Performance of green stormwater infrastructure at the University of Toledo

Aishwarya Penmetcha

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entitled

Performance of Green Stormwater Infrastructure at The University of Toledo

by
Aishwarya Penmetcha

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the
Masters of Science Degree in Civil Engineering

Dr. Cyndee Gruden, Committee Chair
Dr. Defne Apul, Committee Member
Dr. Ashok Kumar, Committee Member

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The University of Toledo
December 2015
An Abstract of

Performance of Green Stormwater Infrastructure at The University of Toledo

by

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Non-point stormwater runoff causes degradation of surface water quality. Particulates and toxic constituents are the most common pollutants associated with urban stormwater runoff. The performance and pollutant removal of green infrastructure, specifically a tree filter, was evaluated. This best management practice was designed to treat the first flush from contributing impermeable drainage areas. Grab samples and time weighted composite samples were collected from a total of 13 major events, some collected at the inlet, some at the outlet, some samples at both ends of the tree filter located near University of Toledo (UT) Law School parking lot. The sample analyses included heavy metals (copper, zinc, cadmium and lead), solids (total, dissolved, suspended), nutrients (nitrates and orthophosphates) and coliform count (including E. coli). No measurable concentrations of nutrients nor coliform bacteria were observed in the stormwater samples collected in 2014 (spring, summer, and fall) or in summer 2015. Suspended solids concentrations in the grab samples collected at front and back end of the tree filter ranged from 15 to 104 mg/L and 2-24 mg/L, respectively, indicating a statistically significant reduction in suspended solids. Notable metals present in the samples included zinc, which was measured in the range of 420-36000 µg/L in the pre-construction samples and 360-2000 ppb in the post construction samples. Grab samples were statistically higher in solids and metals concentrations than time-weighted composite samples during the events
(student’s t-test, alpha = 0.05). During small events (less than 0.3 inches of rain) in fall 2014, the tree filter retained the entire event thus keeping contaminants (up to 175 g of suspended solids and 8 mg of zinc) out of the Ottawa River; whereas during summer 2015, the tree filter could effectively remove 2-30 g of zinc and up to 4 kg of suspended solids from all the rain events. This research suggests that the tree filter is effective and removing solids from stormwater runoff, but other than zinc, no consistent removal of metals (copper, lead, cadmium) was observed.
Dedicated to my Parents.
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List of Abbreviations

ADD ..................... Antecedent Dry Days
BMP ..................... Best Management Practices
Cd ....................... Cadmium
Cu ....................... Copper
d.f ........................ Degrees of freedom
DI ........................ Deionized
DN ........................ Dissolved Nitrogen
DON ...................... Dissolved Organic Nitrogen
EMC ...................... Event Mean Concentration
EPA ...................... Environmental Protection Agency
O&G ...................... Oil& Grease
P ......................... Phosphorus
Pb ........................ Lead
TkN ...................... Total Kjehldahl Nitrogen
TN ........................ Total Nitrogen
TP ........................ Total Phosphorus
TS ........................ Total Solids
TSS ........................ Total Suspended Solids
UT ........................ University of Toledo
Chapter 1

Literature Review

1.1 Urban Stormwater Runoff:

In many developing countries, industrialization and thus urbanization are taking place at a very high pace. Urban stormwater runoff is a problem because of the presence of impervious surfaces like sidewalks, driveways, building roofs, streets and parking lots that increase the volume and rate of stormwater runoff thereby preventing stormwater runoff from naturally infiltrating into the ground (Sansalone et al., 1997). Also, climate change has an impact on the frequency of extreme storm events increasing the risk of flooding (Hatt et al., 2009). It is estimated that throughout USA 10 trillion gallons of untreated stormwater runs off roads, parking lots and other paved surfaces every year into rivers and waterways (Natural Resources Defense Council, 2011). As the stormwater runoff increases, the imbalance between physical, chemical, and biological processes increases resulting in pollution, soil erosion, and flooding.

Urbanization and industrialization have a significant influence on the water quality of runoff and nearby water bodies (Department of Energy & Environmental Protection, 2004). The discharge of untreated urban stormwater has been identified as a significant problem in terms of urban stream quality (Pan et al., 2012; Stagge et al., 2012). The vital source for generation of storm water pollutants may be the atmo-
spheric deposition but runoff due to construction activities, street pavement, motor vehicles, vegetation and waste water contributes more to degradation in stormwater quality (McQueen et al., 2010). Anthropogenic and transportation activities have also been found to contribute to the generation of solids, heavy metals and nutrients in a considerable amount on the catchment surfaces (Miguntanna et al., 2010; Wada et al., 2010). Stormwater washes dusts away from atmosphere and carries off dissolved, colloidal and solid particles in a heterogeneous mixture, which includes metals, nutrients, oil and grease (Gnecco et al., 2005). Anthropogenic and transportation activities cause increase in stormwater pollutants. The problem of urban stormwater pollution is becoming worse day by day because of continuing development, which results in increased impervious area (Lee et al., 2007). Uncontrolled stormwater discharges are deleterious as the stormwater picks up debris, dirt, chemicals, pollutants and flow into receiving waters such as lakes and streams thereby degrading the water quality and posing a risk to aquatic life (Bedan et al., 2009).

1.1.1 Non-point Source Pollutants:

A study performed by the Council of Environmental Quality showed that 75% of urban areas were impacted by non-point source pollution (The Pennsylvania State University Institute of State and Regional Affairs, 1980).

Urban stormwater runoff falls under the category of non-point source pollution because stormwater carries pollution from one place to another, without treatment. Unlike an individual source of pollution, such as a factory which is a point source pollution, stormwater can have a great environmental impact due to the fact that all pollution washed away with stormwater usually ends up in a water source at a different place. (The Pennsylvania State University Institute of State and Regional Affairs, 1980)
1.1.2 The First Flush:

First flush is the initial period of stormwater runoff during which the concentration of pollutants is higher when compared to other periods of storm. The first flush is associated with first half inch or inch of rainfall, which occurs in the smaller storm events within the first half-hour. During the first flush, large amounts of pollutants are discharge into receiving waters. First flush depends on area of the catchment, rainfall intensity, impervious area and antecedent dry days (Lee et al., 2002; 2004). First flush is generally high for metals and suspended solids (Lee et al., 2004). Antecedent dry period is an important factor in the first flush. The antecedent dry days range from 1- 30 days (Lee et al., 2004).

1.2 Stormwater Pollutants and their sources:

1.2.1 Physical Contaminants

Solids

Total suspended solids is the amount of sediment that is suspended in a water sample. Solids are of concern because they act as a carrier in the transport of harmful pollutants in stormwater runoff (Gunawardhana et al., 2011). Solids, which can range from 20-2890 mg/L (typically 150 mg/L) (US EPA Urban Stormwater Preliminary Data Summary 2006), can stay in suspension in the surface water body. During transport, there may be a change in physical properties of the solids, which may exert a strong effect on receiving waters including a change in taste and color (Aryal et al, 2010; Ying et al., 2010). Storm hydrologic characteristics such as runoff coefficient, runoff volume and intensity, rainfall depth, antecedent conditions between storm events, traffic intensity and parking lot maintenance have an impact on the concentration of solids and the toxicity of parking lot storm water runoff (McQueen
et al., 2010; Aryal et al., 2010). The percentage of rainfall that appears as stormwater runoff from a surface is called the runoff coefficient (c). It is a function of the soil type and drainage basin slope. For areas with low infiltration and high runoff, such as parking lots, the runoff coefficient is a large value (0.9). Rational equation is a simple method to determine peak discharge from drainage basin runoff.

\[ Q = c \times i \times A \]

Peak discharge, Q (in cfs) is the product of runoff coefficient, rainfall intensity, i in in/hr and drainage area (A) in acres. The intensity of rainfall is a measure of the amount of rain that falls over time. The intensity of rain is measured in the height of the water layer covering the ground over a period of time. The intensity and duration of rainfall are usually inversely related. For example, the first flush, the initial period of storm water runoff during which the higher pollutant loads are often observed can substantially decrease the storm water runoff quality. At the same rainfall intensity condition, the degree of strength of first flush for smaller watershed is more intense than the larger watershed (Lee et al., 2002). Solids exist in both dissolved and particulate forms and their respective concentrations in stormwater runoff vary widely (Joshi et al., 2010; Aryal et al., 2010). The concentrations of solids in runoff may be different for every event, every site type and for every geographic location (Joshi et al., 2010; Aryal et al., 2010; Lee et al., 2002; McQueen et al., 2010). Solids concentration can also be influenced by seasonal variations (Aryal et al., 2010). Practical range of determination of total suspended solids (TSS) is 4 - 20,000 mg/L (EPA method 160.2) and range of total solids (TS) is 10- 20,000 mg/L (EPA method 160.3) in surface waters. Sources of solids in stormwater runoff from parking lots have been identified in previous studies. Atmospheric deposition and surrounding soil contribute primarily to the origin of solids (Göbel et al., 2007). Other sources of
solids are related to traffic such as tire and brake abrasion, combustion exhaust and pavement wear (Göbel et al., 2007; Sansalone et al., 1997; Shammaa et al., 2001).

1.2.2 Chemical Contaminants:

**Metals**

Metals are of concern because they are toxic to ecosystems in the receiving waters (Joshi et al., 2010; Davis et al., 2001). Due to their non-degradable nature in the environment (Davis et al., 2001; Geronimo et al., 2014), metals will accumulate and increase in concentration over time. The amount of rainfall, antecedent conditions between storm events, traffic intensity and parking lot maintenance have an impact on the type and concentration of metals and the toxicity of parking lot storm water runoff (McQueen et al., 2010). For example, the first flush can decrease the storm water runoff quality (Lee et al., 2002; Ying et al., 2010). Metals exist in both dissolved and particulate forms and their respective concentrations in stormwater runoff vary widely (Joshi et al., 2010; Aryal et al., 2010). The concentrations of trace elements in runoff may be different for every event, every site and for every location (Joshi et al., 2010; Aryal et al., 2010; Lee et al., 2002; McQueen et al., 2010). Metals concentration can also be influenced by seasonal variations (Aryal et al., 2010).

Sources of metals in stormwater runoff from parking lots have been identified in previous studies. Common metals found are zinc, copper, lead and cadmium. (Aryal et al., 2010) because they are related to vehicles and their parts such as tires, brakes, combustion by-products, deicers, motor oil, engine wear, metal plating, bearing and brushing wear, brake lining wear and hydraulic fluid. (McKenzie et al., 2009; Ball et al., 1998). Cadmium, copper and lead are of interest because of their prevalence and toxicity in storm runoff (Joshi et al., 2010). Zinc can be found in tires, combustion by-products, deicers, motor oil, engine wear, hydraulic fluid and car washes (Brown et al., 2006) (McKenzie et al., 2009; Ball et al., 1998). Copper can be found in
brake lining wear, bearing and brushing wear, metal plating and other fluid leakage (Sansalone et al., 1997; McQueen et al., 2010). Lead can be found in parking lot sealers, brakes, lubricating oil and grease, bearing wear, auto exhaust, and yellow paints used on roads. Cadmium can be found in parking lot sealers, tires and car washes (McKenzie et al., 2009; Ball et al., 1998).

**Nutrients**

The advancement in technology improves urban design practices such as rapid increase in imperviousness which results in the increase in levels of nutrients specifically nitrogen and phosphorus in urban runoff (Aryal et al., 2010). Nutrients when present in high levels, promote the growth of algae in receiving waters thereby contributing to eutrophication of water (Vaze et al, 2004). Nutrients primarily include nitrates and phosphates. Nitrates are of concern because they are the most common soluble species in urban runoff and hence, are not well retained by soil particles. Excessive levels of nitrates and nitrites cause eutrophication. Along with nitrates and nitrites, total nitrogen (TN), dissolved nitrogen (DN), dissolved organic nitrogen (DON), total kjehldahl nitrogen (TkN) are also found in stormwater runoff (Taylor et al., 2005). Phosphorous which can be categorized into total P and dissolved P exists in natural ecosystems in many forms such as phosphates, orthophosphates, condensed phosphates, organic phosphates, cause damage to surface and ground waters. Most important form of phosphorus in stormwater runoff is phosphate because it exists in soluble reactive form and hence difficult to separate it from stormwater (Berretta et al., 2011). The amount of nutrients in stormwater runoff also depends on rainfall intensity and duration (Crabtree et al., 2006).

Atmospheric deposition, soil erosion and human/animal waste are the possible sources of nutrients in urban stormwater runoff (Ball et al., 1998; Aryal et al., 2010). Sources of nitrates in stormwater runoff are fertilizers applied to plants, lawns and gardens (Hale et al., 2014; Taylor et al., 2005). Non point sources of phosphorus in
urban runoff include dry deposition of fallen leaves, grass, seeds and pollen, animal waste, lawn use, sediments eroded from parking lots and phosphorous bearing soils, abrasion and leaching from pavement with P-based admixtures (Berretta et al., 2011).

1.2.3 Biological Contaminants:

*E. coli/ Total coliform*

Though urban stormwater is one of the largest sources of microbial contamination, the fate and transport of these contaminants has not been particularly focused on in the previous studies (McCarthy et al., 2012). *E. coli* and total coliform in stormwater are of concern because they have an effect on both public health and nation’s economy (Kleinheinz et al., 2009). Stormwater runoff across impervious surfaces such as roads, roofs, lawns and construction areas has been identified as an important source in microbial concentration (McCarthy et al., 2012). Elevated levels of *E. coli* and total coliform, when discharged from a storm drain in beach waters, result in closure of beaches thus affecting the country’s economy besides degradation of surface water quality (Kleinheinz et al., 2010). Extremely high levels of microbial contamination in stormwater at the outlet pipe may be because of the presence of old, disintegrating storm and sanitary sewers, misplaced sewer pipes and good breeding conditions inside the catchment (Clary et al., 2008). Antecedent climate is one of the reasons for variations in *E. coli* count (McCarthy et al., 2012). Several physical, chemical and biological factors affect the presence, growth and transport of microbes in urban storm water. Some of the factors include moisture, temperature, nutrient availability and hydrologic processes (Selvakumar et al., 2006). Seasons also play an important role in microbial growth. The microbial concentration is usually high in dry weather season when compared to wet weather season. (Selvakumar et al., 2006). The area of the catch basin has an influence on the microbial count, as larger catchments have more complex stormwater infrastructure and thus more variable pollutant sources.
Sources of E. coli and total coliform may be point or nonpoint. Urban stormwater is an important nonpoint source of the bacteria, other important sources are failure of sewage disposal systems and direct deposition of wastes from livestock (Hathaway et al., 2011; Jagals et al., 1995; Kleinheinz et al., 2010)

1.3 Hydrologic characteristics affecting stormwater runoff:

Hydrologic characteristics such as antecedent dry days, first flush, rainfall amount, and rainfall intensity may impact the quality of stormwater runoff. The number of antecedent dry days (ADD) is defined as the time between the end of a precipitation event and the beginning of another (Davis, 2007). The first flush is defined as the percentage of total event pollution load transported by the first 20% of the storm runoff volume (Sansalone and Buchberger, 1997). The first flush is influenced by many factors such as a watershed area, rainfall intensity impervious area and ADD (Li Qing et al., 2007). The first flush is more pronounced in small catchments (McCarthy et al., 2012). The level of stormwater pollution depends on the ADD before the rainfall, size of the rainfall, volume of traffic per day at the study site (Lee et al., 2002, 2004). The quantity and quality of pollutants washed from a roadway depends upon the number of vehicles passing, their speed, ADD and the amount of rainfall (Adedeji et al., 2013). Traffic flow, climate and ADD are important factors in generating pollutants in highway runoff besides rainfall event intensity and duration. (Gnecco et al., 2005). The strength of the first flush is proportional to rainfall intensity and percent imperviousness and inversely related to watershed area. The impact of first flush and ADD on stormwater contaminants is shown in the table below.
Table 1.1: The impact of first flush and ADD on stormwater contaminants

<table>
<thead>
<tr>
<th>Name of contaminant</th>
<th>Impact of first flush and/or ADD</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>High in first flush</td>
<td>Lee et al., 2004</td>
</tr>
<tr>
<td>TP</td>
<td>Not influenced by ADD</td>
<td>Hatt et al., 2009</td>
</tr>
<tr>
<td>Nitrates</td>
<td>High in first flush</td>
<td>Brown et al., 2013</td>
</tr>
<tr>
<td></td>
<td>Depends on ADD</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>High in first flush</td>
<td>Adedeji et al., 2013</td>
</tr>
<tr>
<td></td>
<td>Depends on ADD</td>
<td></td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>not associated with first flush</td>
<td>McCarthy et al., 2012</td>
</tr>
</tbody>
</table>

EMC of most of the stormwater pollutants can be positively correlated with ADD with exceptions for TSS, O&G, NO$_3$-N, TP, and Zn. The pollutant loadings are also influenced by total amount of rainfall, mean intensity, and max 5-min intensity in the catchment areas. ADD is an important variable for predicting the EMC values in the urban catchments. Pollutant build-up increases with the length of ADD. As ADD is a significant factor for pollutant build-up in highly urbanized catchments, the frequent rains imply short ADD, which result in limiting pollutant build-up (Chua et al. 2009). Except for ADD, all rainfall variables (e.g., total amount of rainfall, duration, runoff volume, mean intensity, and max 5-min intensity) were negatively correlated with EMCs of most pollutants. The pollutant loadings of TSS are influenced primarily by total amount of rainfall, mean intensity, and max 5-min intensity. TSS and TP have negative correlation with rainfall duration because prolonged storms produce more runoff volume that dilutes the concentrations of these constituents. (Chow et al., 2013).
1.4 Stormwater Management:

Effective stormwater management reduces the negative impacts of stormwater runoff. Stormwater management focuses mainly on improving water quality besides controlling flooding and reducing erosion. This can be accomplished by implementing best management practices (BMP). The primary goal of BMP should be to reduce the discharge of pollutants in stormwater to the maximum extent practicable. Stormwater BMPs are control measures taken to mitigate the changes to both quality and quantity of urban runoff caused through changes to land use. BMPs are primarily designed and implemented to reduce the amount of nonpoint source pollution through various physical, chemical and biological processes, and to improve receiving water quality (Ahiablame et al., 2012). BMPs are also used to control water quantity as a part of storm water management since concentration of pollutants in stormwater runoff depends upon flow quantity. Flow control methods in storm water management include flow attenuation and volume reduction. These are generally achieved through various BMPs that encourage infiltration, detention, storage, and evaporation (Davis et al., 2007)

BMPs can be categorized into two types: structural and non-structural. Structural BMP refers to the design of devices installed or constructed on site to treat stormwater flow before its release into receiving waters. Structural BMPs involves two or more processes to effectively remove contaminants from stormwater. Examples of structural BMP include: wet ponds, retention ponds, wetlands, infiltration trenches, filter strips, bioretention cells, soil-water separators, bioswales and sand filters. Non-structural BMP includes source control to minimize the amount of contamination entering into stormwater. They involve change in human behavior and the attitude towards stormwater management. Examples of non-structural BMP include: source control and maintenance, storm drain flushing, litter control and pick
up and increasing awareness through public education (Yu et al., 2013).

1.5  Bioretention Systems:

This project focuses on bioretention, a process in which contaminants are removed from stormwater runoff. Bioretention systems are stormwater best management practices (BMPs) that use infiltration to treat stormwater runoff. Like any other natural systems, these systems use vegetation such as trees, shrubs and grasses to remove pollutants from stormwater runoff. They are commonly located in parking lots or within residential areas (Randall et al., 2013). Surface runoff is diverted into bioretention systems directly or through a designed storm drainage system. Typically, runoff is directed into shallow, landscaped depressions, which are designed to incorporate many of the pollutant removal mechanisms such as adsorption, infiltration and so on. (Li et al., 2009). Runoff from larger storms will be held in the ponding area on the surface and then generally diverted past the facility to the storm drain system. The remaining runoff filters through the bioretention media. The filtered runoff is thus collected in a perforated underdrain and returned to the storm drain system (Hsieh et al., 2005).

1.5.1  Trees in Bioretention systems

The role of trees in our ecosystem is absolutely critical because they clean our atmosphere by intercepting airborne particles. Trees in stormwater treatment practices can increase pollutant uptake and also help in reducing stormwater runoff. Trees primarily enhance soil infiltration besides increasing aesthetic appeal. Usually, a tree can hold up to 1-inch (2.54 cm) storm event, typically from impervious surface area (Marritz, 2011). Previous studies have shown that there is a reduction of 65 percent of storm runoff when trees are combined with other natural landscaping.
1.5.2 Tree filter:

Tree filters are in-ground containers used primarily to treat storm runoff quality. Tree filters contain street trees, vegetation and soil, which helps in filtering the storm runoff before it enters a catch basin. They are a retrofit to existing urban areas. The size of tree filter is usually compact which allows volume and water quality control to be adjusted to site characteristics. Selection of the tree plays a vital role because it forms an integral part of the bioretention system. The tree should be selected such that it can withstand drought conditions and also that do not have deep penetrating or invasive root systems, which may reduce the soil’s filtering capacity. Tree filters are designed to control only the first flush of stormwater. The main source of irrigation of tree filter is the storm runoff collected in the tree boxes. They have a good aesthetic value besides the capacity to reduce urban heat island effects (UNH Annual Report, 2007).

Figure 1-1: Tree filter (UNH Stormwater Center, 2009)
This research focused on measuring the effectiveness of a tree filter installed as a stormwater management demonstration project at the University of Toledo in August of 2014. This project focused on the evaluation of its impact on runoff water quality. The specific hypothesis and objectives for the project are provided below:

**Hypothesis**

Green stormwater infrastructure, specifically a tree filter, is effective in removing the stormwater pollutants thereby improving the water quality prior to the release to nearby surface waters.

**Objectives**

Objective 1: Characterize stormwater including contaminants and their concentrations as well as their relationship to hydrologic characteristics prior to tree filter installation at the site.

Objective 2: Characterize stormwater after treatment through the tree filter.

Objective 3: Compare results to determine efficacy of the tree filter.
Chapter 2

Site Description:

Green stormwater infrastructure demonstration projects, including a tree box filter, were installed at the University of Toledo in 2014. The tree filter is located adjacent to an impervious 0.8-acre asphalt parking lot (12W) at the law center on the University of Toledo main campus (Figure 2.1).

Figure 2-1: Tree filter location at the University of Toledo
The site drains to the south directly into the Ottawa River. The catch basin structure at the law center site is 3’ x 3’ x 6’ and is fed from the parking lot graded at approximately 1% slope. The number of parking spots at law center site is 94 (Figure 2.2).

![Figure 2-2: Watershed characteristics for the tree filter](image)

The tree filter system implemented at the site is a pre-engineered, pre-fabricated unit that allows for easy installation and evaluation. The pre-cast concrete stormwater tree filter box and appurtenances were provided by StormTree, LLC. The unit has an open bottom, allowing for increased bioretention and contaminant removal because it allows infiltration of stormwater in the lateral direction as well. The construction
work included an excavation, crushed double washed stone, 24” x 24” x 48” concrete catch basin, and related piping and tie-in to existing stormwater outfall.

**Excavation**

Excavation activities consisted of excavating to tie-in to the existing stormwater outfall, excavation footprint of the tree-filter unit (10’ x 10’ x 8’), excavation for the catch basin and related piping. A trench was excavated for placement of the new 8” inch outfall from the tree filter box. Total excavated material was approximately 30 cubic yards. Excavated material was used as fill for seeding purposes, with approval from University of Toledo Facilities and Construction.

A 24” x 24” x 48” precast concrete catch basin was provided by StormTree, LLC and used to tie-in the existing 18” stormwater outfall, which is approximately 5 feet below ground surface at the existing curb line. The catch basin directs the existing stormwater outfall flow to a 10” pipe outlet for connection to the precast tree filter systems. The precast tree filter unit was placed on top of a 24” layer of crushed stone. The crushed stone was placed in the bottom of the 10’ x 10’ x 8’ excavation shown on the design drawings.

The pre-cast concrete unit was provided by StormTree, LLC (Providence, RI). The unit consisted of a precast concrete box, consisting of a square tree well with open sides below the elevation of the root ball and a sediment sump with an enclosed bottom. The two sections are separated by a precast weir. The sediment sump has weep holes cast into the bottom. The dimensions of the unit are shown on the design drawings. Runoff is directed to the tree box, where it is cleaned by vegetation and soil before entering an outfall directed to the river (UNH Annual Report, 2007). Expected stormwater pollutant removal by tree filter is given in Table 2.1.
Table 2.1: Expected pollutant removal by Tree filter

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>&gt;85%</td>
</tr>
<tr>
<td>Metals</td>
<td>54-88%</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>&gt;48%</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>&gt;63%</td>
</tr>
<tr>
<td>Oil and Grease</td>
<td>85%</td>
</tr>
</tbody>
</table>

The detailed drawing of the tree filter including the media is shown in the figure 2.3.

Figure 2-3: Detailed drawing of Tree Filter
Chapter 3

3.0 Methods:

Composite and grab samples were collected from a 3’x3’x6’ concrete catch basin located on law center parking lot 12S in summer 2014 before the installation of the green infrastructure on campus. Composite samples were collected during storm events using ISCO GLS autosampler (Fig 3.1) and grab samples using grab sampler (Ultra-Universal grab sampler) (Fig 3.2). Grab sampler has been used to collect grab samples— the samples collected during the first flush. Grab sample requires manual operation. The samples were collected by inserting the long tube into the catch basin and by pumping the water out. The pumped water was collected in 1 liter glass bottles.

Figure 3-1: ISCO GLS Autosampler
The GLS autosampler has been used to collect composite samples for stormwater monitoring. It holds a 1 - 2.5 gallon sample bottle. The autosampler is very user friendly as the operation is quick and easy. The program should be pre-written and the sampler collects the composite samples as per the program written. The composite and grab samples after the setup of tree filter were collected in fall 2014 and summer 2015 using time and flow weighted autosampler (as shown in the figure 3.3) that collects both composite and grab samples. The sampling was done based on the criteria: an antecedent dry period of at least 24 hours between two storm events. Auto sampler has been programmed to collect samples once in every 15 min and a volume of 200 ml every time it collects the samples. Depending upon the duration of storm events, the number of samples collected for each storm event ranged from 5 and 20. A total of 50 samples were collected from 16 storm events. Polyethylene bottles (Fisher Scientific) of 1 L volume were used to store grab and composite samples. All the bottles used were rinsed with DI water at least three times before collecting the samples.
Before construction of tree filter in summer 2014, the samples were collected in a 3’ x 3’ x 6’ concrete catch basin located on law center parking lot 12S for 7 rain events in total. Composite samples were collected for 5 rain events and grabs for 6 rain events. The information about the date of the events, amount of rain, type of the sample collected, number of antecedent dry days (ADD) between each event and the duration of each rain event (in minutes) is given in the tables below (Tables 3.1 and 3.2). There were between 2 and 7 antecedent dry days between each rain event. The events lasted between 30 and 300 minutes in length.
Table 3.1: Rain events sampled during summer 2014

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain (in)</th>
<th>Sample type(s)</th>
<th>ADD</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>0.15</td>
<td>Both</td>
<td>3</td>
<td>90</td>
</tr>
<tr>
<td>05.28.14</td>
<td>0.20</td>
<td>Grab</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>06.04.14</td>
<td>0.39</td>
<td>Both</td>
<td>6</td>
<td>300</td>
</tr>
<tr>
<td>06.08.14</td>
<td>0.31</td>
<td>Composite</td>
<td>3</td>
<td>240</td>
</tr>
<tr>
<td>06.11.14</td>
<td>0.40</td>
<td>Grab</td>
<td>3</td>
<td>165</td>
</tr>
<tr>
<td>06.18.14</td>
<td>1.00</td>
<td>Both</td>
<td>6</td>
<td>195</td>
</tr>
<tr>
<td>06.23.14</td>
<td>0.64</td>
<td>Both</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>

After the construction of tree filter, samples were collected at front end and back end of the tree box filter in fall 2014 and summer 2015 to estimate the performance of tree filter in reducing the amount of solids and metals to receiving waters. The information about the date of rain events, amount of rain, type and location of the sample collected at the tree filter, number of antecedent dry days (ADD) between each event and the duration of each rain event (in minutes) is given in the table below. Here, “in” represents front end of tree filter whereas “out” represents back end of the tree filter.
Table 3.2: Rain events sampled during fall 2014 and summer 2015

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain (in)</th>
<th>Sample type</th>
<th>Location</th>
<th>ADD</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.28.14</td>
<td>0.15</td>
<td>composite</td>
<td>only in</td>
<td>7</td>
<td>72</td>
</tr>
<tr>
<td>10.31.14</td>
<td>0.35</td>
<td>grab</td>
<td>only in</td>
<td>2</td>
<td>310</td>
</tr>
<tr>
<td>11.06.14</td>
<td>0.18</td>
<td>Both</td>
<td>only in</td>
<td>1</td>
<td>240</td>
</tr>
<tr>
<td>04.13.15</td>
<td>0.07</td>
<td>grab</td>
<td>in and out</td>
<td>2</td>
<td>45</td>
</tr>
<tr>
<td>04.19.15</td>
<td>0.6</td>
<td>Both</td>
<td>in and out</td>
<td>5</td>
<td>360</td>
</tr>
<tr>
<td>05.10.15*</td>
<td>0.34</td>
<td>Both</td>
<td>in and out</td>
<td>4</td>
<td>240</td>
</tr>
<tr>
<td>05.15.15</td>
<td>0.23</td>
<td>grab</td>
<td>in and out</td>
<td>3</td>
<td>240</td>
</tr>
<tr>
<td>05.26.15*</td>
<td>0.13</td>
<td>grab</td>
<td>only in</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>05.27.15*</td>
<td>0.05</td>
<td>grab</td>
<td>only in</td>
<td>0</td>
<td>73</td>
</tr>
<tr>
<td>05.31.15*</td>
<td>1.69</td>
<td>grab</td>
<td>only in</td>
<td>0</td>
<td>540</td>
</tr>
</tbody>
</table>

* represents the rain event for which there was no out sample even it could have been collected

3.1 Water Quality Methods:

3.1.1 Total Solids

The stormwater sample collected is to be evaporated in a weighed dish and dried to constant weight in an oven at 103-105° C. The dish should be allowed to cool in a desiccator for 30 min. The increase in weight over that of the empty dish represents total solids. 50 ml of the sample was analyzed in triplicates.
3.1.2 Total Suspended Solids:

A well-mixed stormwater sample was filtered through a weighted standard glass-fiber filter and the residue retained on the filter was dried to a constant weight at 103-105° C and then placed in a desiccator for 30 min. The increase in weight of the filter represents the total suspended solids. 50 ml of the sample was processed in triplicates.

3.1.3 Metals (dissolved):

The metals copper, cadmium, lead and zinc are important in the stormwater samples because these four metals are most prevalent in urban stormwater runoff and are of particular interest due to their toxicity, ubiquitousness and the fact that they remain in the system for long time posing a risk to receiving waters (Aryal et al., 2010; Joshi et al., 2010; McKenzie et al., 2008; McQueen et al., 2010). The final report of the U.S. EPA’s Nationwide Urban Runoff Program (NURP) stated that heavy metals, especially copper, lead, and zinc, are the most prevalent constituents found in urban runoff (U.S. EPA, 1983). The dissolved phase of a metal is the most detrimental to ecosystem health whereas the particulate-bound fraction is stable and therefore less toxic. Hardness of dissolved metals plays a crucial role in determining metals concentration because lower hardness causes increase in toxicity (Joshi et al., 2010).

The samples were stored at 4°C in the refrigerator if the analysis is not possible immediately after collection. The analysis was done as per the Standard methods, 20th edition. Since our interest was to analyze dissolved metals in stormwater, the sample was filtered using filter papers of 1.5 μm pore size. The filtered samples (in triplicates) were acidified with 2 ml (0.2 N) HNO₃ trace metal grade and stored at 4°C before proceeding to further analysis. The reason for acidification was to
prevent contamination, if any, through addition of acid. The concentration in the dissolved phase was determined by analyzing the filtrate using Inductively Coupled Plasma- Mass Spectrometry (ICP-MS). The instrument X series 2 ICP-MS (Thermo scientific) was used for the analysis of samples. The eluent (carrier fluid) used was IV- ICPMS-71A of Inorganic Ventures, which is a HNO$_3$ matrix.

### 3.1.4 Nitrates:

The tests for nitrates and phosphates have been done using Hach color wheel apparatus. The detection limit for nitrates using Hach kit with catalog No: 14161-33 is 0.044-44 mg/L and the detection limit for phosphates using Hach kit with catalog No 2248-33 is 0.0133-0.267 mg/L. The test was done for nitrate nitrogen (0- 10 mg/L). 5 ml of the sample volume was tested. The tubes were rinsed well with demineralized water before every test. Using a plastic dropper, 0.5 ml of the sample was added to a rinsed color viewing tube and made up to the 5 ml mark using demineralized water. NitraVer 6 nitrate reagent powder pillow was added to the sample, stopper and shaked for three minutes and the sample was allowed to stand undisturbed for 30 seconds so that the unoxidized particles of cadmium metal settles to the bottom of the tube. The prepared sample was transferred carefully to the second tube without disturbing the settled cadmium particles present in the first tube. NitriVer 3 nitrite reagent powder pillow was added to the sample in the second tube. When the content of the powder pillow gets mixed well, a red color appears if nitrate is present in the sample. The tube should be inserted into the right top opening of the comparator. The unoxidized cadmium present in the first tube was rinsed with the original sample till the mark and the tube was inserted in the left top opening of the comparator. The comparator is to be held up to a light source and should be viewed through the openings in front. The color wheel should be rotated until the colors in front window match and the corresponding reading is to be noted. The reading when multiplied by
10 gives the value of mg/L nitrate nitrogen present in the sample. That value, when
multiplied by 4.4 gives the result as mg/L nitrate.

3.1.5 Orthophosphates:

The test has been done for midrange (0 to 5 mg/L) of phosphates. 5 mL of the
sample volume was tested. The long path viewing adapter is to be removed before
proceeding with the experiment. The two tubes present in the kit are to be filled
with sample. One of the tubes is to be inserted in the left opening of the comparator
and phosphate reagent powder pillow should be added to the second tube. When
the content of the powder pillow gets well mixed, a blue color develops if phosphate
is present in the sample. The tube should be inserted into the right top opening of
the comparator. The comparator should be held in such a way that a light source is
directly behind the tubes. The color wheel should be rotated until the colors in front
windows match and the corresponding value is to be noted. The value when divided
by 10 gives the value of mg/L phosphate.

3.1.6 Coliform/ *E. coli*:

Stormwater samples are to be stored at 4°C immediately after the collection for a
minimum of 2 hours and not more than 24 hours to control the growth of microbial
activity. Test for *E. coli*/ Total Coliform can be done using 3M Petrifilms. 750-1000
L of the sample is tested for *E. coli* and Total Coliform according to the standard
methods 20th Edition. Red color colonies indicate the presence of Total Coliforms
whereas blue color colonies indicate the presence of *E. coli*. 
3.2 Materials and Methods:

Before construction of tree filter in summer 2014, the samples were collected in a 3’ x 3’ x 6’ concrete catch basin for 7 rain events in total. Composite samples were collected for 5 rain events and grabs for 6 rain events. The information about the date of the events, amount of rain, type of the sample collected, number of antecedent dry days (ADD) between each event and the duration of each rain event (in minutes) is given in the table below (Table 3.3). There were between 2 and 7 antecedent dry days between each rain event. The events lasted between 30 and 300 minutes in length.

Table 3.3: Rain events sampled during summer 2014

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain (in)</th>
<th>Sample type(s)</th>
<th>ADD</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>0.15</td>
<td>Both</td>
<td>3</td>
<td>90</td>
</tr>
<tr>
<td>05.28.14</td>
<td>0.20</td>
<td>Grab</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>06.04.14</td>
<td>0.39</td>
<td>Both</td>
<td>6</td>
<td>300</td>
</tr>
<tr>
<td>06.08.14</td>
<td>0.31</td>
<td>Composite</td>
<td>3</td>
<td>240</td>
</tr>
<tr>
<td>06.11.14</td>
<td>0.40</td>
<td>Grab</td>
<td>3</td>
<td>165</td>
</tr>
<tr>
<td>06.18.14</td>
<td>1.00</td>
<td>Both</td>
<td>6</td>
<td>195</td>
</tr>
<tr>
<td>06.23.14</td>
<td>0.64</td>
<td>Both</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>

3.2.1 Grubb’s test:

Grubb’s test is also called the ESD (extreme studentized deviate) method. This method is used to detect outliers. An outlier is one such value which is different from others, when analysing data. One possibility is that the outlier is due to chance. In this case, the value should be kept in the analyses. The value came from the same population as the other values, so should be included. The other possibility is that the outlier was due to a mistake.

How to do Grubb’s test?

Step 1. To quantify how far the outlier is from the others.
The ratio $Z$ as the difference between the outlier and the mean divided by the SD should be calculated. If $Z$ is large, the value is far from the others.

Note: The mean and SD must be calculated from all values, including the outlier.

The presence of an outlier increases the calculated SD. Since the presence of an outlier increases both the numerator (difference between the value and the mean) and denominator (SD of all values), $Z$ does not get very large. In fact, no matter how the data are distributed, $Z$ cannot get larger than, where $N$ is the number of values. For example, if $N=3$, $Z$ cannot be larger than 1.555 for any set of values.

If our calculated value of $Z$ is greater than the critical value in the table (Engineering Statistics Handbook, June 2003), then the $p$ value is less than 0.05. This means that there is less than a 5% chance that we would encounter an outlier so far from the others (in either direction) by chance alone, if all the data were really sampled from a single Gaussian distribution. Note that the method only works for testing the most extreme value in the sample (if in doubt, calculate $Z$ for all values, but only calculate a $p$ value for Grubbs’ test from the largest value of $Z$.

**Example**: TSS concentrations of seven samples are given. Find the outlier.

**Solution**: Here, $N = 7$ (including the outlier),

\[ Z = \frac{\text{TSS concentration} - \text{average}}{\text{STDEV}} \]

<table>
<thead>
<tr>
<th>n</th>
<th>TSS</th>
<th>average</th>
<th>STDEV</th>
<th>Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>208.29</td>
<td>378.13</td>
<td>-0.53</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td></td>
<td></td>
<td>-0.53</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td></td>
<td></td>
<td>-0.51</td>
</tr>
<tr>
<td>4</td>
<td>68</td>
<td></td>
<td></td>
<td>-0.37</td>
</tr>
<tr>
<td>5</td>
<td>104</td>
<td></td>
<td></td>
<td>-0.28</td>
</tr>
<tr>
<td>6</td>
<td>128</td>
<td></td>
<td></td>
<td>-0.21</td>
</tr>
<tr>
<td>7</td>
<td>1128</td>
<td></td>
<td></td>
<td>2.43</td>
</tr>
</tbody>
</table>

Of all the values of $Z$ for $n=7$ samples, only for a particular TSS concentration, $z$-value (2.43) is higher than critical $Z$ value (2.02). That value is the outlier.
### 3.2.2 Student’s t-test:

A t-test assesses whether the means of two groups are statistically different from each other. 95% confidence ($\alpha = 0.05$) is usually considered. This means 95 times out of 100 we find statistically significant difference between the means of two data sets.

$$(n_1 - 1) + (n_2 - 1)$$

where,

- $n_1$ represents no. of data sets in a group A
- $n_2$ represents no. of data sets in a group B.

A t-test tells the probability that two set of values come from different groups.

P- value is the probability of obtaining a test result as extreme or as close to the one that was observed, assuming that the null hypothesis is true.

A t-test computes a t-value.

Larger the t-value is more likely the difference is significant. (Here, t-value is t-stat).

A critical t-value is the minimum t-value we need in order to have $P < 0.05 = \alpha$

If t-value is greater than or equal to the critical t-value, we will have a significant difference between two sets of data.

Note: if p value is less than or equal to alpha, we can reject null hypothesis. If p value is greater than alpha, we fail to reject the null hypothesis. In order to proceed with a t-test, null hypothesis should be defined. Our null hypothesis is: there is no significant difference between means of two sets of samples.

How to do t-test?

Find the means of each data set.

Find standard deviation ($\sigma$) using the formula:
\[
\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2}
\]

T-stat is calculated using the formula:

\[
t = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1-\bar{X}_2}}
\]

where,

\[
S_{\bar{X}_1-\bar{X}_2} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}
\]

S² is the variance of two samples. N₁ is the number of samples in one group. N₂ is of samples in another group. Standard deviation is square root of variance. Degrees of freedom can be calculated using

\[
d.f = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{(s_1^2/n_1)^2/(n_1 - 1) + (s_2^2/n_2)^2/(n_2 - 1)}
\]

### 3.2.3 Hardness:

Total hardness (mg/L as CaCO₃) in water can be found by using EPA method 130.2. In this method calcium and magnesium ions in the sample are sequestered upon the addition of disodium ethylene diamine tetra acetate (Na₂EDTA). The end point of the reaction is detected by means of Eriochrome black T indicator, which has a red color in the presence of calcium and magnesium and a blue color when the cations are sequestered. The four metals copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) measured in the stormwater samples have been compared with the Ohio state regulatory values that are hardness dependent. Hardness is important in determining metals concentration because lower hardness causes increase in toxicity.
(Joshi et al., 2010). This is because, hardness is a measure of the concentration of Ca$^{++}$ and Mg$^{++}$ ions present in solution, with hardness usually measured as calcium carbonate (CaCO$_3$) equivalents mg/L. Hardness of water has an impact on the toxicity of metals. In situations where the hardness is high, metals can be precipitated by the hardness and are no longer available to cause system toxicity. Therefore, it is necessary to always measure hardness when measuring metals concentration.
Chapter 4

4.0 Results and Discussion:

4.1 Solids

This section focuses on presenting the results of solids analyses in the stormwater samples collected at the law school site before and after construction of tree filter. The data presented focuses primarily on TSS because it acts as a mobile substrate in the transport of stormwater pollutants (e.g., bacteria, metals, nutrients) (Gunawardhana et al., 2012), (Hoffman et al., 1985). In addition, the tree filter was designed to treat just the first flush, and the magnitude of first flush phenomenon was found to be greater for suspended solids than dissolved or total solids (Lee et al., 2002).

4.1.1 Pre-construction scenario

A) Grab samples:

Grab samples were collected for six events during 2014. For these events, the concentration of TSS in grab samples collected at the law school site was observed to be in the range of 6 - 47 mg/L (Figure 4.1). These are all well below the Ohio state regulatory value which is 65 mg/L (State of Ohio, 2014).

B) Composite samples:

The concentration of TSS in the composite samples collected at the law school
site was observed to be in the range of 5-25 mg/L and is 2.5 times lower than the Ohio state regulatory value which is 65 mg/L (State of Ohio, 2014) (Figure 4.2).

C) Comparison between composite and grab samples:

A comparison between the amount of TSS measured in composite and grab samples at the law school site (Figure 4.3). The amount of TSS in grab samples collected at the site is almost 2 times higher than the amount of TSS collected in composite samples. Grabs are a snapshot of the characteristics of the water at a specific point in time (samples were collected during first flush) whereas a composite sample is a sample which consists of a mixture of several individual grab samples collected at regular and specified time periods, each sample taken in regular time intervals (US EPA, 2007). The concentration of grab samples was statistically different (higher) than composite samples collected for each event at the law school site (one-tailed t-test, alpha = 0.05) because unlike composite samples, so it may not be completely representative of the entire flow.

Figure 4-1: Concentration of TSS (mg/L) in grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.
4.1.2 Post construction scenario

A) Grab samples

In the post construction scenario, composite samples were collected only for one event. So, emphasis was mainly done on solids collected from grab samples. A comparison has been done for the amount of TSS in grab samples collected at front end and back end of the tree filter located at law school site (Figure 4.4). The concentration of TSS in grab samples collected at front end of the tree filter has been observed to be in the range of 15-104 mg/L, the average concentration is 60 mg/L whereas the concentration of TSS in grab samples collected at back end of the tree filter has been observed to be in the range of 2-24 mg/L, the average concentration is 13 mg/L. The concentration of TSS in the samples collected at front and back ends of the tree filter is less than the Ohio state regulatory value of 65 mg/L. TSS in the grab samples collected at the back end of tree filter was statistically different (lower) than that of in the grab samples collected at front end for the same event at the tree filter.
B) Samples collected at front end in fall 2014:

The samples were collected for only three rain events in fall 2014, out of which composite samples were collected for two rain events and grab samples for two rain events. That is, only for one rain event, we had both composite and grab samples. For the rain events in fall 2014, grab and composite samples were collected only at the front end of tree filter. Neither composite nor grab sample was collected at the back end of tree filter because the treated water was getting mixed with the overflow thereby entering the stream without a chance to collect the sample.

The concentration of TSS in the composite samples collected at front end of the
Figure 4-4: Concentration of TSS (mg/L) in grab samples collected during summer 2015. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

Tree filter was observed to be in the range of 3-50 mg/L, the average concentration being 27 mg/L and is 2.5 times lower than the Ohio state regulatory value of 65 mg/L. In fall 2014, the concentration of TSS in the grab samples collected at front end of the tree filter was observed to be in the range of 6-10 mg/L, the average concentration being 8 mg/L and is 8 times lower than the Ohio state regulatory value which is 65 mg/L. No statistically significant decrease in solids was observed in grab samples from the composite samples.

C) Samples collected in summer 2015

For four rain events in summer 2015, grab samples were collected only at the front end of tree filter. No sample was collected at the back end of tree filter even it could have been collected. The concentration of TSS in the samples collected at front end of the tree filter has been observed to be in the range of 30-400 mg/L, the average concentration being 100 mg/L and is 1.5 times higher than the Ohio state
regulatory value (65 mg/L). The graph below shows the concentration of TSS in the grab samples collected at front end of tree filter in summer 2015. Error bars represent one standard deviation of the mean (figure 4.5).

![Graph showing concentration of TSS in grab samples collected during summer 2015.](image)

Figure 4-5: Concentration of TSS (mg/L) in grab samples collected during summer 2015. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

4.1.3 Discussion:

The data was analyzed to identify any relationship between rain amount, rain intensity, or antecedent dry days and TSS concentration. In the pre-construction scenario, TSS was not correlated with rain amount, antecedent dry days, or rain intensity ($R^2$ value < 0.4 in all cases). On the contrary, other studies have shown that TSS in stormwater is related to rain intensity and ADD. (Gunawardhana et al., 2012) (Lee et al., 2002). Some of the reasons for contradiction is may be because of the less antecedent dry days (less than 5) we had between rain events and less duration of the rain events which was different from others’ work.
In the post construction scenario, the composite samples demonstrate a correlation with ADD (R² value = 0.70) and rain intensity (R² value = 0.70). Also, the grab samples show a good relationship with ADD (R² value = 0.70) and rain intensity (R² value = 0.90). Neither composite nor grab samples were correlated with rainfall amount (R² values < 0.1). These findings are in accordance with other studies where the concentration of TSS in first flush increased with increase in rain intensity and the number of antecedent dry days (Gunawardhana et al., 2012; Lee et al., 2002). An important note is that, in the sequence of determining relationship between TSS and/or rain intensity, rain amount and ADD, TSS concentration at one event i.e. the rain event on 05.10.15 has been neglected because it was found to be a statistical outlier using Grubb’s test. (Explained in methods section).

4.1.4 Mass of Suspended Solids Removed by the Tree Filter:

The tree filter was found to be effective in the removal of suspended solids from the stormwater runoff that enters the tree filter system. Filtration- a series of processes that physically removes particles from water, was the main removal mechanism for the particulates. (Geronimo et al., 2014; Minnesota pollution control agency report, July 2005). During small events (less than 0.3 inches of rain) in fall 2014, the tree filter retained the entire event thus keeping contaminants (175 g of suspended solids and 8 mg of zinc) out of the Ottawa River. Depending on the rain amount in summer 2015, the tree filter effectively removed solids from stormwater runoff (0.25 to 4 kg during this study). The calculations are based on the volume of voids of soil media, area of the tree filter system that can treat storm runoff and so forth, are presented in the appendix. The tree filter is capable of removing up to 85% of TSS (Geronimo et al., 2014) which was proved by our system. The removal efficiency of TSS for our tree filter ranged from 65-87%.
4.2 Metals

4.2.1 Pre-construction scenario

The table below shows the range of Ohio state regulatory values for metals copper, cadmium, lead and zinc that are hardness dependent. The significance of hardness in dissolved metals concentration in stormwater has been explained in section 3.4.3. Zinc values in the samples collected in pre-construction has been eliminated because of the error in analytical approach. The samples collected were not diluted 50 times whereas the samples collected in post construction scenario were diluted 50 times for the analysis of zinc.

Table 4.1: Range of Ohio state regulatory values for metals in stormwater

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ohio state regulatory value range (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>27-100</td>
</tr>
<tr>
<td>Cadmium</td>
<td>8-40</td>
</tr>
<tr>
<td>Lead</td>
<td>200-1000</td>
</tr>
<tr>
<td>Zinc</td>
<td>240-780</td>
</tr>
</tbody>
</table>

Table 4.2: Hardness of baseline samples collected

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample type</th>
<th>Hardness (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>Composite</td>
<td>200</td>
</tr>
<tr>
<td>06.04.14</td>
<td>Composite</td>
<td>240</td>
</tr>
<tr>
<td>06.08.14</td>
<td>Composite</td>
<td>400</td>
</tr>
<tr>
<td>06.18.14</td>
<td>Composite</td>
<td>200</td>
</tr>
<tr>
<td>06.23.14</td>
<td>Composite</td>
<td>200</td>
</tr>
<tr>
<td>05.21.14</td>
<td>Grab</td>
<td>160</td>
</tr>
<tr>
<td>05.28.14</td>
<td>Grab</td>
<td>400</td>
</tr>
<tr>
<td>06.04.14</td>
<td>Grab</td>
<td>200</td>
</tr>
<tr>
<td>06.11.14</td>
<td>Grab</td>
<td>240</td>
</tr>
<tr>
<td>06.18.14</td>
<td>Grab</td>
<td>160</td>
</tr>
<tr>
<td>06.23.14</td>
<td>Grab</td>
<td>200</td>
</tr>
</tbody>
</table>

A) Grab samples:
Table 4.3: Hardness data for the samples collected after the construction of tree filter

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample type</th>
<th>Frontend</th>
<th>Hardness (mg/L)</th>
<th>Backend</th>
<th>Hardness (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.28.14</td>
<td>composite</td>
<td>✓</td>
<td>240</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11.06.14</td>
<td>composite</td>
<td>✓</td>
<td>240</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>04.19.15</td>
<td>composite</td>
<td>✓</td>
<td>240</td>
<td>✓</td>
<td>400</td>
</tr>
<tr>
<td>05.10.15</td>
<td>composite</td>
<td>✓</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.31.14</td>
<td>grab</td>
<td>✓</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11.06.14</td>
<td>grab</td>
<td>✓</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>04.13.15</td>
<td>grab</td>
<td>✓</td>
<td>200</td>
<td>✓</td>
<td>280</td>
</tr>
<tr>
<td>04.19.15</td>
<td>grab</td>
<td>✓</td>
<td>200</td>
<td>✓</td>
<td>320</td>
</tr>
<tr>
<td>05.10.15</td>
<td>grab</td>
<td>✓</td>
<td>200</td>
<td>✓</td>
<td>240</td>
</tr>
<tr>
<td>05.15.15</td>
<td>grab</td>
<td>✓</td>
<td>320</td>
<td>✓</td>
<td>320</td>
</tr>
</tbody>
</table>

The concentration of copper in grab samples collected at law school site was observed to be in the range of 19 - 72 ppb and is below the Ohio state regulatory values that are hardness dependent.

The concentration of cadmium in grab samples has been observed to be in the range of 0.5 ppb - 12 ppb and is 16 times lower than the Ohio state regulatory values that are hardness dependent.
Figure 4-6: Concentration of copper (ppb) in grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of cadmium in grab samples has been observed to be in the range of 0.5 ppb - 12 ppb and is 16 times lower than the Ohio state regulatory values that are hardness dependent.
Figure 4-7: Concentration of cadmium (ppb) in grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of lead in grab samples has been observed to be in the range of 0.47 ppb - 0.93 ppb and is 250 times lower than the Ohio state regulatory values.
Figure 4-8: Concentration of lead (ppb) in grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances

**Composite samples**

The concentration of copper in composite samples collected at law school site has been observed to be in the range of 3.5 - 9.5 ppb and is **10 times** lower than the Ohio state regulatory values that are hardness dependent.
Figure 4-9: Concentration of copper (ppb) in composite samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of cadmium in the composite samples has been observed to be in the range of 0.12 - 0.60 ppb and is **65 times** lower than the Ohio state regulatory values that are hardness dependent.
Figure 4-10: Concentration of cadmium (ppb) in composite samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of lead in the composite samples has been observed to be in the range of 0.40-0.99 ppb and is 200 times lower than the Ohio state regulatory values that are hardness dependent.
Figure 4-11: Concentration of lead (ppb) in composite samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

B) Composite vs. grab in summer 2014

A comparison has been done for the amount of metals measured in composite and grab samples before the construction of tree filter at law school site (Figure 4.12). Grabs are a snapshot of the characteristics of the water at a specific point in time (samples were collected during first flush) whereas a composite sample is a sample which consists of a mixture of several individual grab samples collected at regular and specified time periods, each sample taken in regular time intervals (US EPA, 2007). The amount of copper in grab samples collected at the site is almost 2 times higher than the amount of copper collected in composite samples.
Figure 4-12: Concentration of copper (ppb) in composite and grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The amount of cadmium in grab samples collected at the site is almost 10 times higher than the amount of cadmium collected in composite samples for two rain events.
Figure 4-13: Concentration of cadmium (ppb) in composite and grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The amount of lead in grab samples collected at the site is slightly higher than the amount of lead collected in composite samples for all the rain events. However, a statistical outlier (as per Grubb’s test) has been found for a particular rain event (i.e. on 06.18.14)
Figure 4-14: Concentration of lead (ppb) in composite and grab samples collected during summer 2014. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of grab samples was statistically different (higher) than composite samples collected for each event at the law school site (one-tailed t-test, alpha = 0.05) because unlike composite samples, grabs may not be completely representative of the entire flow. Moreover, the concentration of solids and metals in grab samples is higher than composite samples (Lee et al., 2002).

4.2.2 Post-construction scenario

In the post-construction scenario, composite samples were collected only for one rain event in summer 2015. So, emphasis was mainly done on metals collected from grab samples. A comparison has been done for the amount of metals in grab samples collected at front end and back end of the tree filter located at law school site. Also, the metals concentration has been compared with the Ohio state regulatory values.
A) Front end vs. Back end grab samples

The concentration of copper in grab samples collected at front end of the tree filter has been observed to be in the range of 6-12 ppb, the average concentration being 9 ppb and is almost 10 times lower than the Ohio state regulatory value that is hardness dependent. The amount of copper in grab samples collected at back end of the tree filter has been observed to be in the range of 4-7 ppb, the average concentration being 5 ppb and is 15 times lower than the Ohio state regulatory value.

Figure 4-15: Concentration of copper (ppb) in grab samples collected at front and back ends of tree filter during summer 2015. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of cadmium in grab samples collected at front end of the tree filter has been observed to be in the range of 0.3 -1.2 ppb, the average concentration being 0.6 ppb and is almost 40 times lower than the Ohio state regulatory value. The
amount of cadmium in grab samples collected at back end of the tree filter has been observed to be in the range of 0.3-0.6 ppb, the average concentration being 0.46 ppb and is 65 times lower than the Ohio state regulatory value.

Figure 4-16: Concentration of cadmium (ppb) in grab samples collected at front and back ends of tree filter during summer 2015. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of lead in grab samples collected at front end of the tree filter has been observed to be in the range of 2-4 ppb, the average concentration being 3 ppb and is almost times 67 lower than the Ohio state regulatory value. The amount of lead in grab samples collected at back end of the tree filter has been observed to be in the range of 1.3-3.8 ppb, the average concentration being 2 ppb and is 100 times lower than the Ohio state regulatory value.
The concentration of zinc in grab samples collected at front end of the tree filter has been observed to be in the range of 360-2000 ppb, the average concentration being 1000 ppb and is almost 1.5 times higher than the Ohio state regulatory value. The amount of zinc in grab samples collected at back end of the tree filter has been observed to be in the range of 94-1000 ppb, the average concentration being 500 ppb and is 1.5 times higher than the Ohio state regulatory value.
Figure 4-18: Concentration of zinc (ppb) in grab samples collected at front and back ends of tree filter during summer 2015. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of grab samples collected at the front end of tree filter was statistically different (higher) than the grab samples collected at the back end of tree filter for each event at the law school site (one-tailed t-test, alpha = 0.05).

B) Comparison of metals at the inlet of tree filter for both the scenarios:

An attempt has been made to check for a relation (if any) between the grabs samples collected in pre and post construction scenarios. The concentration of metals before and after construction of tree filter is provided in Table 4.4 and compared with Ohio state regulatory values for metals (State of Ohio, 2014). The main emphasis was done on grab samples because composite samples were collected only on two events after the construction of tree filter.
Table 4.4: Comparison of metals in grab samples collected before and after construction of tree filter with Ohio state regulatory value

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ohio state regulatory values (ppb)</th>
<th>Average concentration at front end pre-construction (ppb)</th>
<th>Average concentration at front end post-construction (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>240-780</td>
<td>NA*</td>
<td>500</td>
</tr>
<tr>
<td>Cd</td>
<td>8-40</td>
<td>4.07</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cu</td>
<td>27-100</td>
<td>10.57</td>
<td>6</td>
</tr>
<tr>
<td>Pb</td>
<td>200-1000</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

The concentration of copper in grab samples collected before the construction of tree filter has been observed to be in the range of 5-72 ppb, the average concentration being 38 ppb and is less than the Ohio state regulatory value. The amount of copper in grab samples collected at back end of the tree filter has been observed to be in the range of 6-12 ppb, the average concentration being 9 ppb and is three times less than the Ohio state regulatory value. A statistically significant decrease has been observed in copper collected from back end of the tree filter (one tailed t-test, $= 0.05$).
Figure 4-19: Concentration of copper (ppb) in grab samples collected before and after construction of tree filter. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of cadmium in grab samples collected before the construction of tree filter has been observed to be in the range of 0.3-12 ppb, the average concentration being 6 ppb and is less than the Ohio state regulatory value. The amount of cadmium in grab samples collected at back end of the tree filter has been observed to be in the range of 0.3-1.2 ppb, and is less than the Ohio state regulatory value.
Figure 4-20: Concentration of cadmium (ppb) in grab samples collected before and after construction of tree filter. Error bars represent one standard deviation of the mean and are too small to be seen in some instances.

The concentration of lead in grab samples collected before the construction of tree filter has been observed to be in the range of 0.5-22 ppb, the average concentration being 11 ppb and is less than the Ohio state regulatory value. The amount of lead in grab samples collected at back end of the tree filter has been observed to be in the range of 2-4 ppb, and is less than the Ohio state regulatory value.
The concentration of grab samples was statistically different (higher) in the samples collected before the construction of tree filter when compared to the grab samples collected after the construction of tree filter for each event at the law school site (one-tailed t-test, alpha = 0.05).

4.2.3 Discussion:

The concentration of metals in the samples has been compared to Ohio state regulatory values for modified warm water surface waters. The concentration of lead in the samples collected before construction of tree filter was very low. This was expected because lead exhibits a weak first flush since it is particulate bound (Aryal et al., 2010; Sansalone et al., 1997). The concentration of zinc was found to be very
high (more than 10000 ppb) in both composite and grab samples collected before and after the construction of tree filter when compared to the Ohio state regulatory value. The reason for huge amount of zinc and its sources are not as easily identified in the literature. The increased use of galvanized and corrosion resistant automobile parts, containing metal plating that includes zinc and the use of zinc in the manufacture of tires likely contributes to increased zinc loadings. Also, during rain events, acidic runoff comes into contact with galvanized vehicular parts elevating the levels of zinc in storm runoff (Aryal et al., 2010; Geronimo et al., 2014; Sansalone et al., 1997).

No statistically significant differences in the metals collected between the samples collected at front end and back end of the tree filter in the post construction scenario except for zinc. Zinc was significantly reduced in 3 of the four events. Zinc was present in all stormwater samples at much higher concentration than other metals. Therefore, it is removed at a consistently higher rate than the other metals. Dissolved metals are removed from stormwater by sorption onto clay and organic matter. After the sorption capacity of a soil is saturated, dissolved heavy metals will breakthrough and hence will be discharged to receiving waters. Because dissolved heavy metals are more bioavailable than particulate bound heavy metals, they pose risk to environment. So long term retention of dissolved heavy metals is especially important (Hatt et al 2011; deeproot 2015)

None of the dissolved metals showed relationship with ADD, amount of rain and intensity of rain event (R² value < 0.3). Zinc was found to be well correlated with ADD and intensity of rain (R² value = 0.6). This agrees with the findings of literature review (Adedeji et al., 2013; Gunawardhana et al., 2012; Lee et al., 2002). There was no specific trend observed for metals in composite and grab samples over the season. In the pre-construction scenario, no correlation was observed between the stormwater contaminants and hydrological characteristics. However, in the post-construction scenario relationships were found. This is likely because there were some differences
in our sampling including the bottle type (glass vs. plastic), the sampler (hand operated vs. electric), and the sampling location (catch basin vs. tree filter intake). So, it is anticipated that there would be some differences between samples collected pre and post construction. In our case, concentration of metals in samples collected in glass bottles in summer 2014 is higher than the concentration of metals collected in polypropylene bottles in summer 2015.

4.2.4 Mass of zinc removed by tree filter

The tree filter is found to be effective in removal of zinc from the stormwater runoff that enters the tree filter system. Based on the rain amount, the tree could effectively remove zinc ranging from 2-30 g overall. The removal efficiency of zinc ranged from 50-75%. These results suggested that the adsorption capability of media and infiltration capacity of the system was the main removal mechanism for metals and thus tree filter is effective in removing up to 70% of the metals from the urban stormwater runoff (Geronimo et al., 2014)
Chapter 5

Conclusions and Future work:

This research work concentrated on the performance assessment of the tree filter installed at UT. The investigation focused on its capability to remove contaminants such as solids, metals, nutrients and indicator bacteria from urban stormwater runoff. In addition, the relationships between solids and metals in urban runoff and their dependence on hydrologic parameters such as ADD, rain amount and rainfall intensity were investigated. The tree filter resulted in a statistically significant (95% confidence) reduction in total suspended solids in stormwater runoff as measured in grab samples. Heavy metals were not consistently removed, with the exception of zinc. Nutrient (nitrates and orthophosphates) concentrations and coliform bacteria in all samples collected before and after the construction of the tree filter were below detection. Nitrates and phosphates were likely not observed in considerable amounts because there was no evidence that fertilizer has been applied on the site during the period of sample collection. The literature review states that phosphorus bearing soils, fertilizers applied to plants and animal waste are the main sources of nutrients in stormwater. Coliform bacteria indicate the presence of human or animal waste. The absence of detectable coliform counts suggests that there is no human or animal waste on the watershed where our samples were collected. The existing tree filter was proven effective at infiltrating rainfall events of up to 0.05 to 0.10 inches. The system has the
capacity to hold approximately 1122 gallons. The exact size of the rain event that can be held will depend on the rainfall intensity.

Specific conclusions drawn from the site assessment, sample analyses, and processed results include the following:

- No correlation was observed between solids and hydrologic parameters such as ADD, rainfall amount, and rainfall intensity before the construction of the tree filter. This is in contrary to the findings of the literature review. This contradiction may be because of the small number of antecedent dry days (less than 5) and smaller duration of the rain events, which was different (statistically lower) from other reported research.

- After construction of the tree filter, hydrologic conditions were correlated to the concentration of solids. TSS concentrations in the samples increased with increasing precipitation intensity.

Future work should include continued monitoring of the tree filter site to determine its performance as the tree filter ages. Debris from the parking lot will eventually clog the top of the tree filter. It is anticipated that removal efficiencies will change as pores become blocked. In fact, more metal removal, due to increased potential to remove smaller particles and to absorb metals, may be observed. In addition, maintenance of the site will be necessary. Continued observation of performance will indicate when maintenance is needed and the effectiveness of the maintenance options.
References


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Wastewater Sampling- Environmental Protection Agency Georgia (2007). Operating Procedure.


Appendix A

Sample Data

Table A.1: Solids data of grab samples collected at Law School site

<table>
<thead>
<tr>
<th>Date</th>
<th>TS (mg/L)</th>
<th>Stdev (mg/L)</th>
<th>TSS (mg/L)</th>
<th>Stdev (mg/L)</th>
<th>TDS (mg/L)</th>
<th>Stdev (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>210.00</td>
<td>0.00</td>
<td>44.00</td>
<td>0.00</td>
<td>166.00</td>
<td>0.00</td>
</tr>
<tr>
<td>05.28.14</td>
<td>206.67</td>
<td>6.24</td>
<td>24.33</td>
<td>4.50</td>
<td>182.00</td>
<td>10.67</td>
</tr>
<tr>
<td>06.04.14</td>
<td>2013.33</td>
<td>9.43</td>
<td>26.00</td>
<td>2.83</td>
<td>1987.33</td>
<td>8.38</td>
</tr>
<tr>
<td>06.11.14</td>
<td>50.67</td>
<td>0.94</td>
<td>20.00</td>
<td>0.00</td>
<td>30.67</td>
<td>0.94</td>
</tr>
<tr>
<td>06.18.14</td>
<td>200.00</td>
<td>0.00</td>
<td>46.67</td>
<td>0.94</td>
<td>153.33</td>
<td>0.94</td>
</tr>
<tr>
<td>06.23.14</td>
<td>200.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>94.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table A.2: Solids data of composite samples collected at Law School site

<table>
<thead>
<tr>
<th>Date</th>
<th>TS (mg/L)</th>
<th>Stdev (mg/L)</th>
<th>TSS (mg/L)</th>
<th>Stdev (mg/L)</th>
<th>TDS (mg/L)</th>
<th>Stdev (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>46.50</td>
<td>0.00</td>
<td>5.00</td>
<td>0.00</td>
<td>41.50</td>
<td>0.00</td>
</tr>
<tr>
<td>06.04.14</td>
<td>803.33</td>
<td>4.71</td>
<td>12.00</td>
<td>4.32</td>
<td>791.33</td>
<td>7.36</td>
</tr>
<tr>
<td>06.08.14</td>
<td>77.67</td>
<td>3.09</td>
<td>16.00</td>
<td>5.66</td>
<td>61.67</td>
<td>8.73</td>
</tr>
<tr>
<td>06.18.14</td>
<td>200.00</td>
<td>0.00</td>
<td>25.33</td>
<td>0.94</td>
<td>174.67</td>
<td>0.94</td>
</tr>
<tr>
<td>06.23.14</td>
<td>200.00</td>
<td>0.00</td>
<td>4.00</td>
<td>0.00</td>
<td>196.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table A.3: TSS data at tree filter site in the samples collected in summer 2015

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample type</th>
<th>Location</th>
<th>TSS (mg/L)</th>
<th>Stdev (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>04.13.15</td>
<td>grab</td>
<td>Front end</td>
<td>68</td>
<td>8.64</td>
</tr>
<tr>
<td>04.13.15</td>
<td>grab</td>
<td>Back end</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>04.19.15</td>
<td>grab</td>
<td>Front end</td>
<td>104</td>
<td>28.47</td>
</tr>
<tr>
<td>04.19.15</td>
<td>grab</td>
<td>Back end</td>
<td>20</td>
<td>6.53</td>
</tr>
<tr>
<td>05.10.15</td>
<td>grab</td>
<td>Front end</td>
<td>1128</td>
<td>244.14</td>
</tr>
<tr>
<td>05.10.15</td>
<td>grab</td>
<td>Back end</td>
<td>242.67</td>
<td>53.07</td>
</tr>
<tr>
<td>05.15.15</td>
<td>grab</td>
<td>Front end</td>
<td>15.33</td>
<td>3.77</td>
</tr>
<tr>
<td>05.15.15</td>
<td>grab</td>
<td>Back end</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Table A.4: Concentration of metals in grab samples before the construction of tree filter

<table>
<thead>
<tr>
<th>Date</th>
<th>Cu (ppb)</th>
<th>Stdev (ppb)</th>
<th>Cd (ppb)</th>
<th>Stdev (ppb)</th>
<th>Pb (ppb)</th>
<th>Stdev (ppb)</th>
<th>Zn (ppb)</th>
<th>Stdev (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>19.07</td>
<td>0.68</td>
<td>0.50</td>
<td>0.01</td>
<td>0.47</td>
<td>0.01</td>
<td>3150.27</td>
<td>128.46</td>
</tr>
<tr>
<td>05.28.14</td>
<td>14.07</td>
<td>0.65</td>
<td>0.71</td>
<td>0.02</td>
<td>0.46</td>
<td>0.01</td>
<td>6333.33</td>
<td>328.79</td>
</tr>
<tr>
<td>06.04.14</td>
<td>21.15</td>
<td>1.01</td>
<td>10.54</td>
<td>0.53</td>
<td>0.93</td>
<td>0.05</td>
<td>419.23</td>
<td>15.06</td>
</tr>
<tr>
<td>06.11.14</td>
<td>4.29</td>
<td>0.20</td>
<td>0.26</td>
<td>0.01</td>
<td>0.72</td>
<td>0.03</td>
<td>71240.30</td>
<td>3234.58</td>
</tr>
<tr>
<td>06.18.14</td>
<td>71.95</td>
<td>5.09</td>
<td>12.11</td>
<td>0.92</td>
<td>22.10</td>
<td>1.41</td>
<td>36430.00</td>
<td>2136.46</td>
</tr>
<tr>
<td>06.23.14</td>
<td>4.85</td>
<td>0.23</td>
<td>0.29</td>
<td>0.01</td>
<td>0.74</td>
<td>0.03</td>
<td>30810.00</td>
<td>2471.01</td>
</tr>
</tbody>
</table>

Table A.5: Concentration of metals in composite samples before the construction of tree filter

<table>
<thead>
<tr>
<th>Date</th>
<th>Cu (ppb)</th>
<th>Stdev (ppb)</th>
<th>Cd (ppb)</th>
<th>Stdev (ppb)</th>
<th>Pb (ppb)</th>
<th>Stdev (ppb)</th>
<th>Zn (ppb)</th>
<th>Stdev (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.21.14</td>
<td>8.34</td>
<td>0.47</td>
<td>0.60</td>
<td>0.04</td>
<td>0.40</td>
<td>0.02</td>
<td>252.80</td>
<td>18.43</td>
</tr>
<tr>
<td>06.04.14</td>
<td>9.51</td>
<td>0.64</td>
<td>0.12</td>
<td>0.01</td>
<td>0.45</td>
<td>0.01</td>
<td>5203.67</td>
<td>375.97</td>
</tr>
<tr>
<td>06.08.14</td>
<td>8.55</td>
<td>0.40</td>
<td>0.22</td>
<td>0.02</td>
<td>1.02</td>
<td>0.06</td>
<td>86739.97</td>
<td>3467.03</td>
</tr>
<tr>
<td>06.18.14</td>
<td>5.39</td>
<td>0.29</td>
<td>0.37</td>
<td>0.01</td>
<td>0.99</td>
<td>0.04</td>
<td>59240.00</td>
<td>5012.43</td>
</tr>
<tr>
<td>06.23.14</td>
<td>3.54</td>
<td>0.22</td>
<td>0.39</td>
<td>0.01</td>
<td>0.70</td>
<td>0.01</td>
<td>40240.00</td>
<td>6861.08</td>
</tr>
</tbody>
</table>
Appendix B

Mass removed by tree filter

B.1 Mass of suspended solids removed by tree filter

Volume of voids of tree filter = 150 Cubic ft = 1122 gallons
Rain (ft) = Rain (in)*0.083
Area of tree filter catchment = 0.8acres*(43560 sq. ft/1 acre) = 34848 sq. ft
Rain (lit) = Rain (ft) * Area of tree filter catchment (in sq. ft)*28.3169 (lit/cubic ft)
Mass removed (mg) = Rain (lit)*TSS (mg/L)
<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Rain (in)</th>
<th>Rain (ft)</th>
<th>Area of tree filter catchment (sq ft)</th>
<th>Rain (lit)</th>
<th>TSS (mg/l)</th>
<th>Mass removed (mg)</th>
<th>Mass removed (mg)</th>
<th>Mass removed (kg)</th>
<th>% removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>04.13.15</td>
<td>front end</td>
<td>0.07</td>
<td>0.01</td>
<td>34848.00</td>
<td>5733.21</td>
<td>68.00</td>
<td>389858.56</td>
<td>137597.14</td>
<td>252261.42</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>back end</td>
<td>0.07</td>
<td>0.01</td>
<td>34848.00</td>
<td>5733.21</td>
<td>24.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04.19.15</td>
<td>front end</td>
<td>0.60</td>
<td>0.05</td>
<td>34848.00</td>
<td>49141.84</td>
<td>104.00</td>
<td>5110750.90</td>
<td>982836.71</td>
<td>4127914.19</td>
<td>81%</td>
</tr>
<tr>
<td></td>
<td>back end</td>
<td>0.60</td>
<td>0.05</td>
<td>34848.00</td>
<td>49141.84</td>
<td>20.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05.10.15</td>
<td>front end</td>
<td>0.34</td>
<td>0.03</td>
<td>34848.00</td>
<td>27847.04</td>
<td>1128.00</td>
<td>31411461.28</td>
<td>6757641.23</td>
<td>24553820.05</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>back end</td>
<td>0.34</td>
<td>0.03</td>
<td>34848.00</td>
<td>27847.04</td>
<td>242.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05.15.15</td>
<td>front end</td>
<td>0.23</td>
<td>0.02</td>
<td>34848.00</td>
<td>18837.70</td>
<td>15.33</td>
<td>288782.00</td>
<td>37675.41</td>
<td>251106.59</td>
<td>87%</td>
</tr>
<tr>
<td></td>
<td>back end</td>
<td>0.23</td>
<td>0.02</td>
<td>34848.00</td>
<td>18837.70</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**B.2 Mass of zinc removed by tree filter**

The calculations are as follows:

Volume of voids of tree filter = 150 cubic ft = 1122 gallons

Rain (ft) = Rain (in) * 0.083

Area of tree filter catchment = 0.8 acres * (43560 sq. ft/1 acre) = 34848 sq. ft

Rain (L) = Rain (ft) * Area of tree filter Catchment (in sq. ft) * 28.3169 (lit/cubic ft)
### Figure B-2: Mass of Zinc removed by tree filter

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Rain (in)</th>
<th>Rain (ft)</th>
<th>Area of tree filter catchment (sq. ft)</th>
<th>Rain (lit)</th>
<th>Zn (ppb)</th>
<th>Mass removed (µg)</th>
<th>Mass removed by tree filter (µg)</th>
<th>Mass removed by tree filter (g)</th>
<th>% removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>04.13.15</td>
<td>front end back end</td>
<td>0.07</td>
<td>0.01</td>
<td>34848.00</td>
<td>5733.21</td>
<td>358.46</td>
<td>2055127.94</td>
<td>1519187.08</td>
<td>1.52</td>
<td>74%</td>
</tr>
<tr>
<td>04.19.15</td>
<td>front end back end</td>
<td>0.60</td>
<td>0.05</td>
<td>34848.00</td>
<td>49141.84</td>
<td>1269.17</td>
<td>62369343.43</td>
<td>40172467.73</td>
<td>40.17</td>
<td>64%</td>
</tr>
<tr>
<td>05.10.15</td>
<td>front end back end</td>
<td>0.34</td>
<td>0.03</td>
<td>34848.00</td>
<td>27847.04</td>
<td>1987.83</td>
<td>55355181.81</td>
<td>27795801.59</td>
<td>27.80</td>
<td>50%</td>
</tr>
<tr>
<td>05.15.15</td>
<td>front end back end</td>
<td>0.23</td>
<td>0.02</td>
<td>34848.00</td>
<td>18837.70</td>
<td>477.57</td>
<td>8996322.12</td>
<td>668361.72</td>
<td>-0.67</td>
<td>-7%</td>
</tr>
</tbody>
</table>
"A"  591'-0"

"B"  589'-10"
Note: Invert @ C will be at same elevation (588'-0"), it will now however be 18" further up the filter frame wall

"C"  588'-0"
585'-6"

"D"  585'-0"

10" PVC COUPLING INVERT

(2) 1" DIA. WEEP HOLES

SIDE "B" & "D" NTS

DESIGN NOTES:
CONCRETE 5,000 PSI @ 28 DAYS
DESIGNED FOR H-20 LOADING
REBAR ASTM A-615 GRADE 60,
1" MIN COVER

SIDE "C" NTS

DESIGN NOTES:
CONCRETE 5,000 PSI @ 28 DAYS
DESIGNED FOR H-20 LOADING
REBAR ASTM A-615 GRADE 60,
1" MIN COVER