Prunus serotina (black cherry)
NCSU Biological and Agricultural Engineering
PLANTING PLAN
NCSU North Creek Stormwater Wetland
Raleigh, NC
SHEET NUMBER
4 OF 8


Cross Section A
Existing Surface
Structure Stone, Class Boulder
Design Surface
1.5' MIN Thickness
Cross Section B
Berm
20.0 ft
Cross Section C
Berm
18.0 ft
Structure Stone, Class Boulder
Cross Section D
20.0 ft
A
B
C
D
E
F
G
H
Cross Section E
12.0 ft
Cross Section F
3.0 ft
Cross Section G
Cross Section H
Extended Detention Depth (El. 308.5 ft)
Normal Pool Depth (El. 307.5 ft)
NCSU Biological and Agricultural Engineering
CROSS-SECTIONS
NCSU North Creek Stormwater Wetland
Raleigh, NC
5 OF 8


18" Slope Drains
(see details Sheet 8)
Sediment Fence
(see details Sheet 8)
Temporary Rock Dam
(see details Sheet 8)
10" Slope Drains
(see details Sheet 8)
Sediment Fence
(see details Sheet 8)
NAG SC150BN
Temporary Matting
NAG SC150BN
Temporary Matting
Check Dam
(see details Sheet 8)
Check Dam
(see details Sheet 8)
Sidewalk
Disturbance Limits
Construction Entrance
(see details Sheet 7)
NAG SC150BN
Temporary Matting
Legend
Slope & Upland Areas
Shallow Land
Shallow Water
Stream Impact/Improvement Area
Permanent Matting
Materials
Erosion Control
NCSU North Creek Stormwater Wetland
Raleigh, NC
6 of 8

PROJECT NARRATIVE:

This project is part of the Water Quality and Biological Integrity Improvement Project in North Creek/Walnut Creek. It is a joint venture between North Carolina's Section 319 NPS Program and N.C. State University. The goal of this project is to construct an innovative stormwater control enhancement to establish a natural corridor through an urban setting while effectively treating urban stormwater pollutants. The proposed wetland and vegetated swale system will not only treat stormwater, but provide improvement in flood control and enhance native wildlife habitat and ecological diversity. The project involves bulk earth movement, fine grading, installation of piping, final grading, and planting.

GENERAL CONSTRUCTION SEQUENCE:

1. Locate and set up an appropriate site for stockpile of materials and storage of equipment.
2. Install all erosion control measures including construction entrance.
3. Remove downed trees and debris from eroded channel.
4. Construct plunge pools, check dams and slope drains at culvert outlets.
5. Remove and stockpile topsoil.
6. Begin mass grading operations.
7. Install outlet pipes/structures in wetland.
8. Replace topsoil and complete fine grading.
9. Implement planting plan.
10. Request a completion inspection from the Project Engineer.

GRADING AND EROSION CONTROL NOTES:

1. All erosion control must be set-up and inspected prior to commencement of grading operations.

2. Strip and stockpile topsoil in indicated areas for use as substrate in wetlands.

3. Culverts shall be reinforced concrete pipe or equivalent.

4. All elevations shown on the Project Drawings are relative. Utilize benchmarks as directed by the Project Engineer. Grading shall be met within a tolerance of 0.1'

5. Stabilization measures shall be initiated as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than fourteen (14) days after work has ceased, unless activity in that portion of the site will resume within twenty-one (21) days.

6. All sediment and erosion control devices shall be inspected every seven (7) days or after each rainfall occurence that exceeds one-half (1/2) inch. Damaged or ineffective devices shall be repaired or replaced, as necessary.

7. All erosion control devices shall be properly maintained during all phases of the construction until the completion of all construction activities and all disturbed areas have been stabilized. Additional control devices may be required during construction in order to control erosion and/or off-site sedimentation. All temporary control devices shall be removed once construction is complete and the site is stabilized.

8. The contractor must take necessary action to minimize the tracking of mud onto the paved roadway construction areas. The contractor shall daily remove mud/soil from pavement, as may be required.

9. Temporary diversion berms and/or ditches will be provided as needed during construction to protect work areas from upslope runoff and/or to divert sediment laden runoff water to appropriate traps or stable outlets.

Recommended Wetland Maintenance Activities

1. Outlet & Inlet inspection/minor maintenance. Once per month (after every 1-1.5" storm). Clean out trash/debris from structures and trash racks.

2. Periodic trash removal. As needed. Clean trash from wetland interior as needed for wetland aesthetics.

3. Destroy muskrat holes (do this when doing #2 above).

4. Do not mow planted wetland sideslopes. The tops of berms and backslopes may be mowed at the City's discretion. "No mow zone" signs are recommended at a minimum 10' foot distance from protected areas.

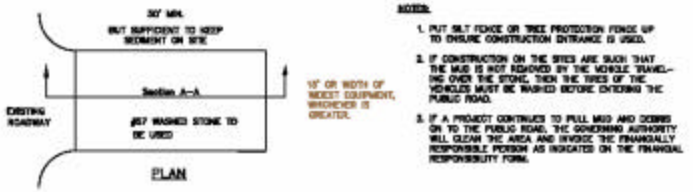
5. Invasive Species Removal. Once per year. Only necessary for cattail removal or to improve site aesthetics.

6. Minor Outlet/Inlet repair. Once every 2-3 years. Identify and repair erosion problems. Replace damaged boards in flashboard risers.

7. Forebay inspection/dipping. Once every 3-5 years (or as needed). Excavator or similar equip may be needed. Due to the developed nature of this watershed, this activity may not ever be necessary.

CONSTRUCTION ENTRANCE

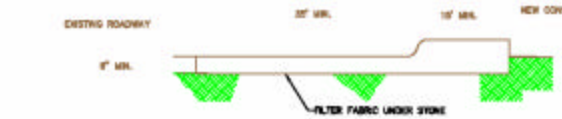
N.T.S.



PLAN

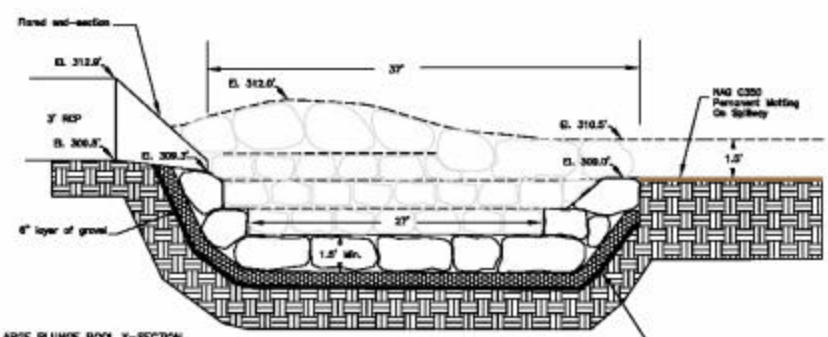
NOTES:

1. PUT SILT FENCE OR TREE PROTECTION FENCE UP TO ENSURE CONSTRUCTION ENTRANCE IS USED.
2. IF CONSTRUCTION ON THE SITES ARE SUCH THAT THE MUD IS NOT RESHAPED BY THE VEHICLE TRAVELING OVER THE STONE, THEN THE TIRES OF THE VEHICLES MUST BE WASHED BEFORE ENTERING THE PUBLIC ROAD.
3. IF A PROJECT CONTINUES TO PULL MUD AND DEBRIS ON TO THE PUBLIC ROAD, THE GOVERNING AUTHORITY WILL CLEAN THE AREA AND INVOICE THE FINANCIALLY RESPONSIBLE PERSON AS INDICATED ON THE FINANCIAL RESPONSIBILITY FORM.

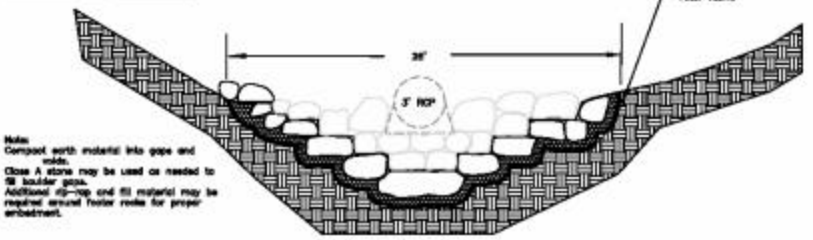


SECTION A-A

LARGE PLUNGE POOL PROFILE



LARGE PLUNGE POOL X-SECTION



Note:
Compact earth material into gaps and voids.
Class A stone may be used as needed to fill boulder gaps.
Additional rip-rap and fill material may be required around footer rocks for proper embedment.

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Biological and Agricultural Engineering

Construction Details

NCSU North Creek Stormwater Wetland
Raleigh, NC

7 OF 8

SEDIMENT FENCE
N.T.S.

I. CONSTRUCTION SPECIFICATIONS

1. Mark the intended line of placement for the sediment fence on the ground at the site as outlined on the plan.
2. Construct the sediment fence of standard strength or extra strength synthetic filter fabric. Do not use fabrics that are quickly biodegradable. Synthetic filter fabric should contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0° to 120° F. Ensure that the height of the silt fence does not exceed eighteen (18) inches above the ground.
3. Construct the filter fabric from a continuous roll cut to the length of the barrier to avoid joints. When joints are necessary, securely fasten the filter cloth only at a support post with overlap to the next post. For reinforcement of filter fabric, use wire fence with a minimum fourteen (14) gauge and a maximum mesh spacing of six (6) inches.
4. Support filter fabric with wire mesh fastened securely to the upslope of the posts using either tie wires or heavy duty wire staples at least one (1) inch long. Extend the wire mesh to support the bottom of the trench.
5. Space posts a maximum of eight (8) feet apart. Support should be driven securely into the ground to a minimum depth of eighteen (18) inches. Ensure that the posts for sediment fences are 1.33 lb/linear ft steel with a minimum length of four (4) feet. Make sure that steel posts have projections to facilitate fastening the fabric.
6. Excavate a trench approximately four (4) inches wide and eight (8) inches deep along the proposed line of posts and upslope from the barrier.
7. Backfill the trench with compacted soil or gravel placed over the filter fabric.
8. Do not attach the filter fabric to existing trees.

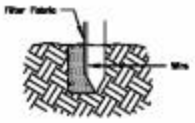
II. MAINTENANCE

1. Fence posts which have become dislodged or displaced for any reason shall be immediately replaced.
2. Tears in the fabric of the fencing shall likewise be repaired to maintain the intended function of the silt fence.
3. The proper function of the sediment fence is to be maintained at all times.

III. REMOVAL

1. Confirm with the Southern Pines Public Works Department that removal of the fence is acceptable.
2. Remove the sediment fence and smooth the disturbed area to blend with the surrounding topography.

Extension of fabric and wire into the trench



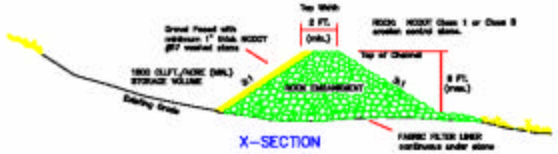
CHECK DAM/SEDIMENT TRAP
N.T.S.

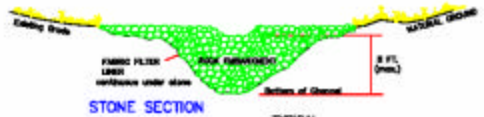
I. CONSTRUCTION SPECIFICATIONS

1. Place stone to the lines and dimensions shown in the plan on a filter fabric foundation.
2. Keep the center stone section at least nine (9) inches below natural ground level where the dam abuts the channel banks.
3. Extend the stone at least one and a half (1.5) feet beyond the ditch banks to keep overflow water from undercutting the dam as it re-enters the channel.
4. Use four (4) to fifteen (15) inch stone (NCDOT class 1 or class B erosion control stone).

II. MAINTENANCE

1. Inspect channel for damage after each runoff event.
2. Remove sediment accumulated behind check dam as needed to prevent damage to channel vegetation, allow the channel to drain through the stone check dam, and prevent large flows from carrying sediment over the dam.
3. Add stones to the dam as needed to maintain design height and cross section.





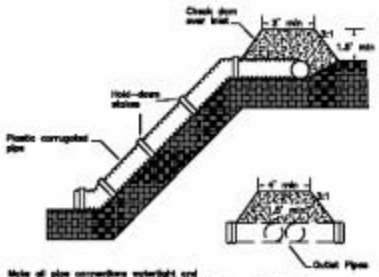
TYPICAL

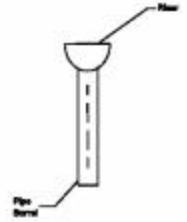
TEMPORARY ROCK DAM

NRCD 6.63

NO SCALE

Slope Drain and Inlet Detail

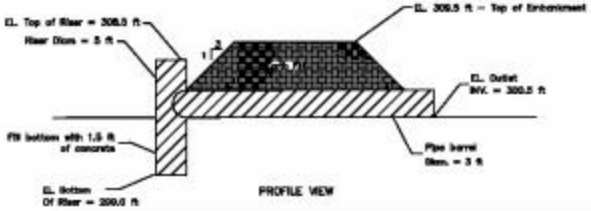




PLAN VIEW

RISER SCHEMATIC

FLASHBOARD RISER DETAIL
N.T.S



PROFILE VIEW

NCSU Biological and Agricultural Engineering

Construction Details

NCSU North Creek Stormwater Wetland
Raleigh, NC

8 or 8

Appendix 2: Native Vegetation Planting List

		Cure Nursery		Mellow Marsh		Coastal Plain Conservation	
Species	**Common Name**	Quantity	Container	Quantity	Container	Quantity	Container
Shallow Water Areas (plugs)							
Carex crinita	fringed sedge				plug	36	large plug
Carex lurida	lurid sedge			36	plug		
Carex stricta	tussock sedge			36	plug		
Iris versicolor	blue flag				plug	36	large plug
Peltandra virginica	arrow arum				peat pot	36	large plug
Sagittaria lancifolia	narrow leaf sagittaria			36	bare root		
Sagittaria latifolia	duck potato					36	large plug
Scirpus amaericanus	american three-square				bare root	36	large plug
Schoenoplectus tabernaemontani	softstem bulrush				plug	36	large plug
Sparganium americanum	sbur-reed					36	bare root
Shallow Land Areas (plugs)							
Carex crinita	fringed sedge				plug	25	large plug
Carex lurida	lurid sedge					25	large plug
Carex tribuloides	bristlebract sedge					50	large plug
Eupatoriadelphus fistulosus	joe-pye weed			75	plug		
Hibiscus mosheutos	marsh mallow					25	tubeling
Juncus effusus	soft rush				plug	75	large plug
Saurus cernuus	lizard tail			50	plug		
Scirpus cyperinus	hardstem bulrush			50	bare root		
Shallow Land Areas (shrubs)							
Alnus serrulata	hazel alder	8	small				gallon
Cephalanthus occidentalis	buttonbush	4	gallon	4	tubeling		gallon
Cornus amomum	silky dogwood	4	small				gallon
Hibiscus mosheutos	marsh mallow	4	gallon				
Lobelia cardinalis	cardinal flower	TBP					
Rosa palustris	swamp rose			4	gallon		gallon
Sambucus canadensis	elderberry			4	gallon		
Wetland Slope and Upland Areas (shrub and small trees)							
Aronia arbutifolia	red chokeberry			25	gallon		tubeling
Asimina triloba	paw paw	TBP					
Callicarpa americana	beautyberry	50	gallon				tubeling
Hibiscus mosheutos	marsh mallow	50	small				
Leucothoe racemosa	fetterbush	10	gallon				
Illex verticillata	winter berry	25	large	25	gallon		
Myrica cerifera	wax myrtle	25	gallon				tubeling
Sambucus canadensis	elderberry	30	small				large plug
Vaccinium corymbosum	highbush	5	2 gal				
Viburnum dentatum	arrowwood	25	small				gallon
Xanthorhiza simplicissima	yellow root	10	gallon				
Wetland Slope and Upland Areas (large trees)							
Magnolia virginia	sweetbay	20	gallon				gallon
Carpinus caroliniana	ironwood			22	tubeling		
Crataegus viridis	hawthorne						gallon
Diospyros virginiana	persimmon	22	large	25	gallon		gallon
Liriodendron tulipifera	tulip poplar	25	gallon				

Appendix 3: Bentonite Proposal

November 16, 2006

Robert Tucker
NORTH CAROLINA STATE UNIVERSITY
909 Capability Drive, Suite 3200
Raleigh, NC 27606

Re: Proposal for Testing Services
Proposed North Creek Wetlands Reconstruction
Raleigh, North Carolina
GeoTechnologies Proposal No. 1-06-0412

Dear Mr. Tucker:

GeoTechnologies, Inc. is pleased to present this proposal to provide testing services for wetlands mitigation planned on the North Carolina State University campus. It is our understanding that that a wetlands area comprising about 4,000 square feet is planned for construction. Based on our familiarity with similar projects on the NCSU campus, we anticipate that the project will require a minimum 6 inch liner with a permeability of 1 times 10^{-6} cm/second. Based on the 6 inch thickness, approximately 75 cubic yards of treated material will be required for the 4000 square foot construction. We understand that the current plan is to Bentonite amend on-site material in order to achieve the desired permeability.

We understand that GeoTechnologies' personnel will collect the materials proposed for testing. The initial testing should include grain size distribution, Atterberg Limits, standard Proctor compaction, and laboratory permeability testing on the existing materials. Assuming that the material does not meet the project requirements for permeability when recompacted at 3% on the wet side of optimum, it will be necessary to evaluate the requirements for Bentonite amendment. If Bentonite amendment testing is necessary, we suggest performing two different Bentonite mixtures on a sample of the more sandy material which exists on the site.

If Bentonite amendment is used, we anticipate that the cost of our services for this phase of the work would be $1,292 as outlined in the attached Table 1. We are proposing to begin the project immediately, however, the laboratory testing will likely require at least five to seven days. We can provide preliminary estimates ahead of time regarding estimated Bentonite quantities.

We appreciate the opportunity to submit this proposal and hope that we may be of service on this project. Please contact us if you should have questions regarding this proposal or if we may be of further assistance.

Sincerely,

GeoTechnologies, Inc.

David L. Israel, P.E.
President

TABLE 1
COST ESTIMATE FOR TESTING SERVICES

NCSU Wetlands Reconstruction
Raleigh, North Carolina

GeoTechnologies Proposal No. 1-06-0412

Assume 1 sample for testing prior to Bentonite amendment –	
Grain size tests; 1 @ $50.00/ea.	50.00
Atterberg Limits tests; 1 @ $50.00/ea.	50.00
Standard Proctor compaction tests; 1 @ $100.00/ea.	100.00
Permeability tests; 1 @ $270.00/ea.	270.00
Technician to pull samples; 2 hrs. @ $35.00/hr.	70.00
Mileage; 24 miles @ $0.50/mile	12.00
Report preparation	200.00
Subtotal	**$752.00**
Assume 1 samples tested for amendment at two different concentrations –	
Permeability tests; 2 @ $270.00ea.	540.00
Subtotal	**$540.00**
TOTAL ESTIMATED COST	**$1,292.00**

Appendix 4: Project Manual for Construction Contractor

NCSU North Creek Stormwater Wetland Project

1. Introduction

The following sections describe special instructions for construction of the project. The Project Engineer should be available at all times during the construction to answer any questions and to inspect all aspects of the construction. The construction should cover all necessary items for equipment, materials, and labor associated with the construction. The Project Engineers, however, will arrange the ordering and planting of the wetland plants. Construction drawings for the stormwater wetland system are attached.

2. Project Engineers

CONSTRUCTION MANAGER
Ryan Breedlove
Facilities Planning and Design
Phone: (919) 515-1101
Fax: (919) 515-3395

Kris Bass
NCSU Dept. of Biological and Agricultural Engineering
Phone: (919) 515-8245
Fax: (919) 515-7448

Bill Hunt
NCSU Dept. of Biological and Agricultural Engineering
Phone: (919) 515-6751
Fax: (919) 515-6772

Project Designer/Construction Contact
Robert Tucker
NCSU Dept. of Biological and Agricultural Engineering
Phone: (919) 515-7475
Fax: (919) 515-7448

3. Construction Sequence

1. Install construction entrance, silt fence, and sediment dam
2. Remove downed trees and debris from eroded channel and selected trees from wetland area
3. Excavate and build plunge pools
4. Install slope drains and check dams and plunge pool spillway
5. Begin vegetated waterway/wetland grading operations

6. Spread fill/complete grading
7. Complete tillage/soil preparation
8. Install outlet structure
9. Commence seeding and shrub planting
10. Finish wetland planting
11. Install outlet device boards and drawdown device

4. Grading

In order to construct the stormwater wetland and vegetated waterway system, the existing ground will be excavated. Part of the road bank of Capability Drive will be graded to a slope no greater than 2/1 in order to meet the grade requirements for the wetland while maintaining 3/1 side slopes within the wetland as well as a required distance of 15 ft from any trees larger than 9-inches. Excess cut soil from the wetland will be used to fill the existing scour-hole and re-stabilize that section of the North Creek stream bank.

5. Erosion Control

During the project, excavated soil will be stockpiled in designated areas, and check dams (Class 1 or B stone) with slope drains will be installed at the spillways to the two plunge pools to safely divert stormwater to North Creek. In addition, a temporary sediment dam constructed of Class 1 or B stone with a Wash #57 stone front will be installed at the exit of the scour-hole before the confluence with North Creek to help remove any remaining sediment. Silt fence will be installed along the entire stream-side of the project site and all disturbed road banks and the entire disturbed area between the top of the wetland berm and North Creek will be seeded with fescue or other approved grass mix at a rate of 100 lbs/acre and covered with NAG SC150BN temporary matting.

Proposed Erosion Control Installation Sequence

1. Install construction entrance.
2. Install silt fence along top-bank of North Creek.
3. Build temporary sediment dam at confluence with North Creek.
4. After construction of plunge pools, install check dams and slope drains at spillways.
5. Upon completion of grading, sow temporary seeding and install temporary matting.

6. Plunge Pools

Two plunge pools are to be constructed at the culvert outlets. Each plunge pool will be excavated in stair-step geometry for boulder stacking. The plunge pools will contain a bottom layer of filter fabric followed by a 6 inch layer of gravel. Structure stone of Class Boulder will be installed on top of the gravel and filled with Class A stone and more gravel.

7. Vegetated Waterway

The vegetated waterway with triangular swale geometry is designed to handle peak flows from the 25-yr storm event. The plunge pool at the SOC 3 culvert will discharge stormwater over a spillway reinforced with NAG C350 turf matting to the 1% sloped vegetated waterway. This first section of the waterway has a top width of 12 feet with a maximum depth of 1.5 feet. The second section of the waterway (between the spillway from the SOC 4 culvert plunge pool and the wetland) has a top width of 16 feet, a maximum depth of 2.0 feet, and a channel slope of 0.5%. All waterway side slopes are to be no greater than 4:1.

8. Stormwater Wetland

The surface area of the stormwater wetland at extended detention depth is 3,978 sq ft. Approximately 16% of the wetland contains two deep pools (at most 2.5 ft deep below normal pool) and one shallow pool (at most 1.5 ft deep below normal pool). A sinuous low-flow channel 2 feet wide and 1 foot deep connects the three pools and comprises about 18% of the wetland surface area. A shallow water area between 0-6 inches below the normal pool will encompass 36% of the total wetland surface area. The remainder of the wetland surface area (45%) will contain shallow land that will only be completely covered with water during storm events that reach the extended detention depth of 1-foot.

9. Bentonite Liner

In order to maintain permanent stormwater wetland conditions the bed of the wetland will be sealed using bentonite clay liners at the depth of excavation, with a minimum permeability of 0.01 in/hr. The liners will be constructed by spreading bentonite onto the soil surface, vertically distributing the bentonite into the existing soil using a pug-mill mixer or other suitable mixing equipment, and then compacting the liners using a backhoe, track hoe, or other compacting equipment. A soil geotechnical consultant will be required to determine the amount of bentonite to add, the degree of compaction, and will oversee the installation of the liner. The permeability of the liner will be tested for quality assurance before construction of inner wetland features begins. A layer of topsoil (44 cy) approximately 4 inches thick will also be added over the bentonite clay liner to prevent pH spikes and provide a healthy media for vegetation.

10. Outlet Installation

The outlet structure shall be constructed of corrugated aluminum piping and will be delivered with appropriate flashboard risers. The structure shall be installed to the designated elevation. An appropriate area approximately 6 feet wide shall be excavated around the culvert also to complete the proper installation. The pipe area shall be backfilled and compacted with sand. Completely backfill the area with soil after installation is finished and blend the grade into existing slope. The slope should be reseeded as necessary.

Potential Sources
Cahoon Farms Pomona Pipe

Arapahoe, NC	Snow Hill, NC
252.249.2856	Contact: Tom Glover
	336.210.8006

11. Vegetation Planting

The final phase of the stormwater wetland/waterway construction will be the addition of vegetation within the wetlands and along the perimeter of the project site. A variety of native wetland species will be placed in specified areas within the wetland, grasses will be planted on the berms and vegetated waterway, and upland plants including shrubs and trees will be added surrounding the wetland boundary to further improve the riparian function of the floodplain. The Contractor shall provide labor, temporary seed, and mulch, while NCSU shall provide the plants and permanent seed. In addition, repair and re-seed any disturbed areas outside of the grading boundaries. See Plan Sheet 4 for plant list.

12. Stream Repair/Enhancement

In conjunction with the stormwater wetland system are stream enhancements within the same stream reach. The primary stream impacts proposed are to repair, stabilize, and vegetate a massively eroded area of the stream that the wetland will protect. Additional impact areas are in support of protecting the primary and emergency outlets of the wetland. Stream impacts in these areas will be limited to reconstruction of streambanks in the immediate area. The areas of impact are shown on the stormwater wetland plans. The impact will be temporary and limited to one side of the bank unless otherwise necessary. The total stream length impact is estimated at 20 feet at each of two locations for a total less than 100 feet.

Appendix 5: Analysis Results From All Samples Collected (TSS & Nutrients in mg/L, Heavy Metals in ug/L)

Site	Storm	Date	Time	Bottles	Sample #	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	3/1-2/07	3/2/07	12:00 PM	1-2	1	55	46	0.343	1.506	0.449	0.455	3.641	4.6	10.2	188.9	9.7	77.1	BDL	2.47	11.2
SOC3	3/1-2/07	3/2/07	12:00 PM	3-4	2	108	76	0.148	0.6	0.211	0.2835	1.6655	6.6	9.7	355.2	14.5	73.5	0.590	3.23	16.7
SOC3	3/1-2/07	3/2/07	12:00 PM	5-6	3	76	91	0.125	0.567	0.275	0.262	1.634	5.4	7.1	327.5	13.7	45.2	0.664	2.81	13.4
SOC3	3/1-2/07	3/2/07	12:00 PM	7-8	4	53	61	0.121	0.528	0.389	0.211	1.55	3.8	5.3	208.4	9.1	36.6	BDL	2.54	8.9
SOC4	3/1-2/07	3/2/07	12:00 PM	1-2	5	92	32	0.16	0.668	0.188	0.276	1.789	4.0	7.0	238.6	8.1	64.4	BDL	1.93	10.0
SOC4	3/1-2/07	3/2/07	12:00 PM	3-4	6	135	30	0.096	0.374	0.11	0.159	1.075	3.5	4.7	216.4	6.8	43.9	BDL	1.49	8.9
SOC4	3/1-2/07	3/2/07	12:00 PM	5-6	7	101	38	0.14	0.4	0.126	0.218	1.328	5.4	5.6	303.6	8.9	51.4	BDL	2.36	11.2
SOC4	3/1-2/07	3/2/07	12:00 PM	7-9	8	54	28	0.135	0.487	0.214	0.219	1.675	2.8	3.7	157.4	5.2	34.2	BDL	1.65	6.3
Outlet	3/1-2/07	3/2/07	12:00 PM	1-2	9	21	40	0.219	1.082	0.404	0.319	3.219	3.1	4.7	130.9	6.1	34.5	BDL	1.49	6.1
Outlet	3/1-2/07	3/2/07	12:00 PM	3-4	10	66	72	0.147	0.594	0.308	0.244	1.768	4.1	5.5	283.6	11.2	36.0	BDL	2.22	10.7
Outlet	3/1-2/07	3/2/07	12:00 PM	5-6	11	44	53	0.108	0.496	0.443	0.199	1.566	3.4	4.0	229.7	8.5	25.8	0.810	1.62	7.8
Outlet	3/1-2/07	3/2/07	12:00 PM	7-8	12	47	51	0.104	0.497	0.571	0.185	1.618	2.8	3.6	188.9	7.6	21.5	BDL	1.42	6.6
SOC3	3/16/07	3/16/07	5:00 PM	1-4	1	246	103	0.07	0.735	0.552	0.313	2.416	13.8	26.7	680.6	26.8	254.3	0.001	6.72	28.7
SOC3	3/16/07	3/16/07	5:00 PM	5-8	2	272	111	0.066	0.346	0.168	0.26	1.221	10.2	16.6	685.4	23.3	128.8	0.001	5.41	23.3
SOC3	3/16/07	3/16/07	5:00 PM	9-12	3	87	84	0.079	0.365	0.242	0.184	1.088	5.2	8.7	288.1	11.6	63.4	0.001	2.63	11.3
SOC3	3/16/07	3/16/07	5:00 PM	13-16	4	142	98	0.066	0.238	0.204	0.186	1.006	7.0	10.3	450.1	17.2	61.1	0.001	3.92	15.6
SOC3	3/16/07	3/16/07	5:00 PM	17-22	5	76	69	0.067	0.239	0.27	0.169	0.979	4.5	6.8	280.0	10.6	43.9	0.001	2.37	9.7
SOC4	3/16/07	3/16/07	5:00 PM	3-4	6	22	37	0.141	0.184	0.237	0.236	1.076	2.0	2.6	115.9	4.0	26.1	BDL	1.16	3.8
SOC4	3/16/07	3/16/07	5:00 PM	5-6	7	23	33	0.111	0.151	0.308	0.185	0.933	1.6	2.3	94.5	3.5	25.7	BDL	0.92	3.2
SOC4	3/16/07	3/16/07	5:00 PM	7-9	8	40	51	0.174	0.119	0.315	0.294	1.438	4.2	3.3	163.1	6.3	25.6	BDL	2.05	4.7
Outlet	3/16/07	3/17/07	10:00 AM	1-2	9	138	114	0.022	0.652	0.594	0.266	2.027	8.9	12.8	549.3	19.6	72.8	0.001	4.17	17.7
Outlet	3/16/07	3/17/07	10:00 AM	3-4	10	137	108	0.061	0.36	0.221	0.219	1.088	7.4	10.9	623.0	18.4	50.5	0.001	3.29	15.5
Outlet	3/16/07	3/17/07	10:00 AM	5-6	11	76	88	0.067	0.227	0.318	0.172	0.911	5.1	6.2	391.1	12.7	35.6	0.001	2.37	10.8
Outlet	3/16/07	3/17/07	10:00 AM	7-9	12	44	79	0.0845	0.2405	0.5055	0.19	1.111	4.2	5.0	287.8	10.0	27.5	0.001	1.98	7.9
SOC3	3/29/07	3/29/07	12:30 PM	1-2	1	81	69	0.142	1.327	1.298	0.514	5.363	4.3	17.1	142.2	11.6	79.8	0.001	2.65	9.4
Outlet	3/29/07	3/29/07	12:30 PM	1	2	49	45	0.007	0.259	0.268	0.202	2.044	3.1	4.6	200.3	9.0	30.4	0.001	1.63	6.0
SOC3	4/11-12/07	4/12/07	12:30 PM	1	1	93	63	0.015	1.072	1.288	0.46	4.586	6.2	23.6	218.2	12.1	125.7	0.002	3.37	8.0
SOC3	4/11-12/07	4/12/07	12:30 PM	2	2	47	56	0.014	0.968	1.443	0.35	3.282	4.3	17.9	134.0	7.9	87.1	0.002	1.71	7.5

Site	Storm	Date	Time	Bottles	Sample #	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	4/11-12/07	4/12/07	12:30 PM	3-4	3	920	163	0.011	0.634	0.695	0.613	6.299	18.6	38.3	10645	40.0	199.9	0.005	8.57	27.3
SOC3	4/11-12/07	4/12/07	12:30 PM	5-6	4	167	95	0.054	0.368	0.499	0.292	2.136	7.4	13.9	440	15.6	67.9	0.004	3.15	9.2
SOC4	4/11-12/07	4/12/07	12:30 PM	1-2	5	125	54	0.012	0.442	0.735	0.183	1.798	4.0	10.6	277	6.1	64.8	0.001	BDL	6.9
Outlet	4/11-12/07	4/12/07	12:30 PM	1-2	6	30	46	0.026	0.734	0.452	0.23	2.535	3.0	8.8	165	5.4	37.7	0.003	BDL	4.2
Outlet	4/11-12/07	4/12/07	12:30 PM	3-4	7	29	43	0.018	0.802	0.871	0.252	2.716	3.1	11.8	131	5.5	50.7	0.001	BDL	4.3
Outlet	4/11-12/07	4/12/07	12:30 PM	5-6	8	21	39	0.018	0.845	0.646	0.199	2.514	2.7	10.3	130	4.6	39.1	0.002	BDL	3.7
Outlet	4/11-12/07	4/12/07	12:30 PM	7-8	9	133	108	0.008	0.38	0.615	0.407	2.603	8.0	15.2	491	17.3	67.1	0.003	3.23	10.4
Outlet	4/11-12/07	4/12/07	12:30 PM	9-10	10	58	81	0.01	0.333	0.476	0.231	1.553	4.2	8.9	262	8.7	35.8	0.002	1.38	4.9
Outlet	4/11-12/07	4/12/07	12:30 PM	11-12	11	26	47	0.013	0.288	0.366	0.145	1.128	2.6	7.3	148	4.7	32.0	0.001	BDL	3.0
SOC3	4/15/07	4/15/07	5:00 PM	1-3	1	74	38	0.023	0.302	0.725	0.316	2.42	3.6	9.3	173	6.0	57.4	BDL	BDL	7.5
SOC3	4/15/07	4/15/07	5:00 PM	4-7	2	52	29	0.04	0.185	0.244	0.149	1.113	2.2	4.2	132	2.4	25.5	BDL	BDL	3.2
SOC3	4/15/07	4/15/07	5:00 PM	8-12	3	55	48	0.043	0.065	0.17	0.172	0.917	2.7	4.0	171	3.6	21.5	BDL	BDL	3.9
SOC3	4/15/07	4/15/07	5:00 PM	13-18	4	220	104	0.029	0.092	0.154	0.274	1.259	7.9	12.2	648	18.8	56.1	0.002	3.02	9.1
SOC3	4/15/07	4/15/07	5:00 PM	19-24	5	57	71	0.047	0.069	0.487	0.178	1.243	4.2	5.5	278	7.5	26.7	0.001	1.03	4.0
SOC4	4/15/07	4/15/07	5:00 PM	1-2	6	51	9	0.032	0.243	0.2	0.095	0.742	0.7	2.3	49	BDL	12.2	BDL	BDL	2.2
SOC4	4/15/07	4/15/07	5:00 PM	3-4	7	27	17	0.062	0.126	0.14	0.155	0.966	1.1	2.3	67	BDL	16.9	BDL	BDL	1.5
Outlet	4/15/07	4/15/07	5:00 PM	1-2	8	54	57	0.012	0.27	0.142	0.271	2.367	4.7	8.0	320	10.4	35.7	0.001	1.57	4.8
Outlet	4/15/07	4/15/07	5:00 PM	3-4	9	42	49	0.02	0.092	0.236	0.148	1.098	2.6	4.5	187	4.2	20.5	0.001	BDL	3.2
Outlet	4/15/07	4/15/07	5:00 PM	5-6	10	70	76	0.021	0.03	0.093	0.14	0.995	4.0	5.8	315	8.5	26.0	0.001	0.99	3.9
Outlet	4/15/07	4/15/07	5:00 PM	7-9	11	113	102	0.028	0.103	0.226	0.157	1.279	6.4	7.6	520	14.7	30.8	0.002	2.00	5.7
SOC3	4/27/07	4/27/07	2:00 PM	1-2	1	798	242	0.188	0.688	0.484	0.686	3.597	217.1	358.0	16620	526.5	1397.0	0.025	93.40	240.5
SOC3	4/27/07	4/27/07	2:00 PM	3-4	2	219	120	0.211	0.606	0.553	0.691	2.357	88.6	147.6	5545	192.5	661.3	0.009	32.80	90.4
SOC4	4/27/07	4/27/07	2:00 PM	1	3	104	19	0.067	0.256	0.272	0.175	0.901	19.1	41.2	1055	14.6	168.4	BDL	BDL	25.9
Outlet	4/27/07	4/27/07	2:00 PM	1	4	1191	344	0.057	0.534	0.368	0.872	4.743	291.2	411.5	28770	697.7	1898.0	0.038	119.70	282.9
Outlet	4/27/07	4/27/07	2:00 PM	2-3	5	585	316	0.09	0.594	0.408	0.477	3.021	184.1	295.2	17430	509.3	1099.0	0.030	75.80	178.9
Outlet	4/27/07	4/27/07	2:00 PM	4-5	6	161	133	0.171	0.571	0.453	0.399	3.346	75.5	128.4	5639	179.5	525.2	0.009	28.90	75.6
SOC3	5/9/07	5/10/07	10:00 AM	1	1	878	168		0.534	0.421	0.821	8.657	225.4	288.2	11830	375.8	2349.0	0.022	86.10	324.3
SOC3	5/9/07	5/10/07	10:00 AM	2	2	567	125		0.318	0.456	0.587	3.929	127.0	113.3	7371	224.7	1019.0	0.009	43.40	203.5
SOC3	5/9/07	5/10/07	10:00 AM	3	3	162	94		0.280	0.865	0.315	2.387	63.6	54.7	3489	101.4	488.6	0.005	19.30	70.5

Site	Storm	Date	Time	Bottles	Sample #	TSS	Turb	O-PO_4	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
SOC3	5/9/07	5/10/07	10:00 AM	4	4	47	57		0.302	0.810	0.210	1.486	19.9	17.3	1114	17.7	209.9	BDL	BDL	16.1
SOC4	5/9/07	5/10/07	10:00 AM	1	5	66	24		0.321	0.648	0.245	1.554	14.6	13.9	834	BDL	196.3	BDL	BDL	20.5
Outlet	5/9/07	5/10/07	10:00 AM	1	6	289	125		0.404	0.488	0.496	4.125	122.9	141.5	7266	214.7	956.4	0.010	42.50	157.1
Outlet	5/9/07	5/10/07	10:00 AM	2	7	112	78		0.252	0.498	0.264	2.154	46.2	49.0	2717	73.0	374.3	BDL	11.90	48.1
SOC3	6/2-3/07	6/4/07	6:00 PM	1-5	1	80	44		0.385	0.513	0.242	1.791	25.7	201.0	1239	53.5	526.7	BDL	7.35	49.2
SOC3	6/2-3/07	6/4/07	6:00 PM	6-10	2	166	97		0.142	0.244	0.215	1.101	39.5	81.3	2927	46.0	339.3	BDL	13.05	47.9
SOC3	6/2-3/07	6/4/07	6:00 PM	11-15	3	42	52		0.168	0.337	0.138	0.768	13.7	40.0	848	14.4	157.4	BDL	BDL	21.2
SOC3	6/2-3/07	6/4/07	6:00 PM	16-24	4	37	29		0.166	0.290	0.123	0.748	14.0	40.0	679	14.0	143.4	BDL	BDL	16.2
SOC4	6/2-3/07	6/4/07	6:00 PM	1-3	5	19	9		0.208	0.219	0.121	0.661	6.6	25.2	350	BDL	131.2	BDL	BDL	16.8
SOC4	6/2-3/07	6/4/07	6:00 PM	4-5	6	38	13		0.221	0.243	0.118	0.675	8.6	48.8	477	BDL	127.9	BDL	BDL	17.3
Outlet	6/2-3/07	6/4/07	6:00 PM	1-3	7	48	41		0.252	0.341	0.165	1.180	20.1	61.5	921	25.4	214.1	BDL	BDL	28.6
Outlet	6/2-3/07	6/4/07	6:00 PM	4-7	8	135	86		0.171	0.181	0.191	1.087	38.5	100.9	3091	92.2	278.6	0.006	13.10	49.3
Outlet	6/2-3/07	6/4/07	6:00 PM	8-10	9	80	64		0.209	0.235	0.166	1.091	23.5	55.5	1629	46.7	218.0	BDL	6.10	24.9
SOC3	6/6/07	6/6/07	3:30 PM	1-2	1	127	44		0.606	0.509	0.255	2.29	4.0	8.2	220	7.5	56.9	BDL	BDL	7.4
SOC4	6/6/07	6/6/07	3:30 PM	1	2	17	8		0.653	0.488	0.124	1.21	0.6	1.8	36	BDL	11.0	BDL	BDL	1.9
Outlet	6/6/07	6/6/07	3:30 PM	1	3	29	23		0.687	0.557	0.273	2.55	4.4	9.1	259	8.8	58.8	0.001	BDL	7.8
Outlet	6/7/07	6/7/07	11:30 AM	1	1	14	17		0.096	0.075	0.172	1.40	0.8	2.2	31	BDL	17.5	0.002	BDL	1.7
SOC3	6/9/07	6/10/07	11:30 AM	1	1	390	73	0.006	0.304	0.4742	0.355	2.495	12.5	20.7	709	27.6	182.9	0.004	7.04	19.0
SOC3	6/9/07	6/10/07	11:30 AM	2-3	2	241	80	0.003	0.196	0.332	0.254	1.576	3.9	7.2	219	16.1	49.8	0.001	2.65	6.5
Outlet	6/9/07	6/10/07	11:30 AM	1	3	12	13	0.005	0.205	0.4202	0.248	1.606	0.7	2.4	26	BDL	20.9	0.002	BDL	1.6
Outlet	6/9/07	6/10/07	11:30 AM	1-2	4	96	14	0.007	0.228	0.0588	0.146	1.303	4.7	9.1	267	10.3	64.4	0.001	1.43	6.9
SOC3	6/13/07	6/13/07	6:00 PM	1	1	282	82	0.059	0.729	0.735	0.306	2.739	11.0	19.7	660	26.5	125.3	0.002	4.78	18.7
SOC3	6/13/07	6/13/07	6:00 PM	2	2	356	106	0.093	0.488	0.469	0.294	2.065	15.1	26.9	801	27.0	105.8	0.003	5.95	17.0
SOC3	6/13/07	6/13/07	6:00 PM	3	3	191.4	123	0.073	0.521	0.536	0.271	1.485	10.9	17.0	672	22.7	58.5	0.002	4.27	10.6
SOC3	6/13/07	6/13/07	6:00 PM	4-5	4	219	149	0.055	0.521	0.577	0.298	1.451	11.2	17.5	801	29.5	58.1	0.004	4.51	9.7
SOC4	6/13/07	6/13/07	6:00 PM	1	5	83	11	0.072	0.282	0.360	0.122	0.803	1.4	2.2	104	BDL	17.0	BDL	BDL	3.4
Outlet	6/13/07	6/13/07	6:00 PM	1	6	116	77	0.034	0.408	0.437	0.199	1.619	6.5	10.0	415	15.0	57.4	BDL	2.04	10.1
Outlet	6/13/07	6/13/07	6:00 PM	2	7	88	83	0.047	0.399	0.486	0.172	1.231	4.5	7.0	357	12.9	32.2	0.001	BDL	5.8

Site	Storm	Date	Time	Bottles	Sample #	TSS	Turb	$O\text{-}PO_4$	NH_3	NO_3	TP	TKN	Cr	Cu	Ti	V	Zn	As	Ni	Pb
Outlet	6/13/07	6/13/07	6:00 PM	3	8	13	32	0.0120	0.477	0.210	0.114	1.221	1.1	2.3	67.3	BDL	19.5	0.002	BDL	1.6
SOC3	6/19/07	6/20/07	11:00 AM	1	1	184	65	0.0132	0.398	0.831	0.465	4.169	13.0	30.2	435.9	20.1	138.2	0.002	5.11	15.5
Outlet	6/19/07	6/20/07	11:00 AM	1	2	22	23	0.0127	0.662	0.186	0.218	2.665	6.9	12.1	146.1	3.3	28.2	BDL	1.82	6.6
SOC3	6/20/07	6/20/07	2:00 PM	1	3	30	48	0.026	0.411	0.694	0.187	2.054	2.6	5.8	226.8	3.2	31.6	0.001	BDL	4.6
SOC4	6/20/07	6/20/07	2:00 PM	1	4	29	43	0.071	0.542	0.641	0.175	1.482	1.1	3.7	44.6	1.8	37.4	0.002	BDL	2.2
Outlet	6/20/07	6/20/07	2:00 PM	1	5	23	37	0.009	0.190	0.324	0.256	2.559	1.6	4.9	84.5	3.1	24.7	BDL	BDL	2.8
SOC3	7/27/07	7/28/07	11:00 AM	1	1	97	68	0.008												
Outlet	7/27-28/07	7/28/07	11:00 AM	1	2	18	16	0.006												
SOC3	7/28/07	7/29/07	3:00 PM	1-2	1	139	61	0.019												
SOC4	7/28/07	7/29/07	3:00 PM	1	2	25	13	0.033												
Outlet	7/28/07	7/29/07	3:00 PM	1	3	54	36	0.014												
SOC3	7/30/07	7/30/07	2:00 PM	1	1	176	205													
SOC3	7/30/07	7/30/07	2:00 PM	2	2	257	437													
SOC3	7/30/07	7/30/07	2:00 PM	3	3	150	137													
SOC4	7/30/07	7/30/07	2:00 PM	1	4	55	15													
SOC4	7/30/07	7/30/07	2:00 PM	2	5	49	16													
SOC4	7/30/07	7/30/07	2:00 PM	3	6	34	17													
Outlet	7/30/07	7/30/07	2:00 PM	2	7	156	220													
Outlet	7/30/07	7/30/07	2:00 PM	3	8	142	296													
Outlet	7/30/07	7/30/07	2:00 PM	4-5	9	265	275													
Outlet	7/30/07	7/30/07	2:00 PM	6-7	10	91	120													

Appendix 6: Calculated EMCs for all Events (TSS & Nutrients in mg/L and Heavy Metals in ug/L)

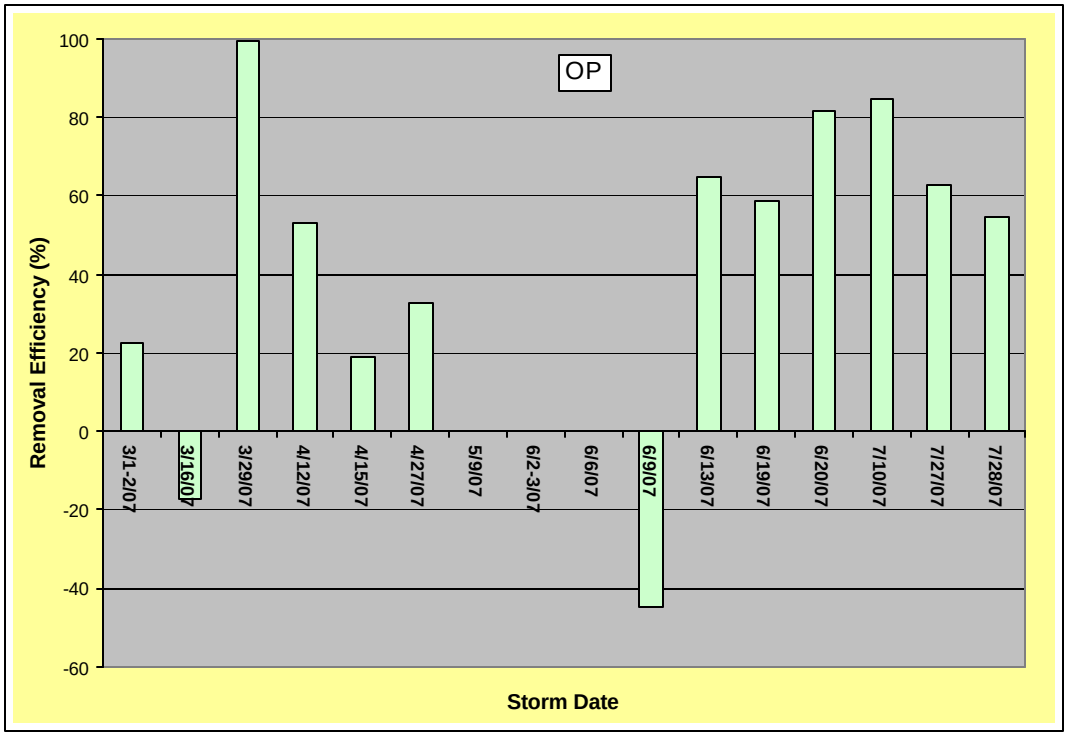
Storm Date	Rain (in)	TSS (3)	TSS (4)	TSS (IN)	TSS (O)	O-PO_4 (3)	O-PO_4 (4)	O-PO_4 (IN)	O-PO_4 (O)	NH_3 (3)	NH_3 (4)	NH_3 (N)	NH_3 (O)	$NO_{3/2}$ (3)	$NO_{3/2}$ (4)	$NO_{3/2}$ (IN)	$NO_{3/2}$ (O)	TP (3)	TP (4)	TP (IN)	TP (O)
3/1-2/07	0.62	74	92	76	54	0.186	0.133	0.180	0.149	0.809	0.483	0.769	0.647	0.241	0.096	0.223	0.109	0.306	0.218	0.295	0.245
3/16/07	2.08	159	28	155	106	0.069		0.069	0.061	0.376		0.376	0.326	0.286		0.286	0.314	0.219		0.219	0.202
3/29/07	0.19	81		81	49	0.142		0.142	0.007	1.327		1.327	0.259	1.298		1.298	0.268	0.514		0.514	0.202
4/12/07	0.64	402	125	394	90	0.024	0.012	0.024	0.011	0.689	0.442	0.682	0.427	0.876	0.735	0.871	0.556	0.439	0.183	0.431	0.316
4/15/07	1.42	100	37	99	78	0.036	0.049	0.037	0.023	0.134	0.175	0.135	0.089	0.403	0.165	0.396	0.200	0.227	0.130	0.225	0.154
4/27/07	0.55	543	104	534	478	0.198	0.067	0.195	0.118	0.652	0.256	0.644	0.580	0.514	0.272	0.509	0.421	0.688	0.175	0.678	0.482
5/9/07	0.36	455	66	450	206	Not Analyzed				0.365	0.321	0.365	0.332	0.619	0.648	0.619	0.493	0.514	0.245	0.511	0.387
5/12/07	2.08	353	56	338	384	Not Analyzed															
6/2-3/07	1.20	69	45	69	92	Not Analyzed				0.202	0.213	0.202	0.207	0.331	0.229	0.330	0.245	0.164	0.120	0.164	0.123
6/6/07	0.15	127	17	123	21	Not Analyzed				0.606	0.653	0.608	0.386	0.509	0.488	0.509	0.311	0.255	0.124	0.251	0.222
6/9/07	0.24	304		304	57	0.004		0.004	0.006	0.241		0.241	0.217	0.392		0.392	0.227	0.297		0.297	0.194
6/13/07	0.40	257	83	256	82	0.068	0.072	0.068	0.034	0.560	0.282	0.557	0.420	0.579	0.360	0.577	0.405	0.293	0.122	0.291	0.170
6/19/07	0.07	184		184	22	0.013		0.013	0.013	0.398		0.398	0.662	0.831		0.831	0.186	0.465		0.465	0.218
6/20/07	0.08	30	29	30	23	0.026	0.071	0.028	0.009	0.411	0.542	0.417	0.190	0.694	0.641	0.692	0.324	0.187	0.175	0.186	0.256
7/10/07	0.13	Not Analyzed				0.007	0.142	0.008	0.006												
7/27/07	0.10	97		97	18	0.008		0.008	0.006												
7/28/07	0.18	139	25	138	54	0.019	0.033	0.019	0.014												
7/30/07	0.51	211	45	207	176																

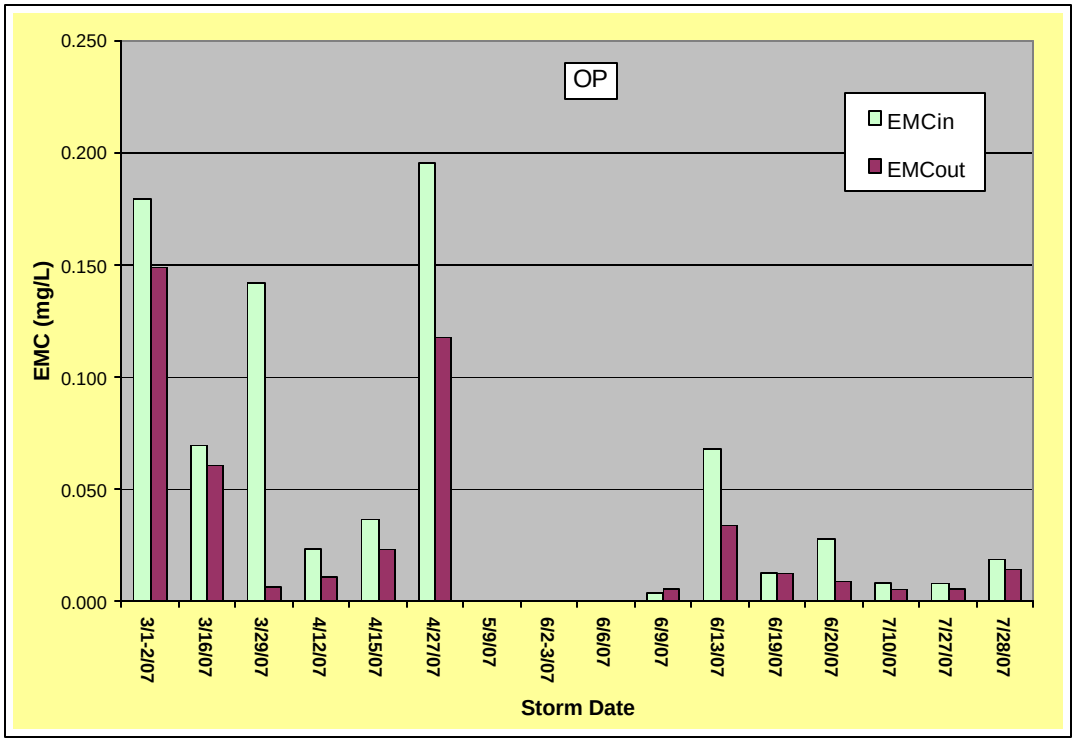
Storm Date	Rain (in)	TKN (3)	TKN (4)	TKN (IN)	TKN (O)	Cr (3)	Cr (4)	Cr (IN)	Cr (O)	Cu (3)	Cu (4)	Cu (IN)	Cu (O)
3/1-2/07	0.62	2.141	1.485	2.060	1.949	5.1	3.8	5.0	3.8	8.1	5.1	7.8	5.0
3/16/07	2.08	1.321		1.321	1.106	7.9	0.0	7.9	6.4	13.4	0.0	13.4	8.7
3/29/07	0.19	5.363		5.363	2.044	4.3	0.0	4.3	3.1	17.1	0.0	17.1	4.6
4/12/07	0.64	4.196	1.798	4.121	2.243	10.4	4.0	10.2	5.9	24.6	10.6	24.2	12.3
4/15/07	1.42	1.451	0.872	1.435	1.191	4.6	0.9	4.5	4.6	7.7	2.3	7.6	6.2
4/27/07	0.55	3.051	0.901	3.007	3.294	160.5	19.1	157.6	152.3	265.3	41.2	260.7	242.3
5/9/07	0.36	4.412	1.554	4.377	3.195	119.0	14.6	117.7	86.7	129.8	13.9	128.4	97.9
5/12/07	2.08	Not Analyzed											
6/2-3/07	1.20	1.007	0.667	1.002	1.116	20.7	7.4	20.5	28.3	77.0	35.0	76.4	75.0
6/6/07	0.15	2.294	1.211	2.258	1.963	4.0	0.6	3.9	2.6	8.2	1.8	8.0	5.6
6/9/07	0.24	1.963		1.963	1.444	7.5	0.0	7.5	2.8	12.9	0.0	12.9	6.0
6/13/07	0.40	1.882	0.803	1.872	1.379	12.0	1.4	11.9	4.5	20.0	2.2	19.8	7.1
6/19/07	0.07	4.169		4.169	2.665	13.0	0.0	13.0	6.9	30.2	0.0	30.2	12.1
6/20/07	0.08	2.054	1.482	2.030	2.559	2.6	1.1	2.6	1.6	5.8	3.7	5.7	4.9
7/10/07	0.13												
7/27/07	0.10					Lab Results Pending							
7/28/07	0.18												
7/30/07	0.51												

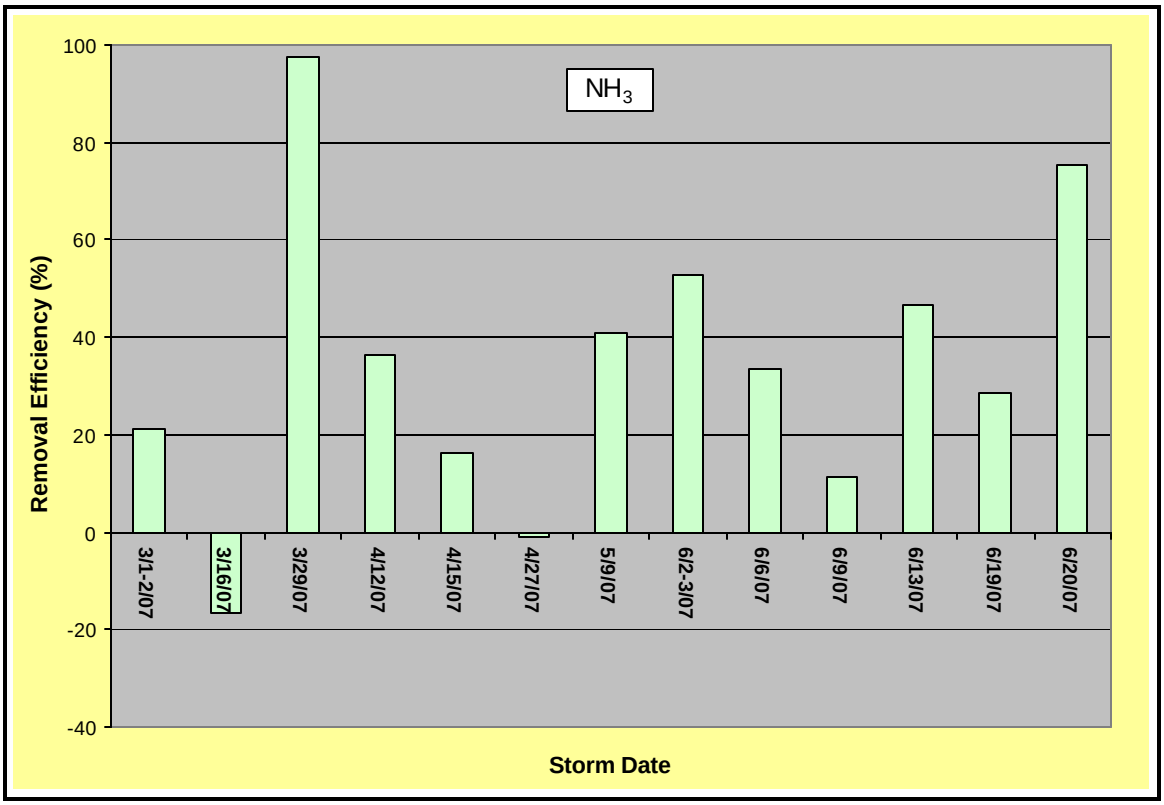
Storm Date	Rain (in)	Ti (3)	Ti (4)	Ti (IN)	Ti (O)	V (3)	V (4)	V (IN)	V (O)	Zn (3)	Zn (4)	Zn (IN)	Zn (O)	Pb (3)	Pb (4)	Pb (IN)	Pb (O)
3/1-2/07	0.62	272.0	222.9	265.9	245.8	11.9	7.1	11.3	9.7	58.8	47.3	57.4	33.2	12.7	8.9	12.2	9.3
3/16/07	2.08	465.3	0.0	465.3	497.9	17.5		17.5	15.6	106.4	0.0	106.4	45.2	17.3	0.0	17.3	13.3
3/29/07	0.19	142.2	0.0	142.2	200.3	11.6		11.6	9.0	79.8	0.0	79.8	30.4	9.4	0.0	9.4	6.0
4/12/07	0.64	560.2	277.4	551.3	354.1	21.9	6.1	21.4	12.3	127.1	64.8	125.1	53.0	14.9	6.9	14.7	7.5
4/15/07	1.42	324.2	59.1	316.9	359.0	9.1		9.1	9.7	39.8	14.9	39.1	26.4	5.9	1.8	5.8	4.4
4/27/07	0.55	11740.8	1055.0	11521.2	13961.0	379.4	14.6	371.9	401.1	1072.9	168.4	1054.3	951.7	174.4	25.9	171.3	148.9
5/9/07	0.36	6497.8	834.3	6428.2	5120.4	198.2		198.2	147.9	1107.8	196.3	1096.6	681.9	169.1	20.5	167.3	105.7
5/12/07	2.08																
6/2-3/07	1.20	1224.1	402.6	1212.7	1992.2	27.1		27.1	58.2	252.0	129.8	250.3	240.5	28.9	17.0	28.8	35.5
6/6/07	0.15	220.4	35.5	214.2	142.8	0.0				56.9	11.0	55.4	37.7	7.4	1.9	7.2	4.7
6/9/07	0.24	425.1	0.0	425.1	154.6	20.9		20.9	5.8	105.8	0.0	105.8	44.1	11.7	0.0	11.7	4.4
6/13/07	0.40	741.0	104.2	734.9	15.1	26.7	0.7	26.5	11.0	83.8	17.0	83.1	39.1	13.6	3.4	13.5	6.5
6/19/07	0.07	435.9	0.0	435.9	146.1	20.1		20.1	3.3	138.2	0.0	138.2	28.2	15.5	6.6	15.4	6.6
6/20/07	0.08	226.8	44.6	219.1	84.5	3.2	1.8	3.2	3.1	31.6	37.4	31.8	24.7	4.6	2.2	4.5	2.8
7/10/07	0.13																
7/27/07	0.10																
7/28/07	0.18																
7/30/07	0.51																

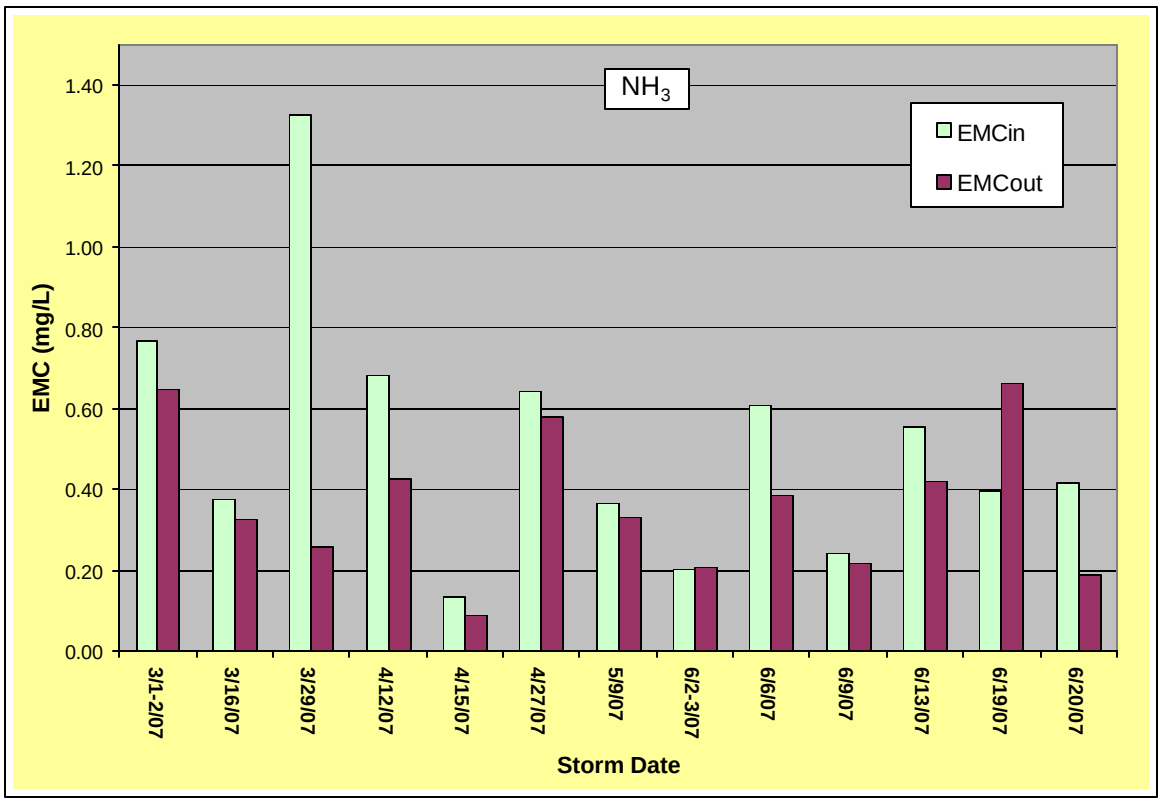
Lab Results Pending

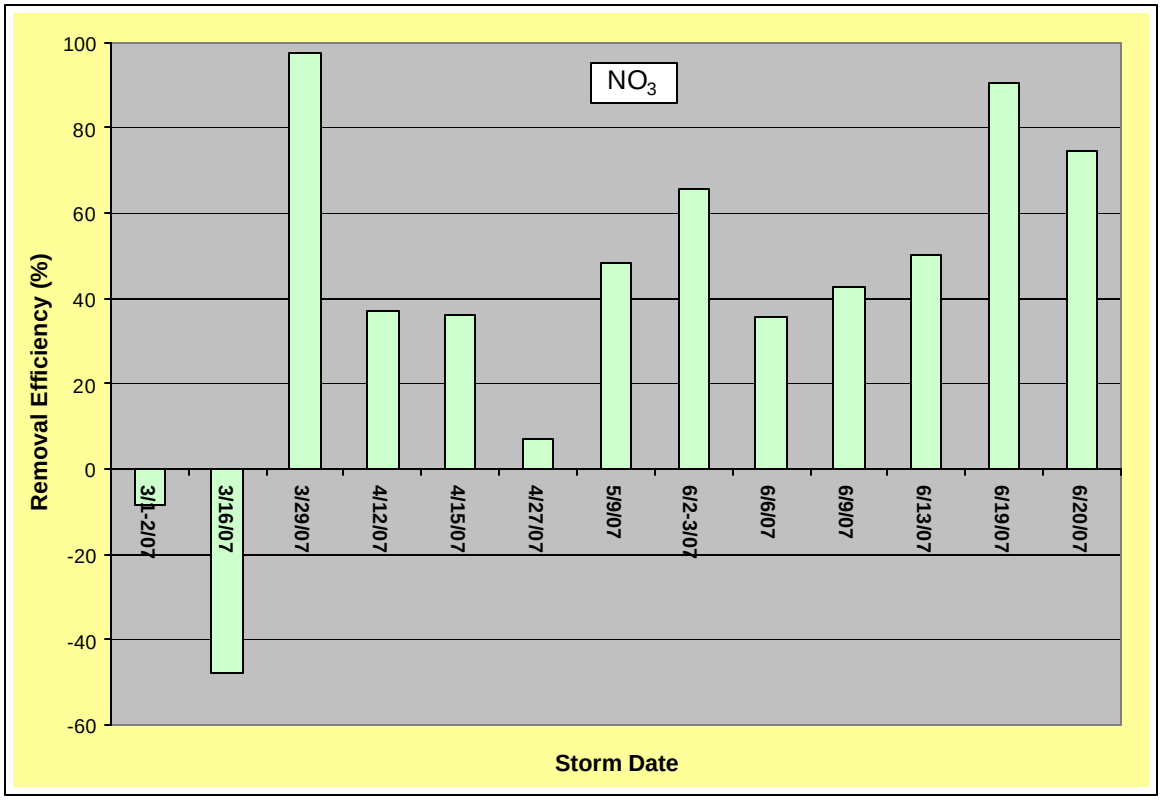
Appendix 7: Graphs of Pollutant Removal Efficiencies and EMCs

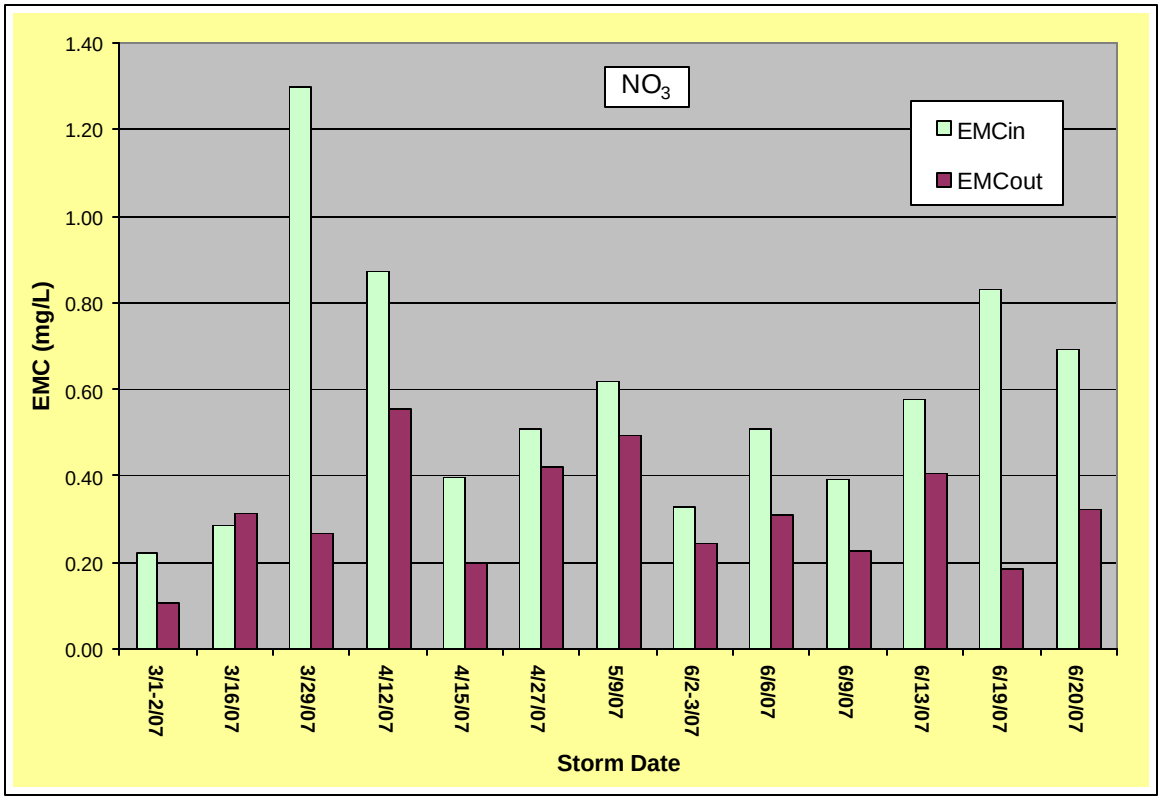


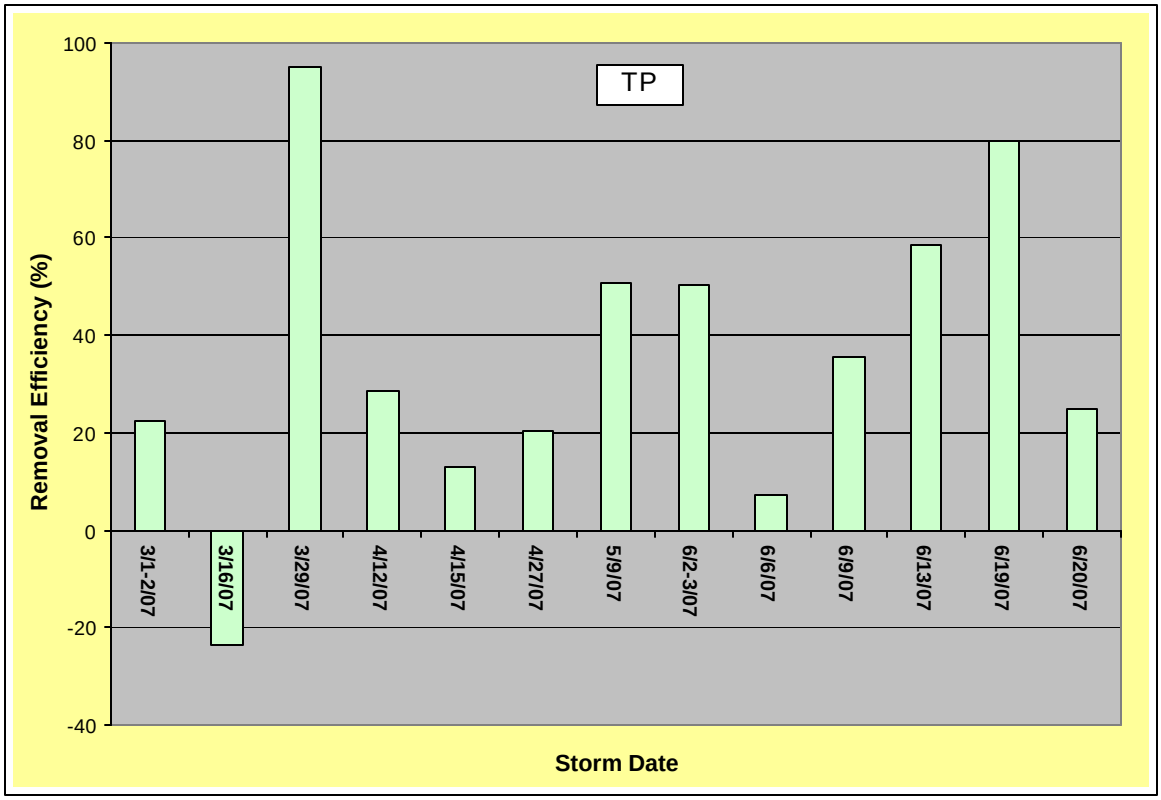


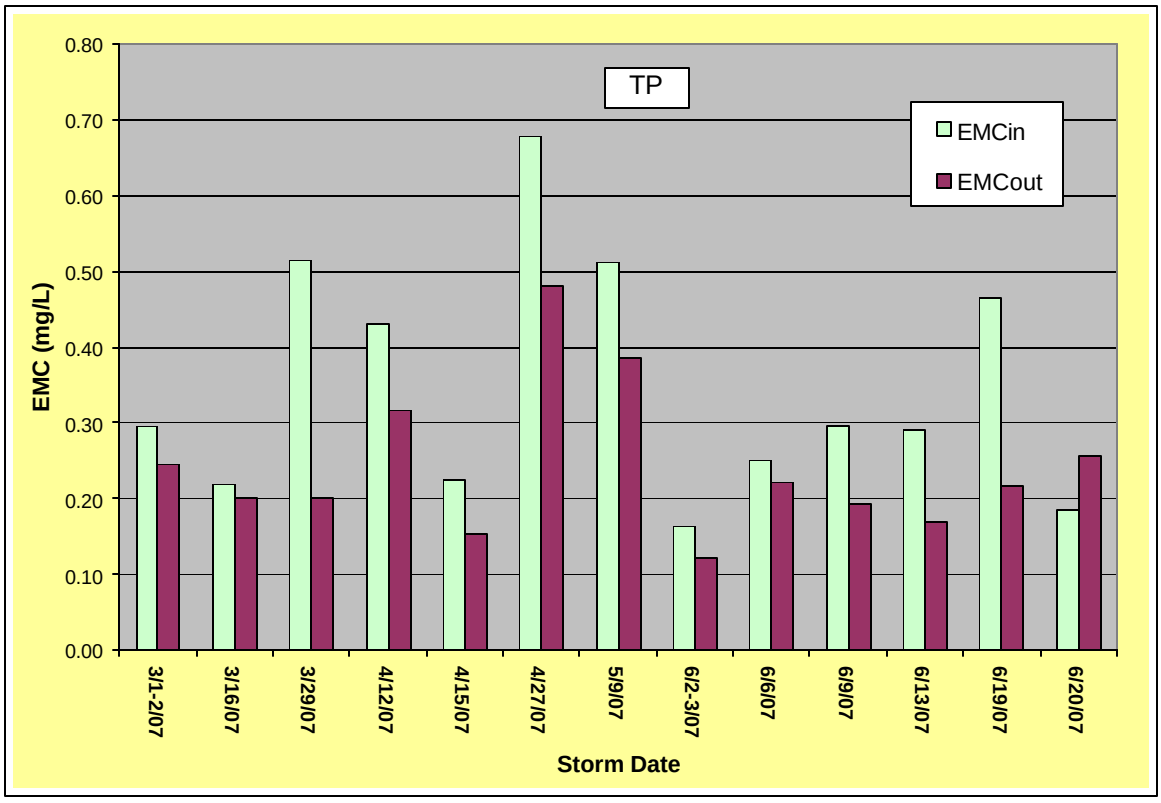

NH3
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

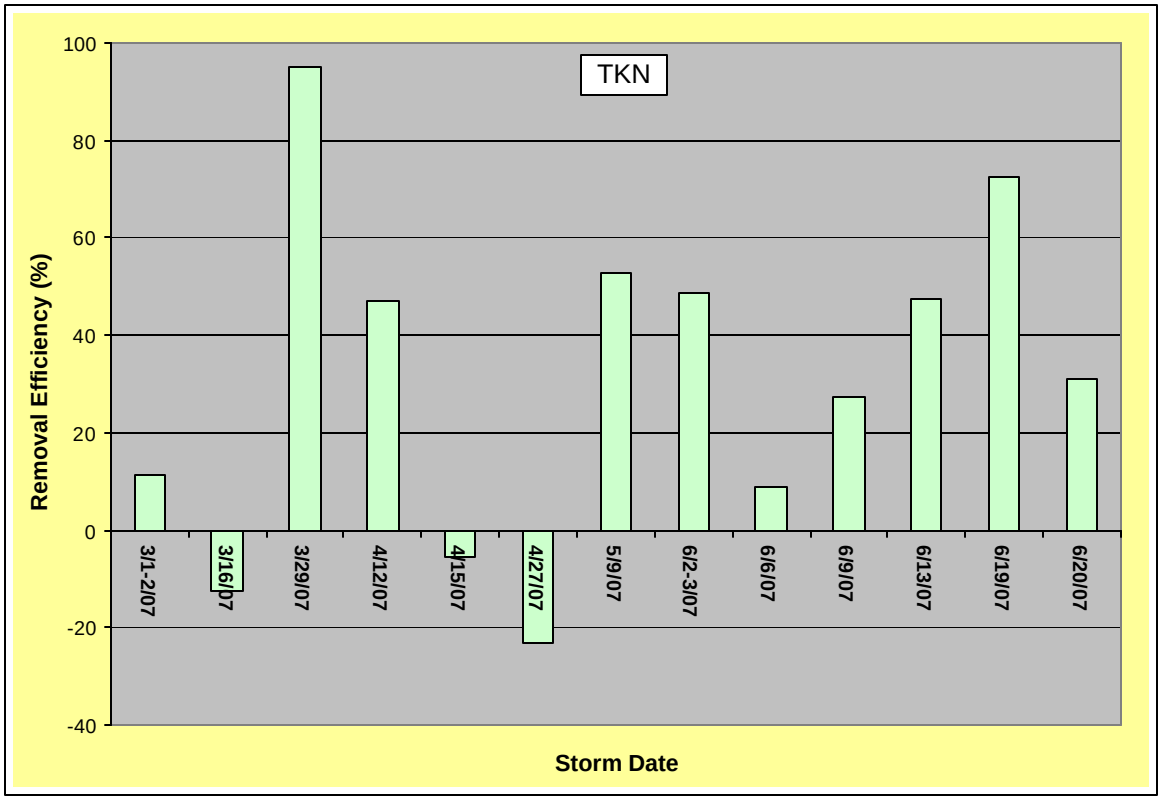

NH3
EMCin
EMCout
EMC (mg/L)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

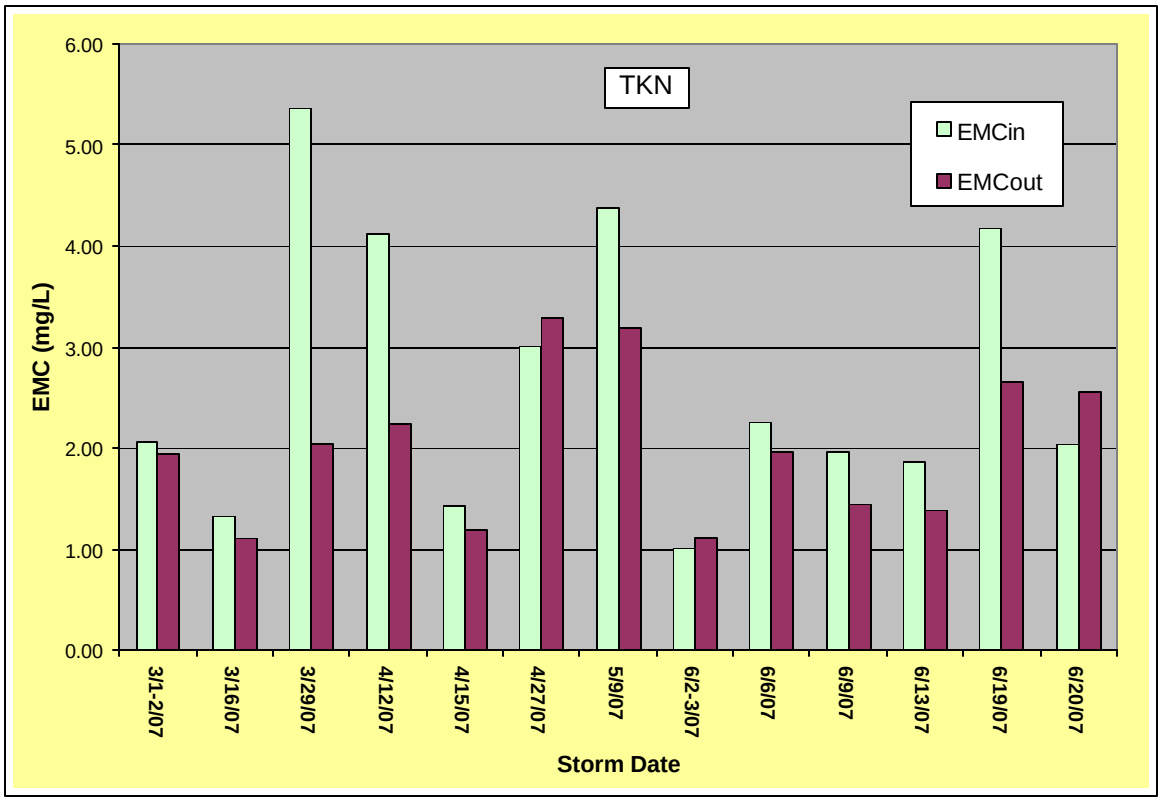

NO3
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
-60
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

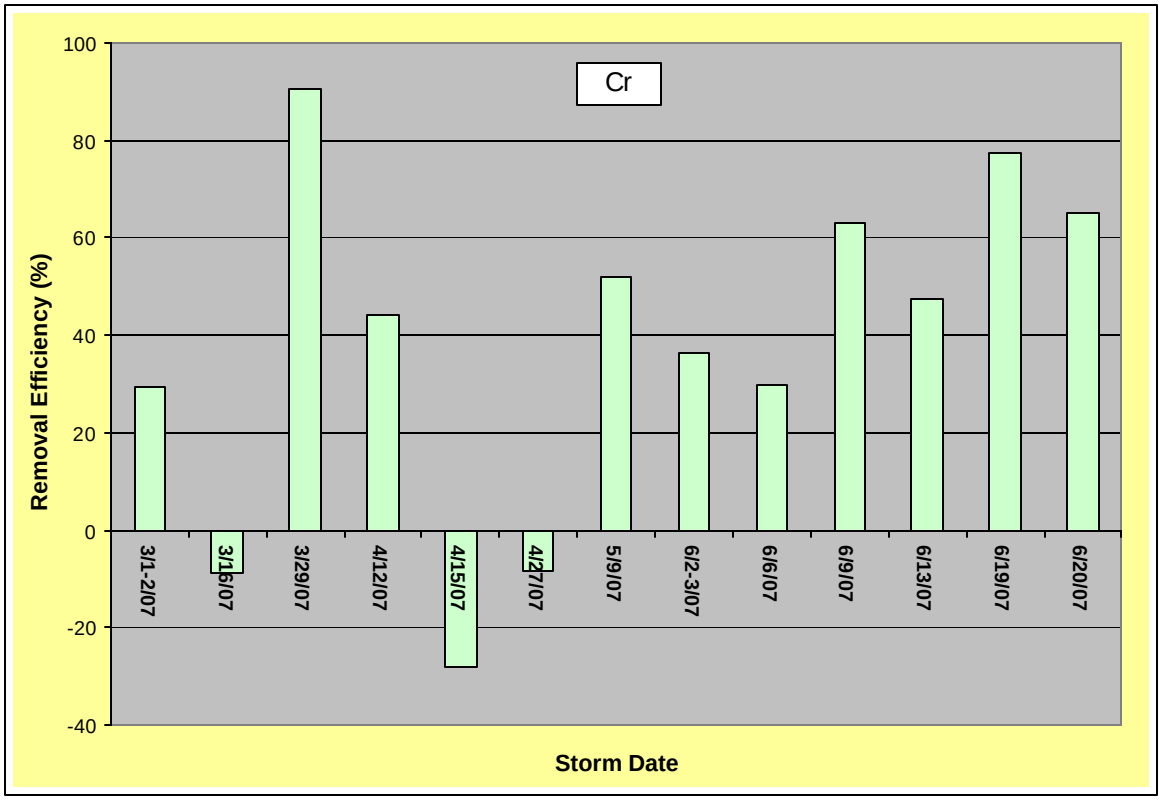

NO3
EMCin
EMCout
EMC (mg/L)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

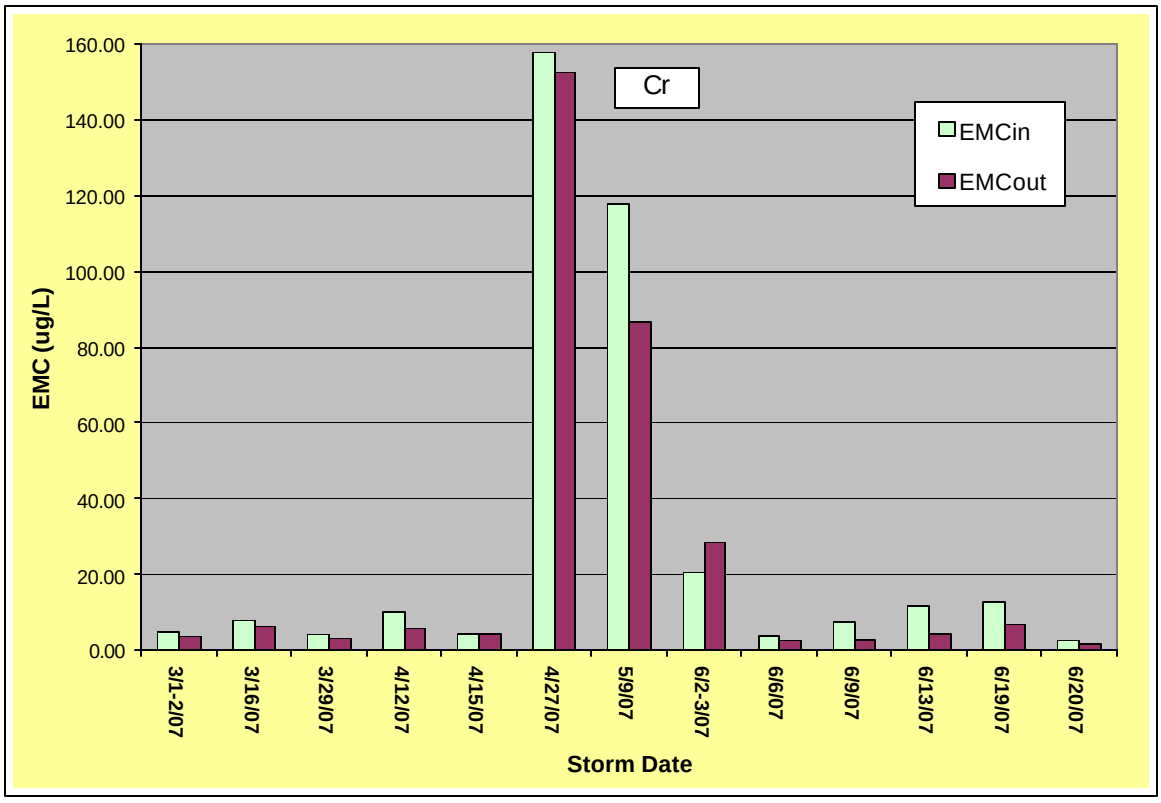

TP
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

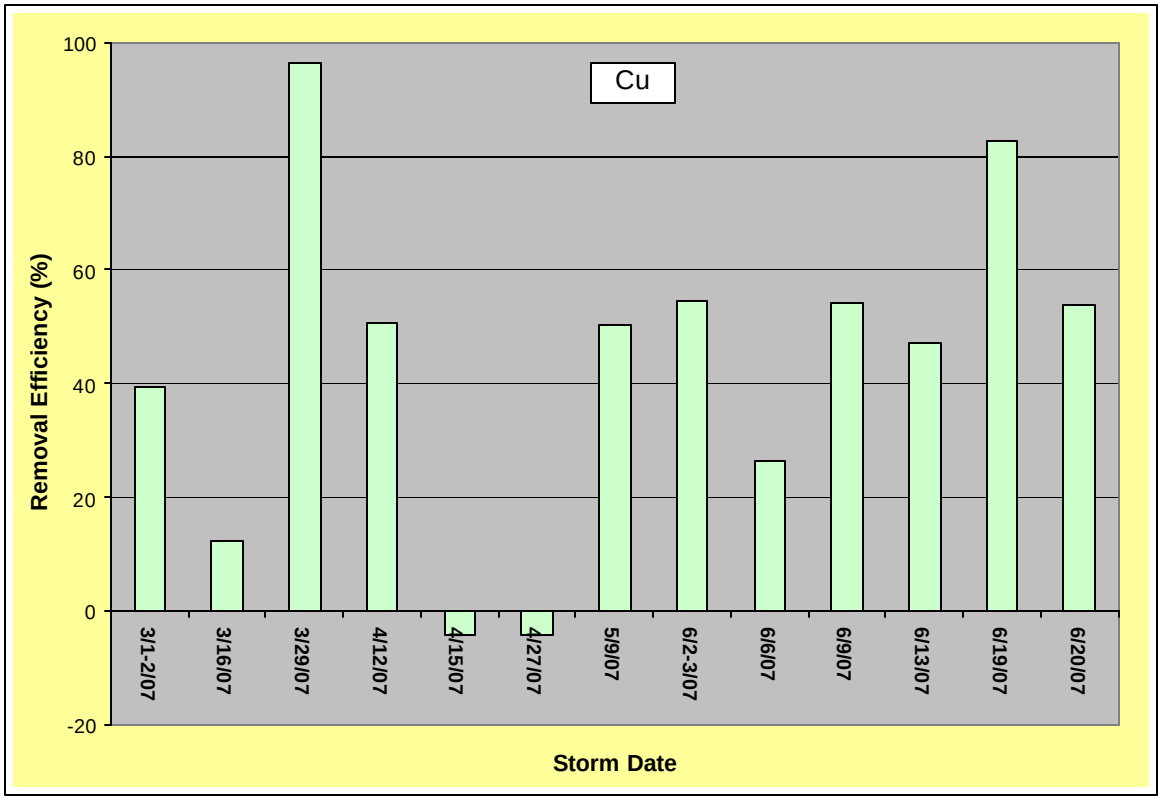

TP
EMCin
EMCout
EMC (mg/L)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

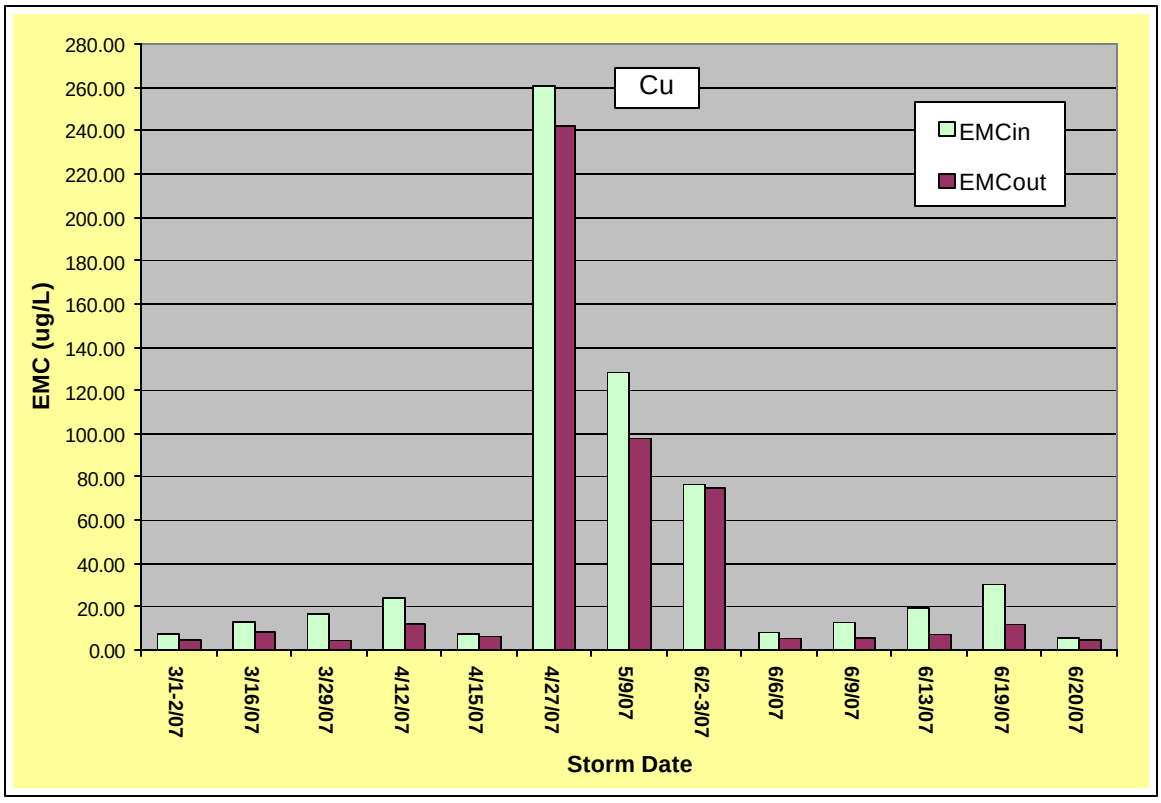

TKN
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

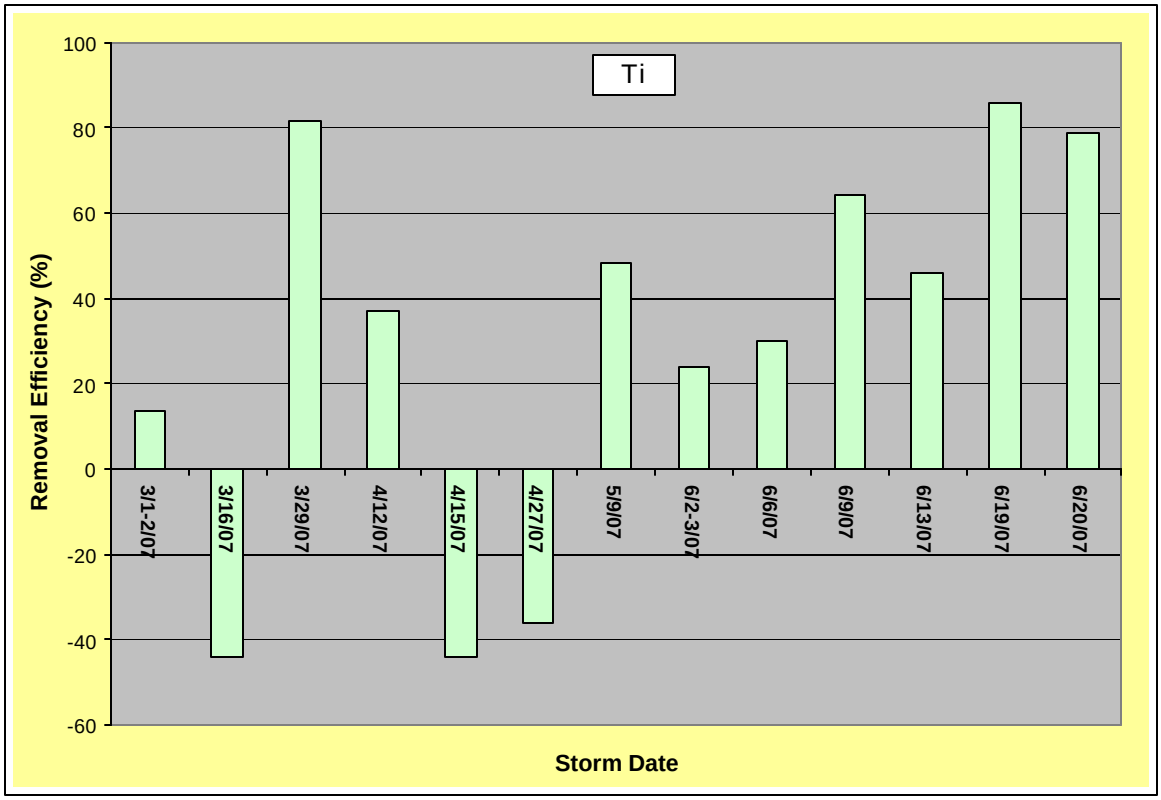

TKN
EMCin
EMCout
EMC (mg/L)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

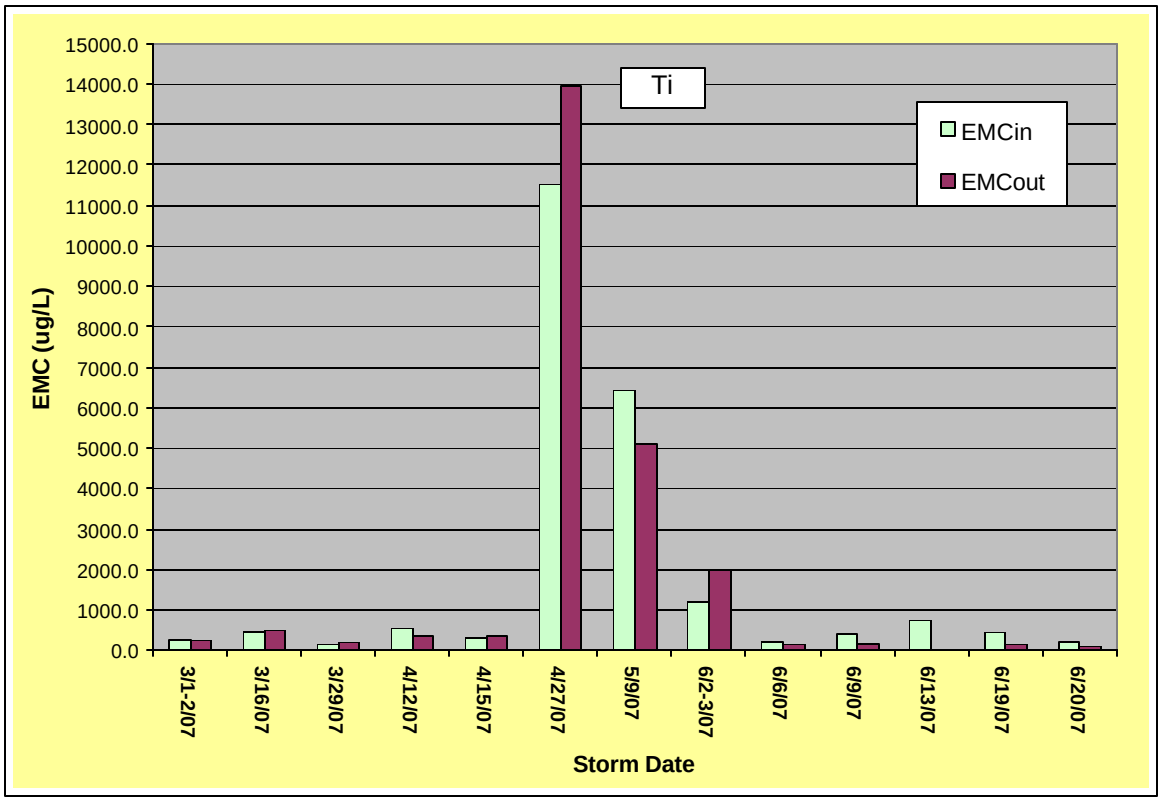

Cr
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

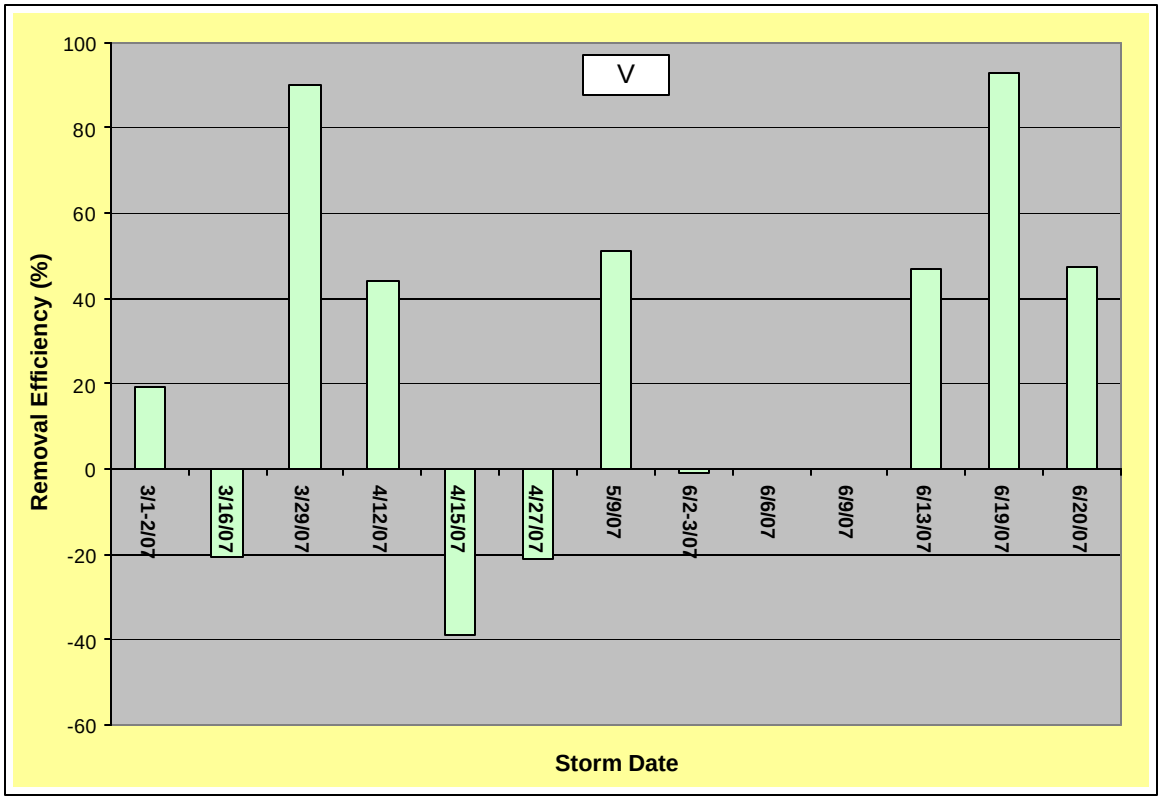

Cr
EMCin
EMCout
EMC (ug/L)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

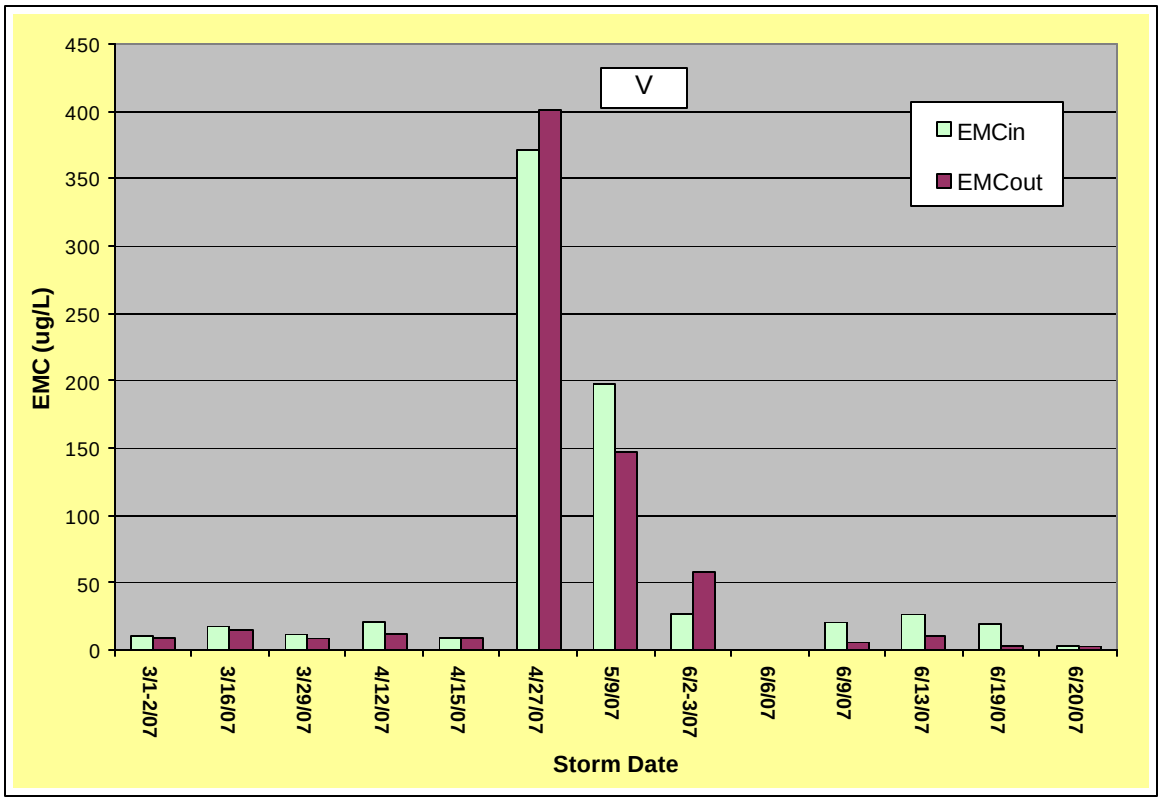

Cu
Removal Efficiency (%)
100
80
60
40
20
0
-20
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

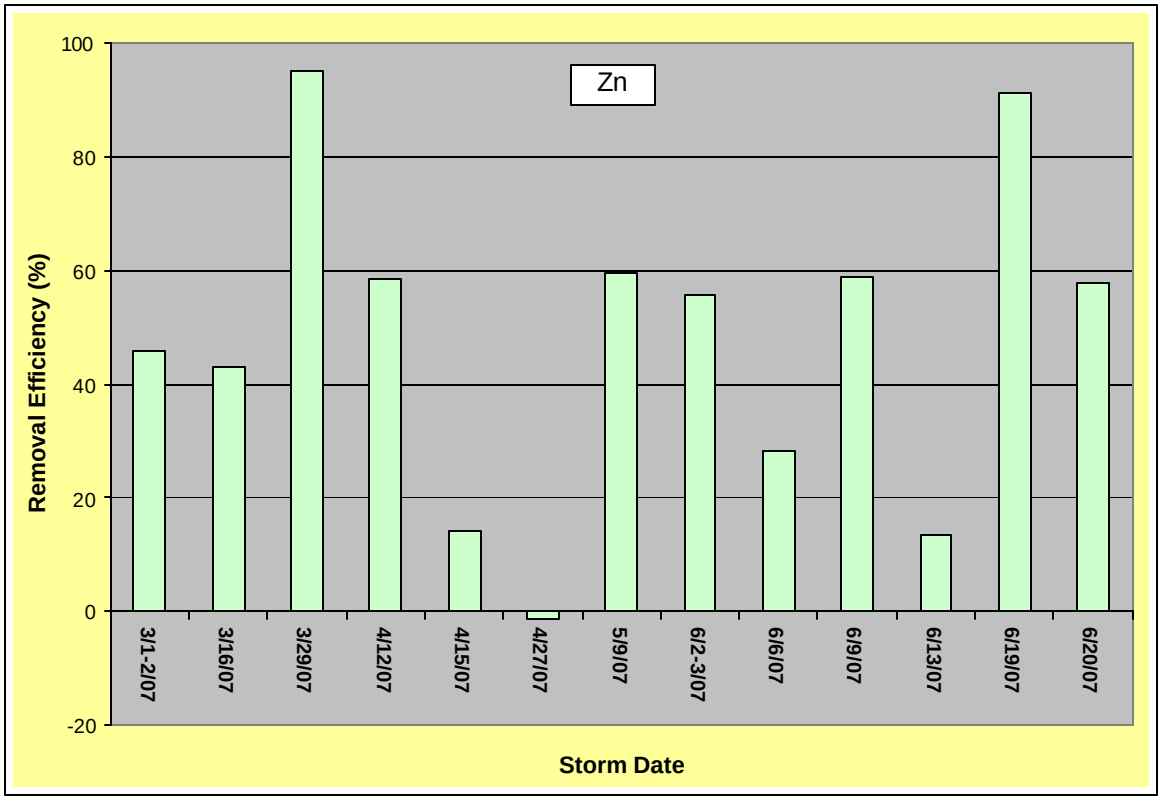

Cu
EMCin
EMCout
EMC (ug/L)
280.00
260.00
240.00
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

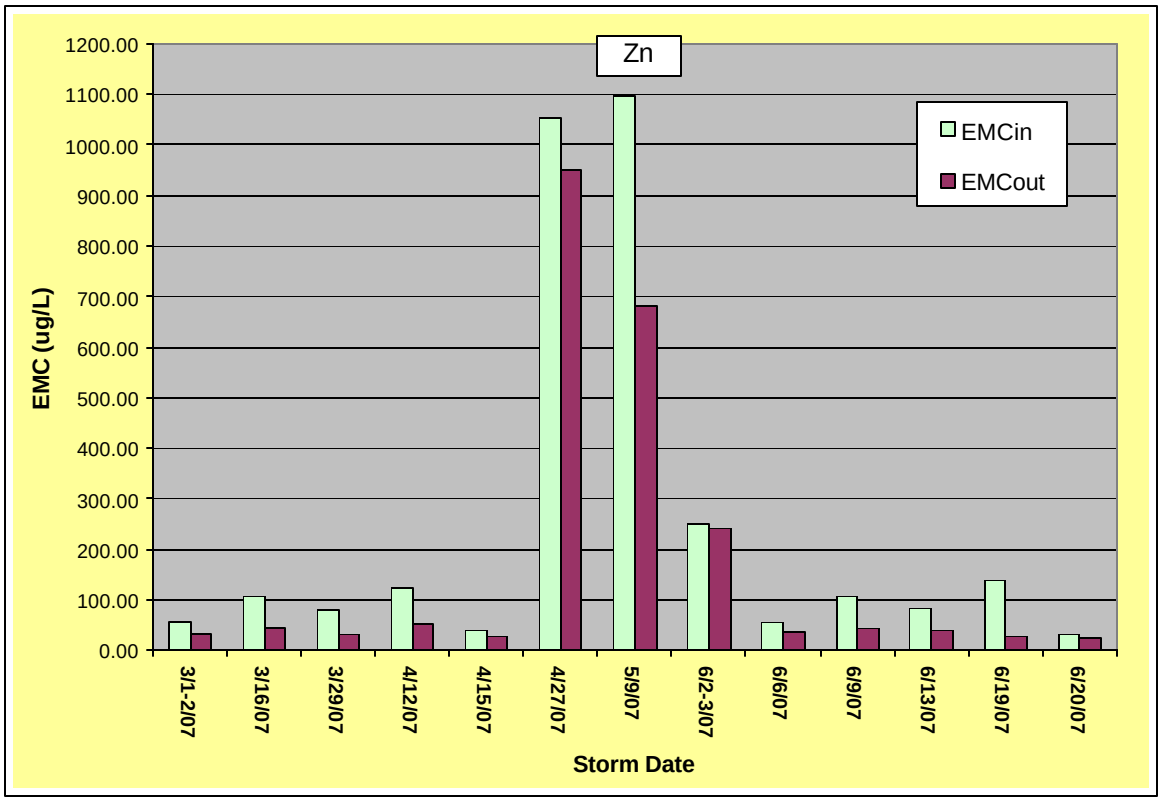

Ti
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
-60
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

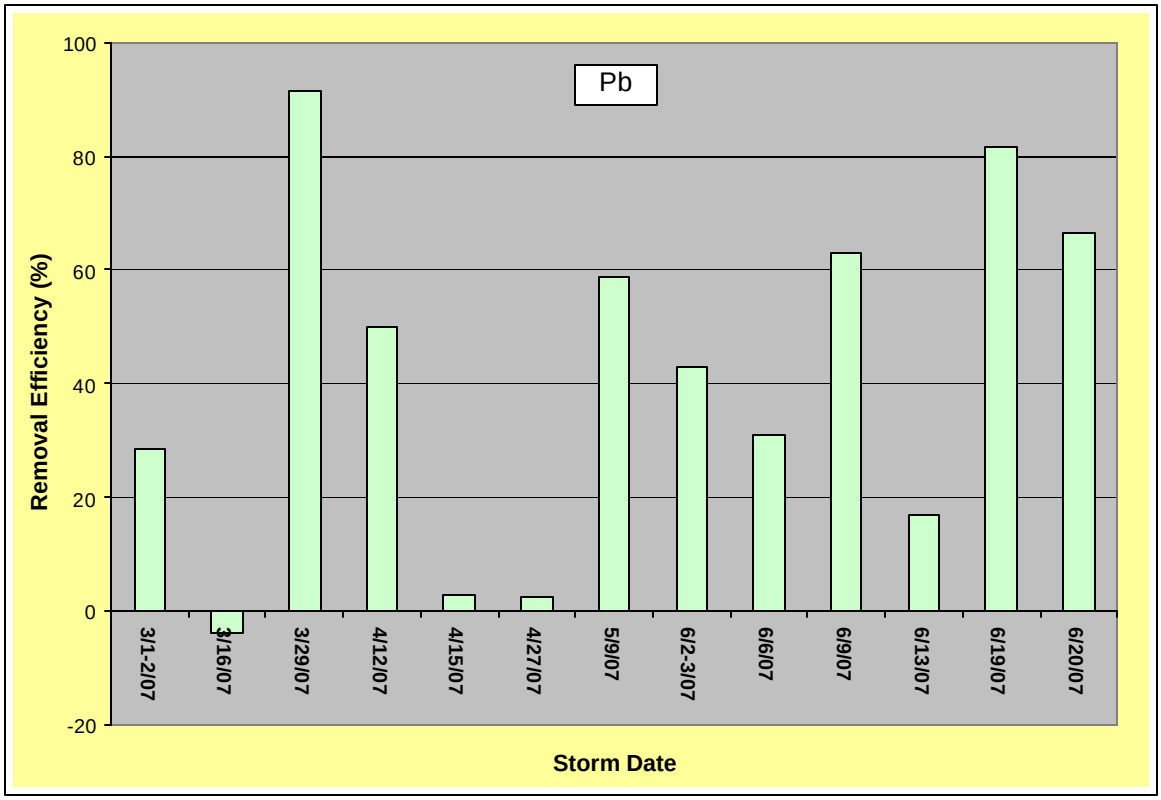

Ti
EMCin
EMCout
EMC (ug/L)
15000.0
14000.0
13000.0
12000.0
11000.0
10000.0
9000.0
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date

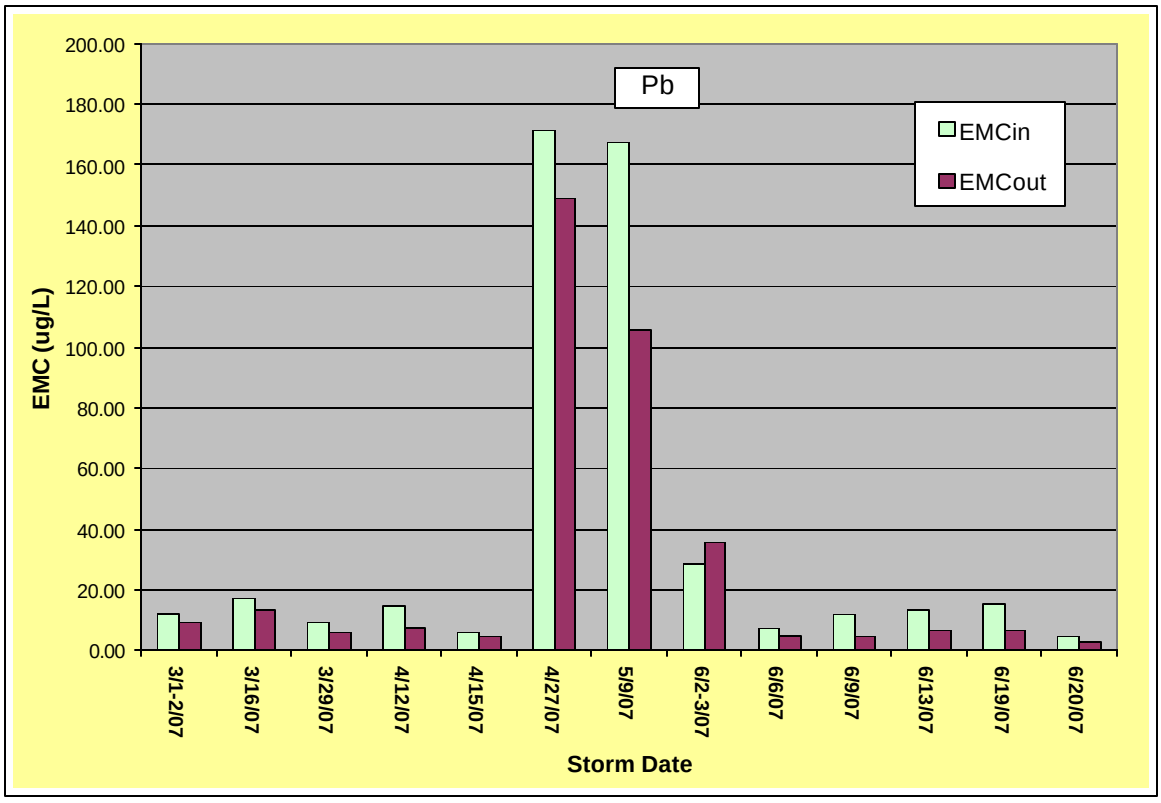

V
Removal Efficiency (%)
100
80
60
40
20
0
-20
-40
-60
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date


V
EMCin
EMCout
EMC (ug/L)
450
400
350
300
250
200
150
100
50
0
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date


Zn
Removal Efficiency (%)
100
80
60
40
20
0
-20
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date


Zn
EMCin
EMCout
EMC (ug/L)
1200.00
1100.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date


Pb
Removal Efficiency (%)
100
80
60
40
20
0
-20
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date


Pb
EMCin
EMCout
EMC (ug/L)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
3/1-2/07
3/16/07
3/29/07
4/12/07
4/15/07
4/27/07
5/9/07
6/2-3/07
6/6/07
6/9/07
6/13/07
6/19/07
6/20/07
Storm Date