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QUANTIFYING STORMWATER RUNOFF CONTAMINANT MITIGATION BY BIORETENTION CELLS

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BY

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QUANTIFYING STORMWATER RUNOFF CONTAMINANT MITIGATION BY BIORETENTION CELLS

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This research study has three objectives, quantify the presence and concentration of selected contaminants in urban stormwater runoff from several urban locations within Lincoln, Nebraska, quantify the effectiveness of two, 10-year old bioretention cells, for reducing concentrations of contaminants in effluent and quantify the effectiveness of six rain gardens.

The primary research sites were two bioretention cells using automated samplers collecting grab samples of stormwater runoff influent and effluent for at least six precipitation events during a two-year period. Additional research sites included samplers for two rainfall, six rain garden, two commercial rooftop, two commercial parking lot, and six residential rooftop sites. Stormwater runoff sample collection occurred from April 21, 2013 to May 22, 2014.

Comparing the average influent against the average effluent, both the large and small bioretention cells had pollutant reductions (+) respectively for metolachlor 70%/21%, propazine 21%/45%, TKN 28%/9%, zinc 49%/69%, total fecal coliform 99.6%/88%, total E.coli 97%/66%, TSS 93%/71%, and oil/grease 52%/17% , while cells were a source(-) for nitrate -431%/-91%, and TDS -79%/-41%. The cells differed in pollutant removal/source for acetochlor, atrazine , DEA, total phosphorus and

conductivity as the large cell had pollutants calculated at; 75%, 75%, 52% -255% and -45% respectively, while the small cell measured opposite of what the large cell at; -11%, -14%, -14% 5% and 25% respectively.

Concentrations of pollutants in the rain garden runoff were 51% and 66% less than residential rooftop runoff for zinc and nitrate respectively. Concentrations of pollutants TKN and total phosphorus measured in the rain gardens runoff were 15% and 129% respectively greater than residential rooftop runoff.

Similarities seen between the rainfall and bioretention cells in seasonal changes and statistically similar pollutant levels during the same storm events, indicate that rainfall contributed a majority of pollutant concentrations to both cells. Pollutants measured at all of the sites showed a decreasing trend from spring to late summer, with the exception of zinc.

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To my parents, Barbara and Christopher Walsh, thank you for always encouraging me to keep moving forward in my career passions, your support and example role models is second to none. To my aunt, Dr. Virginia Walsh, thank you for inspiring me to become involved in the sciences and engineering. To my grandparents, Eugene and Augusta Shultz, and Rosemary Walsh, thank you for all of the hugs over the years. Lastly, I would like to thank my siblings Andrea, Nathaniel, Jillian and my girlfriend Dr. Nikki Abdulla, for all of their enormous love and support.

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Chapter 1 Introduction

Abstract

Urbanization in the last 50 years has had a profound impact on the hydrology and surface water quality in many areas of the United States. The development of urban areas has caused the hydrologic cycle associated with a watershed to shift away from that associated with a natural or forested watershed. These changes in the watershed hydrologic cycle have caused intense, high flow stormwater runoff that often comes quickly and unexpectedly causing pollutants to be directly transported into a water body without any retention time to naturally adsorb or decay. Bioretention cells and rain gardens are seen as a best management practice (BMP) aimed to improve water quality of stormwater runoff before it enters the receiving body of water. This research study has three objectives, quantify the presence and concentration of selected contaminants in urban stormwater runoff from several urban locations within Lincoln, Nebraska, quantify the effectiveness of two, 10-year old bioretention cells, for reducing concentrations of contaminants in effluent and quantify the effectiveness of six rain gardens. These objectives will be met through statistical analysis, observations and comparison to other available research, data and literature.

One component of this research is the analysis of the “first flush” phenomenon or the increased pollutant load that is first detected in the stormwater runoff after periods of dry weather. Pollutant removal efficiency has been documented for bioretention cells and rain gardens under a variety of field conditions.

Introduction

Urbanization or the growth of urban areas characterized by increased population density and developed infrastructure; has led to concerns of the potential effects on water quality in nearby receiving bodies of water. It is projected that 3 billion people born over the next century will reside in urban areas; causing significant water quality issues such as increased nutrient and pathogenic loading (Zimmerman et al. 2008). In addition to water quality issues: loss of wetlands, riparian cover and increased sedimentation, are a result of urbanization, leading to increase flows and frequent flooding.

Urban Hydrologic Cycles vs. Predevelopment Hydrologic Cycles

Different watersheds have different hydrologic cycles that are dependent on the morphology of the watershed catchment area. Certain water movement mechanisms will have more influence than others. Two of the more common types of hydrological cycles, predevelopment and urban, can be seen below in Figure 1, showing the differences in water movement mechanisms.

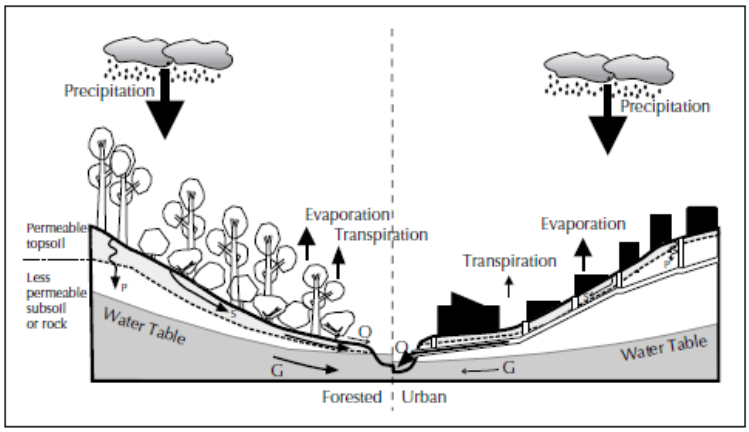

Figure 1 The water cycle in a predevelopment catchment and in an urbanized catchment with a conventional stormwater system (Walsh, et al., 2004)

In an urban watershed, high concentrations of impermeable surfaces such as roads and parking lots, coupled with few green spaces, shifts the primary water movement

mechanism to runoff with less evaporation, transpiration, and infiltration occurring. This shift in water movement mechanisms will cause the lag time (t_p) or time from the center of mass of rainfall excess to the peak of the hydrograph, to change significantly (Bedient et al. 2008). A longer lag time will allow more time for infiltration in the predevelopment watershed; during which, pollutants will be adsorbed to soil, taken up by vegetation or naturally dissipate. Pollutants in the urban watershed have little to no time to dissipate, be taken up by vegetation or adsorbed to sediment due to short periods of lag time and higher discharge intensity.

Urban Runoff

Urbanization, characterized by an increase in impermeable surfaces such as roadways and parking lots, leads to a shorter lag time and higher discharge intensity during a storm runoff event. This storm runoff, also known as urban runoff, is characterized by higher peak flow and shorter lag time compared to predevelopment runoff.

Increased overland flow, erosion rates, magnitude of flows and reduced lag times of peak flows are seen as environmental problems. Intense overland flow will contribute to land loss, greater susceptibility to floods, and flash floods will be more frequent as urbanization increases in an area (Walsh, et al., 2005). This change from gradual runoff, seen in a predevelopment cycle, to a fast runoff in an urban hydrologic cycle, has caused issues with water quality. For example, increasing urbanization has led to urban runoff containing pollutants from biological (E-coli, total fecal coliforms), chemical (pesticides, oil/grease, zinc, etc.) and physical (total suspended solids, total dissolved solids, etc.) sources (Houng & Davis, 2009).

Bioretention Cells

Definition

Bioretention cells came into practice from studies of agricultural and wastewater biological processes pollutant removal. Bioretention cells were designed to mimic agricultural and wastewater biological process of pollutant removal from water by implementing predevelopment hydrology with bioretention cells in urban areas (Prince George's County, 2007).

The term bioretention was defined in Maryland's Bioretention Manual as a terrestrial-based (upland as opposed to wetland), water quality and water quantity control practice using the chemical, biological, and physical properties of plants, microbes, and soils for removal of pollutants from stormwater runoff (Prince George's County, 2007). Bioretention cells typically consist of areas that are excavated and backfilled with a mixture of high-permeability soil and organic matter designed to maximize infiltration and vegetative growth and planted with native terrestrial vegetation (Roy-Poirier et al. 2010). Figure 2 shows the basic schematic of a bioretention cell. Bioretention cells have many different design standards and criteria based on what pollutants or volume of water the cell is intended to target (Hunt & Lord, 2006)

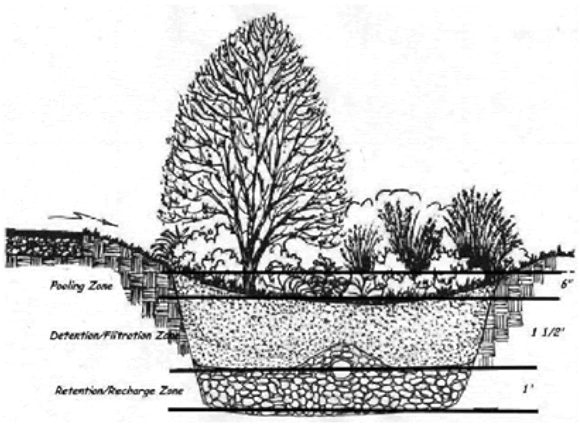

Figure 2 Bioretention Cell Basic Schematic (HydroCAD, 2015)

Design

Basic Construction

Bioretention cells consist of a constructed or natural depression filled with a heterogeneous soil media, designed to remove target pollutant(s). Several different species of water-tolerant flora are planted in the soil media and are used for water quality control practices that include biological, chemical and solids removal as well as erosion control (Prince George's County, 2007). As the runoff filters through the soil media in the bioretention cell, an underdrain consisting of either a single or multiple perforated pipe(s) collects the filtered runoff and transports it to a connected storm sewer. Generally, bioretention cells will not function properly if built in an area where the water table is within six feet from the ground surface as it creates a saturation zone in the bioretention cell preventing filtering of pollutants or storage of storm water (United States Environmental Protection Agency, September 1999).

Underdrain

A component of a bioretention cell is the underdrain, built into the bottom of the cell. Underdrains are designed to convey some of the ponded water in the bioretention cell to the stormwater sewer, while other water exfiltrates into the surrounding soil (Brown & Hunt, 2011). The underdrain of bioretention cell uses perforated pipes set in a gravel or sand/gravel mix to anchor them into place. The North Carolina Department of the Environment and Natural Resources recommends an underdrain system in bioretention cells built with soils that have infiltration rates less than two inches per hour (Prince George's County, 2007; North Carolina Department of Environment and Natural Resources, 2007). Other design manuals, such as Maryland’s, recommend that an underdrain have a hydraulic capacity greater than the bioretention soil infiltration rate

(Prince George's County, 2007). When an underdrain is installed, there should be no less than two feet between the bottom of the underdrain pipe and the groundwater table (Claytor & Schieler, 1996; North Carolina Department of Environment and Natural Resources, 2007). Some bioretention cells may not have an underdrain due to a lack of sewer system, as in rural communities; however, they should be built with an underdrain whenever it is possible or in areas prone to high drainage swell or volume (Prince George's County, 2007)

Soil Media/Filter

After the underdrain of a bioretention basin is installed, soil is placed on top. The reactivity of soil media is the primary mechanism for removing pollutants and pathogens and functions by having high permeability, providing adsorption of organic nitrogen and phosphorus, having a high porosity, and being suitable for water tolerant plants (Prince George's County, 2007; North Carolina Department of Environment and Natural Resources, 2007). The Maryland handbook for bioretention design identified as a general rule of thumb that the bioretention cell should be able to drain in less than forty eight (48) hours after the storm event has ceased (Prince George's County, 2007). Consensus on what type of soil media to be used differs as different bioretention cells may be designed for certain pollutants. Several studies or manuals have tested or recommended different types of bioretention cell soil media based on laboratory or field tests. These research studies will be explored in more detail in the Literature Review section.

Many states have their own bioretention design parameters. In Maryland, the bioretention manual recommends a composite mix of soil media consisting of 50% sand, 20-30% topsoil, and 20-30% leaf compost and detritus material. This recommendation allows the bioretention cell to handle storm water runoff volumes between one inch per

hour to ten inches per hour (Prince George's County, 2007). In North Carolina, soil specification for the bioretention cell consists of two layers. The first or planting layer should have a minimum of 10% organic material by dry weight, with a clay composition no more than 10 % (North Carolina Department of Environment and Natural Resources, 2007). The second or the filtration layer is to have 85% to 88% sand; 8% to 12% fines of silt or clay and 3% to 5% organic. North Carolina's recommended filter soil mixture can be adjusted to decrease permeability if the pollutant or pathogen loadings are too high

Vegetation

Vegetation is essential for a bioretention cell as it provides erosion control, evapotranspiration for additional removal of runoff, pollutant removal through phytoremediation/assimilation, and aesthetics to the surrounding area. A vegetated bioretention cell offers two mechanisms in improving storm water quality: interception or capture of sediments from runoff, and uptake of nutrients and other pollutants from runoff (Prince George's County, 2007). Selection of vegetation should consider the following conditions of the bioretention cell: soil moisture; pollutant loadings; above and below ground infrastructure both in and near the bioretention cell; and adjacent plant communities (North Carolina Department of Environment and Natural Resources, 2007). These considerations of the structure of the bioretention cell before selecting vegetation will help ensure that the vegetation can flourish under the bioretention cell conditions, so future maintenance and replanting are kept at a minimum. Bioretention cells should not harbor invasive species due to their rapid growth, encroachment on native plants and high maintenance costs (Department of Environmental Resources, 2007). In addition, overgrowth of invasive species can increase the ponding time of the stormwater runoff by

clogging the soil media with detritus, causing possible overflow of untreated stormwater effluent into the stormwater sewer.

Rain Gardens

Rain gardens are similar to bioretention cells in terms of functionality, as they are designed to mitigate runoff and pollutants. The main difference between a rain garden and a bioretention cell is rain gardens do not employ an underdrain connected to storm sewer, and let the ponded runoff recharge back into the ground. Rain gardens are built using an excavated lowered (depressed) area, used to pond 2-4 inches of runoff; this differs from bioretention cells using a soil media to mound the excavated area (Prince George's County, 2007). Flora tolerant of saturated conditions are planted in the bottom of the rain garden.

Pathways of Runoff

Runoff into bioretention cells can take many different pathways that can be broken down into primary and secondary pathways. Bioretention cells are usually constructed near areas of impervious pavement, such as roads or parking lots, which are characterized by high overland flow and little to no transpiration, evaporation or infiltration. These impermeable surfaces are characterized as primary runoff pathways as they have the shortest travel path of runoff into the bioretention cell. Secondary pathways include rooftops and residential home lawns. These secondary pathways have a greater travel time before reaching or combining with primary pathways to a bioretention cell.

First Flush of Runoff

Deposition of pollutants onto primary and secondary pathways into bioretention cells will occur during periods of no runoff between storm events. Pollutants such as litter and street dust accumulate on the surface due to urban activity (Novotny, 2008). The

amount of deposition will vary depending on the amount of time between storms. When runoff occurs, the first volume leaving the surface will have a higher portion of pollutants when compared to the pollutant load in the discharge at later times; a phenomenon known as the “first flush” (Novotny, 2008; Bertrand-Krajewski et al. 1998).

Performance of Bioretention Cells and Rain Gardens

Bioretention cells and rain gardens function properly in the ability to mitigate pollutants in stormwater runoff as well as the ability to pond stormwater runoff. A brief synopsis of field studies testing bioretention cells and rain gardens ability to mitigate pollutant and hydraulic performance is discussed in Chapter 2: Literature Review.

Pollutant Mitigation

Some field studies on the performance of rain gardens have shown some pollutant mitigation by comparing pollutant measurements found in the effluent against the influent. The pollutants tested in these studies for bioretention cells were: total phosphorus (TP), nitrate and total kjeldahl nitrogen (TKN). As of writing this paper, no peer reviewed field studies have tested rain gardens ability to mitigate zinc. Table 1 shows the amount of pollutant mitigation and methods used for calculating pollutant mitigation of selected pollutants between the influent and effluent in rain gardens field studies. The pollutant removal mitigation of rain gardens will be discussed more in detail in the section: Literature Review.

Table 1 Review of Pollutant Removal Efficiency of Rain Gardens

Contaminant	Pollutant Reduction (+) or Source (-)	Calculation of Pollutant Reduction and/or Source	Source
Total Phosphorus	60% to 80%	Mass removal rates of the influent and effluent	Komlos & Traver, 2012
	-110.60%	Difference between influent and effluent concentrations	Dietz & Clausen, 2005
Nitrate	35.40%	Difference between influent and effluent concentrations	Dietz & Clausen, 2005
TKN	31.20%	Difference between influent and effluent concentrations	Dietz & Clausen, 2005

Multiple field studies on the performance of bioretention cells have shown significant reduction in pollutants by comparing pollutant measurements found in the effluent against the influent. The pollutants tested in these studies for bioretention cells were: total suspended solids (TSS), total dissolved solids (TDS), TP, nitrate, zinc, selected pesticides, TKN, e-Coli and total fecal coliforms. As of writing this paper, no peer reviewed field studies have tested bioretention cells mitigation of the pollutants: conductivity and TDS, oil/grease. Table 2 shows the amount of pollutant mitigation and methods used for calculating pollutant mitigation of selected pollutants between the influent and effluent in bioretention cell field studies. The pollutant removal mitigation of bioretention cells will be discussed more in detail in the section: Literature Review.

Table 2 Review of Pollutant Removal Efficiency of Bioretention Cells

Contaminant	Pollutant Reduction (+) or Source (-)	Calculation of Pollutant Reduction and/or Source	Source
Total Phosphorus	34%	EMC of influent and effluent comparison	University of New Hampshire Stormwater Center, 2010
	-240% to 68%	Mass removal rates of the influent and effluent	Hunt, Jarrett, Smith, & Sharkey, 2006
	68%	EMC of influent and effluent comparison	Davis, 2007
	99%	Cumulative mass removal comparison of influent and effluent in limited storm events	DeBusk & Wynn, 2011
Nitrate	86%	EMC of influent and effluent comparison	Davis, 2007
TKN	45% to -4.9%	Mass removal rates of the influent and effluent	Hunt, Jarrett, Smith, & Sharkey, 2006
Zinc	63%	EMC of influent and effluent comparison	Davis, 2007
Pesticides	99% to 90%	Net mass removal of influent and effluent	Yang, Dick, McCoy, Phelan, & Grewal, 2013
TSS	97% to 87%	EMC of influent and effluent comparison	University of New Hampshire Stormwater Center, 2010
	41%	EMC of influent and effluent comparison	Davis, 2007
	99%	Cumulative mass removal comparison of influent and effluent	DeBusk & Wynn, 2011
Total Fecal Coliform/E-Coli	-92% to 89%	Mass removal rates of the influent and effluent	Hunt, Jarrett, Smith, & Sharkey, 2006

Hydrologic Performance

Very few studies have evaluated the hydrologic performance of a bioretention cells and rain gardens under different hydrological conditions (wet vs. dry periods) and in determining the pollutant removal efficiency. While proper soil media and vegetation selection for the targeted pollutants is essential, if the bioretention cell is not built

properly (i.e. sized for hydrologic conditions), the cell will fail both in pollutant removal and increased lag time.

Poorly constructed bioretention cells and rain gardens with improper consideration for infiltration rates, porosity, area of catchment and hydraulic conductivity can lead to unforeseen ecological conditions in the cell. A poorly designed cell with low porosity can lead to the creation of an anaerobic zone near the bottom that may result in decreasing the pollutant removal efficiency; particularly nitrate (Hunt et al. 2006).

Objectives

This research study has three objectives, quantify the presence and concentration of selected contaminants in urban stormwater runoff from several urban locations within Lincoln, Nebraska, quantify the effectiveness of two, 10-year old bioretention cells, for reducing concentrations of contaminants in effluent and quantify the effectiveness of six rain gardens.

Chapter 2 Literature Review Bioretention Cells

Abstract

Bioretention cells have different biological, chemical and physical mechanisms of pollutant removal, including sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage. Field studies observed total phosphorus, nitrate, TKN, zinc, pesticides, TSS, and total fecal/E.coli concentrations reduced in a bioretention cells' effluent when compared against the influent. Pollutants having high removal efficiency greater than 80% were pesticides, zinc, TSS and total fecal coliform/E.coli. Variation among the research studies testing nutrient pollutants total phosphorus, TKN and nitrate, saw disagreement for effective pollutant removal efficiency. Quantifying stormwater pollutant concentration explored various studies and reports, for rooftops, rainfall and pavement runoff for pesticides, TKN, zinc, TSS, total phosphorus and zinc in stormwater runoff. Rain gardens pollutant removal ability has been limited; nitrate and TKN showed some reduction, while total phosphorus acted as a source in the few studies completed.

Introduction

The literature review will explore aspects of bioretention cells including mechanisms associated with bioretention cells and rain gardens, documented pollutant removal/efficiency, and characterization of pollutant concentrations in urban stormwater runoff.

Mechanisms of Bioretention Cells

Bioretention cells remove pollutants through different physical, chemical and biological mechanisms. The primary mechanisms are sedimentation, adsorption,

filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage. These primary mechanisms can be sub-categorized into interception, infiltration, settling, evaporation, filtration, absorption, transpiration, evapotranspiration, assimilation, adsorption, nitrification, denitrification, thermal attenuation, volatilization, degradation, and decomposition (Prince George's County, 2007).

Hydraulic Performance of Bioretention Cells

Bioretention cell characteristics such as, pore space, saturation, and hydraulic conductivity, should be considered in pollutant removal as they affect the retention time of the ponded water. A greater retention time will increase the chance that the ponded stormwater held in the bioretention cell overtops and drains untreated into a stormwater sewer.

Initial pollutant removal efficiencies in bioretention cells degrade over time. To prevent degradation of the bioretention cell, regular maintenance is needed as a hydraulic design characteristic (North Carolina Department of Environment and Natural Resources, 2007). A study evaluated how a bioretention cell's pollutant removal degrades over time by testing a cell column under wet and dry conditions. When stressed between dry and wet conditions, the porosity of the cell column increased due to shrinking and swelling of the organic material and clay particles in the soil, causing the column to recover only a part of its original pollutant removal efficiency (Hatt et al. 2007). A similar study showed that bioretention cells that maintained a constant saturation zone had significant reduction in overflow events of untreated effluent (Dietz & Clausen, 2006).

Using built mesocosms or pilot bioretention cells, a study evaluated the effects of interception and vegetation on pollutant capture of different hydraulic properties (Lucas & Greenway, 2011). Each constructed cell had different soil media used; with one control

cell having no vegetation. The study showed cells with greater infiltration rates effectively intercepted stormwater runoff by minimizing the ponding time compared to reduced infiltration rates having poor interception. The study also showed that fewer clay aggregates in the soil media lead to greater soil infiltration rates causing better hydraulic performance in the bioretention cell.

Characterization of Urban Runoff Pollutant Concentration

Field studies measuring pollutant loads in stormwater runoff from different urban surfaces such as rooftop and parking lots, help establish background pollutant concentrations. Pollutants measured in this research and studies/surveys of pollutant loads in urban stormwater runoff; will then be compared against each other to gage how similar or dissimilar they are.

Rainfall

The United States Geological Survey (USGS) took pesticides measurements in rainfall in Nebraska from 2003 to 2004 (Vogel et al. 2008). The rainfall measured in the collected samples from three different sites in Nebraska and had 82 pesticides measured and compared with estimated application amounts in the watersheds at local, intermediate, and broad scales. Levels of wet deposition or the process, by which chemicals removed from the atmosphere and deposited on the surface via rain, sleet, snow, cloud water, and fog, was calculated. The study showed that wet deposition greatly affected pesticide levels measured in Nebraska; Figure 3 shows the different wet deposition flux seen from 2003 to 2004 for Nebraska, Maryland, Indiana and California. The study showed levels of atrazine, acetochlor, alachlor, metolachlor and trifluralin in Nebraska rainfall. Each of the five pesticides seen in the USGS study showed elevated

levels in the spring, gradually decreasing as the growing season progressed from spring to fall.

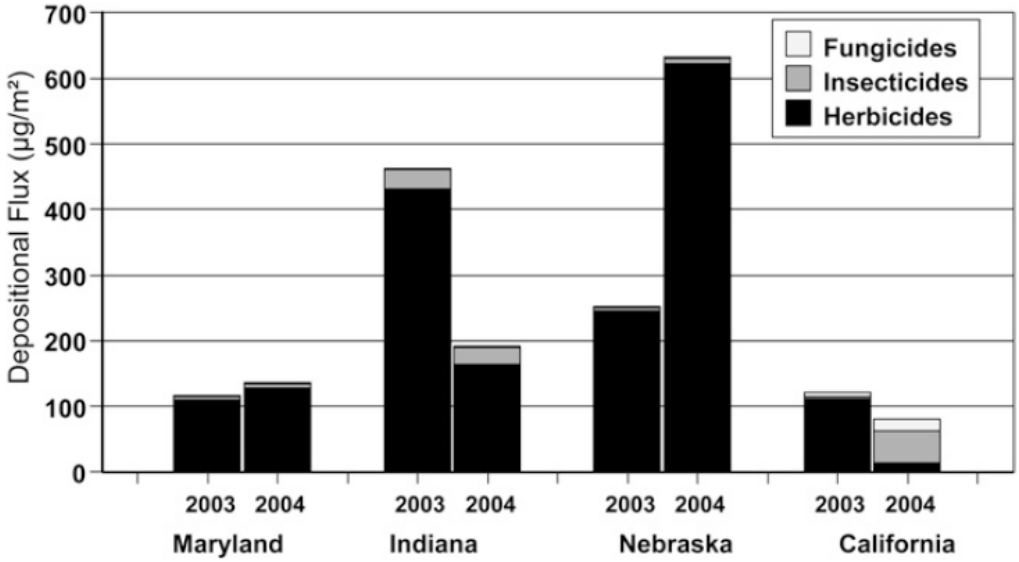

Figure 3 Total seasonal mass deposition of herbicides, insecticides, and fungicides in rain at the Maryland, Indiana, Nebraska, and California sites in 2003 and 2004 (Vogel et al. 2008)

Parking Lot

One field survey in Florida measured multiple pollutant loads from two asphalt parking lots (F1 and F2) with no best management practices implemented. Table 3 shows the pollutant measurements from samples collected from 30 storm events (Rushton, 2001).

Table 3 Average Runoff Concentrations of Selected Pollutants for Asphalt No Swale Parking Lots in Florida (Rushton, 2001)

Pollutant	Asphalt No Swale Parking Lots	
	F1	F2
Nitrate (mg/L)	0.273	0.278
Total Phosphorus (mg/L)	0.106	0.105
Zinc (µg/L)	45.7	43.8
TSS (mg/L)	11.24	13.45
TKN (mg/L)	0.556	0.548

A bioretention cell study monitored the water quality of runoff from a parking lot and going into a bioretention cell (DeBusk & Wynn, 2011). The study monitored the parking lot for 28 different storm events occurring from fall to spring. Influent into the bioretention cell from the parking lot had total phosphorus and TSS ranges from 0.59 to 1.2 mg/L and 25.8 to 77.0 mg/L respectively for all samples collected during the springtime sampling (March 21- June 22).

Another study observed TSS, total phosphorus, zinc, and nitrate in runoff from an asphalt parking lot over a 2-year study, Table 4 (Davis, 2007).

Table 4 Mean Concentration for Individual Storm Events for the Inflow into Two Bioretention Cells from Parking Lot Runoff (Davis, 2007)

Event Date	Pollutants			
	TSS (mg/L)	TP (mg/L)	Zinc (µg/L)	Nitrate (mg/L)
7/28/2003	24	3.84	190	0.07
8/5/2003	24	5.29	180	-
9/12/2003	13	0.31	120	-
4/26/2004	13	0.28	31	-
5/27/2004	46	0.92	104	-
6/17/2004	43	0.27	106	0.2
8/11/2004	50	0.9	62	-
8/21/2004	38	0.95	110	-
9/9/2004	100	0.82	160	-

Rooftop

A field study evaluated pollutant concentration for two residential asphalt shingled rooftops by collecting weekly composite samples from the end of a downspout off of each roof (Dietz & Clausen, 2005). Geometric means for nitrate, TKN and total phosphorus were 0.5 mg/L, 0.5 mg/L and 0.012 mg/L respectively.

Another study tested runoff from both a stone and asphalt roof during a one-year sampling period from spring to late summer, with 21 different samples from each rooftop

collected over the period (Carpenter & Kaluvakolanu, 2011). The stone roof had an average mean concentration for pollutants TSS, total phosphorus and nitrate of 152, 0.1 and 0.81 mg/L respectively. The asphalt roof had an average mean concentration for pollutants TSS, total phosphorus and nitrate measured of 108 mg/L, 0.19 mg/L and 0.37 mg/L respectively.

Experimental Findings on Bioretention Pollutant Reductions

Multiple pollutant removal performances of bioretention cells from field studies are previously listed in Chapter 1: Introduction. The pollutants tested in this research study will be the main pollutants when reviewing research on effectiveness of bioretention cells in improving water quality. Soil bioretention columns in laboratory studies not reviewed had factors not controlled in this research.

Nutrient Pollutants (Phosphorus/Nitrates/TKN)

Phosphorus and nitrates or nitrogen-producing compounds are primary pollutants of concern in stormwater runoff. Both considered a limiting nutrient for the growth of algae in receiving bodies of waters. Algae will exponentially grow when in contact with excess phosphorus and/or nitrates, severely depleting the amount of available dissolved oxygen in the waterway, creating eutrophic conditions. These highly eutrophic waterways can create ‘dead zones’ or places that do not support aquatic life due to insufficient dissolved oxygen.

Total Phosphorus

The greater the mobility that phosphorus has in the soil decreases the availability for vegetation as degradation time decreases (Hsieh et al. 2007). Phosphorus indices or P-index is a field-level assessment tool designed to evaluate the relative potential for off-site movement of phosphorus from the landscape (Natural Resources Conservation

Service, 2008). P-Index categorized into runoff classes, organic phosphorus source, etc.; these factors are weighted against each other in determining the P-Index level for the soil. A numerical value given to P-indices to show transport efficiency of phosphorus, high values greater than 100 have significant transport capabilities, while values less than 5 have little to no transport.

A field study done by the University of New Hampshire Stormwater Center evaluated a bioretention cell located at an end-of-pipe treatment, with a mixed soil media having approximately 3% organic matter (University of New Hampshire Stormwater Center, 2010). Over the two-year study, the influent compared against the effluent showed an average 34% reduction in total phosphorus removal from the bioretention cell.

Another field study done by the University of North Carolina at Chapel Hill and North Carolina Agricultural and Technical State University, evaluated six bioretention cells, with different P-indices of the bioretention cell media, finding a direct correlation between P-index levels and total phosphorus removal. Bioretention cells with a P-index ranging from 86-100 had an increase of -240% in total phosphorus concentrations in the effluent compared to levels found in the influent (Hunt, Jarrett, Smith, & Sharkey, 2006). Soil media with a P-index ranging from 1-14 showed a 64% to 68% reduction in total phosphorus concentrations in the effluent compared to levels found in the influent.

A field study in Maryland evaluated the effectiveness of pollutant removal from bioretention cells using two different soil media composition for total phosphorus removal (Davis, 2007). Each of the cells had a soil mix of 50% sand, 30% topsoil and 20% mulch; which were similar to the soil composition of the bioretention cells used in this research study. Samples of the influent and effluent were taken from the bioretention

cells for two years and the event mean concentration (EMC) was calculated from each storm event found total phosphorus had a mean reduction of 68%.

A field study in Virginia evaluated pollutant removal by monitoring total phosphorus in the influent and effluent of the bioretention cell (DeBusk & Wynn, 2011). The bioretention cell had a designed soil media mixture of 88% medium sand, 8% clay and silt and 4% leaf compost. The sum of each pollutant concentrations for the influent against all the effluent, determined the pollutant removal. A measured total phosphorus reduction in the study was 99% when using the cumulative comparison.

Nitrate

Unlike phosphorus; which interacts with the bioretention soil media through adsorption by cation exchange capacity (CEC), nitrate is marginally held in bioretention soil media due to its high mobility in soils by being an anion and will not adsorb readily to soil media (Hsieh et al. 2007b). Because of this minimal adsorption capability, nitrate requires a much longer retention than phosphorus to degrade when interacting with a soil media (Stevenson, 1986).

Nitrification, or when bacteria oxidize ammonia and ammonium ions to form nitrates, occurs in bioretention cell and nitrates being produced are highly soluble which is readily untaken by plants (Prince George's County, 2007). Reduction of nitrates occurs through denitrification, or the reduction of nitrates into nitrous oxides and nitrogen gas, when soil conditions contain low oxygen, high temperatures and organic matter.

The study in Maryland evaluated the effectiveness of bioretention cells pollutant removal abilities as described in section: Experimental Findings on Bioretention Pollutant Reductions, subsection: Total phosphorus, took nitrate measurements and compared the percent reduction of the EMC against the influent and effluent (Davis, 2007). The study

found an average 86% reduction in nitrate concentration when comparing the influent and effluent.

Total Kjeldahl Nitrogen (TKN)

TKN is the total measure of the organic and ammonia nitrogen in the water (Davis & Masten, 2004). A study in North Carolina, as described in section: Experimental Findings on Bioretention Pollutant Reductions, subsection: Total Phosphorus, examined for pollutant removal abilities, which included TKN. Two of the bioretention cells built with 1.2 m soil media aerobic zone, while a third cell had internal water storage (IWS) (Hunt et al. 2006). TKN removal for the two identical bioretention cells to be 4.9%, while in cell G2 showed the cell as a source of TKN as concentrations rose by 45% in the effluent. The IWS bioretention cell found no statistical impact on TKN removal.

Oil and Grease

Quantifying the toxicity of oil and grease products is difficult due to the varying degrees of toxicity, solubility, volatility, and degradation found in different compounds (United States Environmental Protection Agency, 1986; Irwin et al. 1997). Oil and grease have carcinogenic compounds that bio accumulate in species, causing ecological damages. As of researching this paper, no field studies have been completed testing oil/grease removal via bioretention cells.

Zinc

Zinc's toxicity changes when in different water qualities. Water quality properties such as, calcium, magnesium, hardness, pH, and ionic strength; affect the toxicity of zinc by influencing the proportion or inhibiting the sorption of available zinc (United States Environmental Protection Agency, 1980).

The study in Maryland that evaluated the pollutant removal of bioretention cells described in section: Experimental Findings on Bioretention Pollutant Reductions, subsection: Total Phosphorus, took zinc measurements and compared the percent reduction of the EMC by comparing the influent and effluent (Davis, 2007). The study found an average 63% reduction in zinc concentration when comparing the influent and effluent.

Pesticides

When pesticides are applied, a phenomenon called vapor drift occurs or pesticides volatilizing from agricultural fields, transported and deposited onto surrounding areas via atmospheric forces (Bedos et al. 2002). As much as 50% of applied pesticides may volatilize by mass and subject to vapor drift with instances of 99% pesticide deposition occurring (Davie-Martin et al. 2012). Chronic and acute health complications in humans occur when exposed to pesticides (United States Environmental Protection Agency, 2009). Ecological exposure to pesticides cause's photosynthesis disruptions, bioaccumulation toxicity, etc. Species affected by pesticide exposure, have been documented by the USEPA in their ecotoxicology database or ECOTX (USEPA, 2014).

Twenty-one different pesticides; commonly used in Nebraska, were tested for this research. A profile of each pesticide tested in the research with information including, toxicity to humans, carcinogenic effects, toxicity to the ecosystem and half-life degradation of the pesticide, seen in Appendix A Pesticide Profiles, Table 26, Table 27 and Table 28.

Biphasic rain gardens or hybrid bioretention cells have shown pesticide removal from stormwater runoff. A biphasic rain garden has stormwater runoff going through a saturated (anaerobic) and unsaturated (aerobic) zone before exiting (Yang et al. 2013).

Biphasic rain gardens have an underdrain like bioretention cells as well as similar soil media. Figure 4 shows the configuration of a biphasic rain garden with all of the components explained in three subfigures showing a picture of a site (a), an isometric view of the zones associated with the biphasic rain garden (b), and an overhead and side view of biphasic rain garden (c).

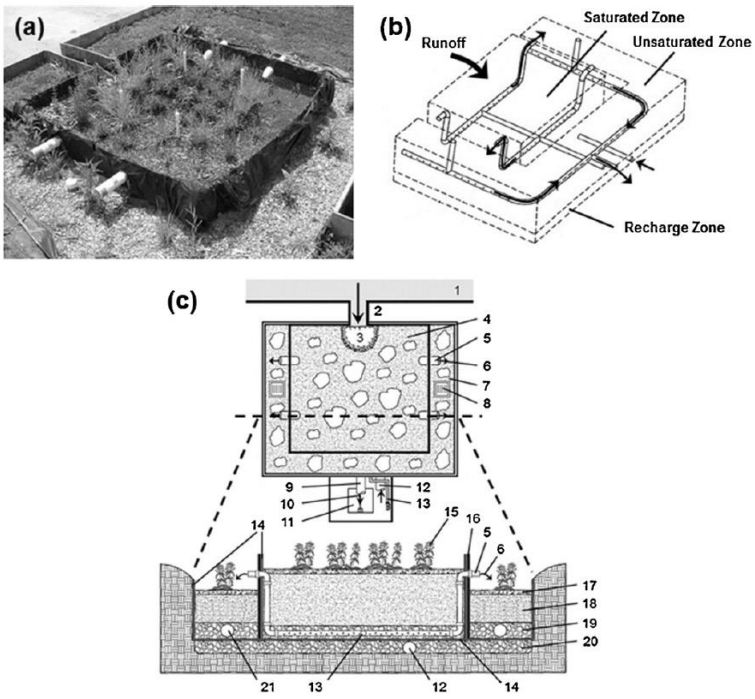

Figure 4 Biphasic Rain Garden Configuration and Explanation of Components Adapted from Yang et al. 2013

A field study of biphasic rain gardens evaluated pesticide removal efficiency (Yang et al. 2013). Using two identically constructed biphasic rain gardens and comparing influent and the effluent concentrations, both showed a 90% reduction for atrazine.

Total Suspended Solids (TSS)

TSS comprises of both organic and inorganic components by measuring the turbidity or the measure of the clarity of water by the amount and volume of suspended

materials (United States Environmental Protection Agency, 2014). Water having high levels of TSS, have low concentrations of dissolved oxygen due to particulates absorbing more UV radiation, causing eutrophic conditions. TSS also harbors pathogenic microorganisms such as E. coli that uses it as a growth medium (Davis & Masten, 2004).

The University of New Hampshire's Stormwater Center that evaluated bioretention cells pollutant removal ability in a field study, explained in section: Experimental Findings on Bioretention Pollutant Reductions subsection: Total Phosphorus, also measured TSS. The study showed higher TSS removal rate for bioretention cells having a greater soil media depth when comparing concentrations of the influent against the effluent (University of New Hampshire Stormwater Center, 2010). The TSS removal from a bioretention cell with 48 inches of soil media showed a 97% reduction, while only 30 inches of soil media had an 87% reduction.

The study in Maryland that evaluated bioretention cells pollutant removal ability described in section: Experimental Findings on Bioretention Pollutant Reductions subsection: Total Phosphorus, also measured TSS and compared the EMC of the influent and effluent against each other (Davis, 2007). The study found an average 41% reduction in TSS when comparing the influent and effluent.

The study in Virginia evaluated the bioretention cells pollutant removal ability described in section: Experimental Findings on Bioretention Pollutant Reductions, subsection: Total Phosphorus, measured TSS by comparing a cumulative influent concentration against the effluent for three storms (DeBusk & Wynn, 2011). The study showed a 99% reduction in TSS concentration using cumulative comparison.

Total Dissolved Solids (TDS)

TDS are particulates in the water that are able to pass through a filter that have a pore diameter of 2 microns or 0.002 cm (United States Environmental Protection Agency, 2014). TDS is associated with dissolved ions from other pollutants such as total phosphorus, nitrates, etc. As of researching this paper, no field studies have been completed testing TDS pollutant removal via bioretention.

Conductivity

Conductivity is the measure of the waters ability to pass an electrical current through it (United States Environmental Protection Agency, 2014). The presence of inorganic dissolved solid ions carrying a negative charge affected the level of conductivity. These conductivity ions may include other pollutant compounds such as chloride, nitrates, and phosphates and used as an indicator pollutant for water quality. As of researching this paper, no field studies have been completed testing conductivity pollutant removal via bioretention.

Total Fecal Coliforms/E.coli

Water bodies naturally contain bacteria and viruses some of which are harmful to humans. Compiled by the EPA; Table 5, Table 6 and Table 7, show different known pathogens found in water affecting human health for bacteria, protozoans and viruses.

Table 5 Pathogenic bacteria of concern to water quality and their associated diseases (United States Environmental Protection Agency, 2001)

Bacteria	Disease	Effects
Escherichia coli 0157:H7 (enteropathogenic)	Gastroenteritis	Vomiting, diarrhea
Salmonella typhi	Typhoid fever	High fever, diarrhea, ulceration of the small intestine
Salmonella	Salmonellosis	Diarrhea, dehydration
Shigella	Shigellosis	Bacillary dysentery
Vibrio cholerae	Cholera	Extremely heavy diarrhea, dehydration
Yersinia enterolitica	Yersinosis	Diarrhea

Table 6 Protozoans of concern to water quality and their associated diseases (United States Environmental Protection Agency, 2001)

Bacteria	Disease	Effects
Balantidium coli	Balantidiasis	Diarrhea, dysentery
Cryptosporidium	Cryptosporidiosis	Diarrhea, death in susceptible populations
Entamoeba histolytica	Amebiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion

Table 7 Viruses of concern to water quality and their associated diseases (United States Environmental Protection Agency, 2001)

Bacteria	Disease	Effects
Adenovirus (48 serotypes; types 40 and 41 are of primary concern)	Respiratory disease, gastroenteritis	Various effects
Enterovirus (68 types, e.g., polio, echo, encephalitis, conjunctivitis, and Coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis	Various effects
Hepatitis A	Infectious hepatitis	Jaundice, fever
Reovirus	Gastroenteritis	Vomiting, diarrhea
Rotavirus	Gastroenteritis	Vomiting, diarrhea
Calicivirus (e.g., Norwalklike and Sapporo-like viruses)	Gastroenteritis	Vomiting, diarrhea
Astrovirus	Gastroenteritis	Vomiting, diarrhea

Estimations of harmful microorganisms in the water can be determined through measurements of total fecal coliforms. Total E.coli is an indicator organism or nonpathogenic bacteria that are associated with pathogens transmitted by fecal contamination (United States Environmental Protection Agency, 2001). For this research, total fecal coliform/E.coli is measured. Figure 5 shows the hierarchy between total coliforms, total fecal coliforms and total E.coli.

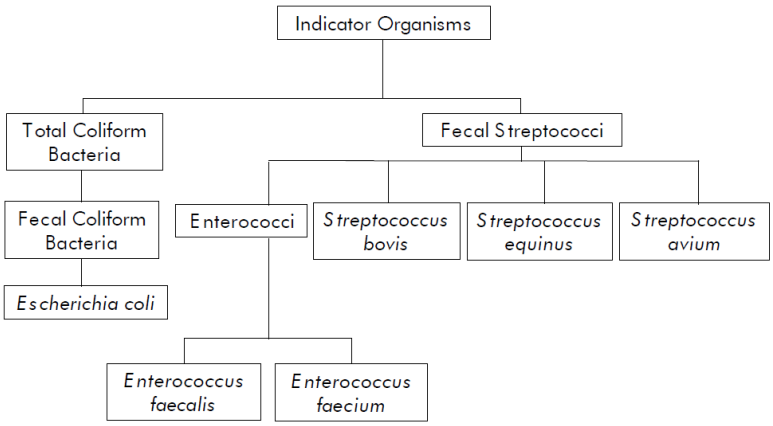

Figure 5 Relationships among indicator organisms (United States Environmental Protection Agency, 2001)

A field study in Charlotte North Carolina evaluated the total fecal coliform/E.coli removal efficiencies of bioretention cells. Comparing the influent against the effluent the bioretention cell found to have an 89% and 92% reduction respectively (Hathaway et al. 2009).

Rain Gardens

Rain gardens are a constructed depression near a downspout of a rooftop with a berm placed around the depression needed with various types of water tolerant flora planted in the depression (Prince George's County, 2007). Rain gardens function similarly to bioretention cells, the main difference being bioretention cells have an underdrain.

A field study of rain gardens, evaluated pollutant removal from urban stormwater runoff completed at Villanova University. The rain garden had a sample access box installed below berm to draw effluent samples at five different locations, while comparing them to ponded influent samples (Komlos & Traver, 2012). The study showed an 85% reduction in total phosphorus between influent and effluent samples taken.

A field study evaluated two rain gardens pollutant removal ability by comparing nutrients found in residential roof and percolated/overflow runoff from rain gardens. Figure 6 shows a cross sectional setup of the rain garden and its collection system used in the research study (Dietz & Clausen, 2005).

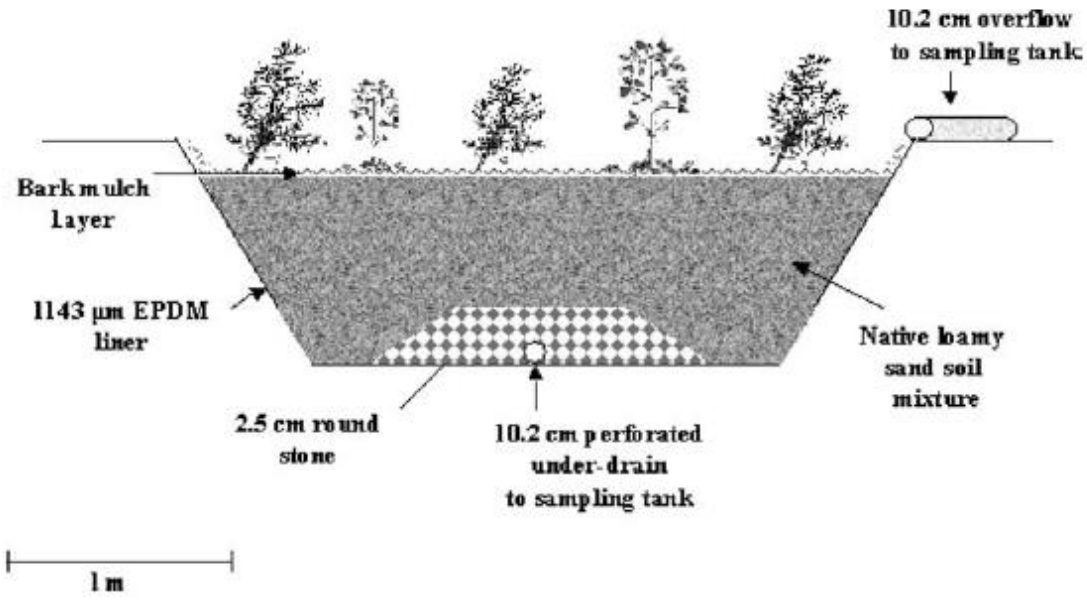

Figure 6 Cross Section of Rain Garden (Dietz & Clausen, 2005)

47 sample events were taken from both the rooftop and the rain gardens over the course of two years and compared against the mass pollutant retained by the rain garden; results showed that nitrate, TKN and total phosphorus had a reduction or source of 35.4%, 31.2% and -110.6% respectively (Dietz & Clausen, 2005).

Summary

Bioretention cells having pollutants found in stormwater runoff with high removal efficiencies greater than 80% were pesticides, zinc, TSS and total fecal coliform and total E.coli. Variations between the research studies testing nutrient pollutants total phosphorus and nitrate, showed multiple disagreements in the pollutant removal efficiency. Additional bioretention cells and rain gardens in field studies research is needed measuring pollutant removal for TDS, TSS, oil/grease and conductivity.

Pollutant concentrations saw measurable levels in rainfall for pesticides' atrazine, acetochlor, alachlor, meolachlor and trifluralin that changed seasonally in Nebraska. Different parking lot runoff studies showed similar nitrate, total phosphorus, zinc, TKN and TSS concentrations. Commercial and residential rooftops studies showed similar concentrations for TKN, nitrate, total phosphorus and TSS.

Rain gardens ability to mitigate pollutants in stormwater runoff has seen some pollutants. In the few studies that have been done, nitrate and TKN have been reduced, while total phosphorus is conflicted as some studies have shown reduction of total phosphorus in the effluent while others have seen total phosphorus acting as a source.

Chapter 3 Methodology

Abstract

The primary research sites were two bioretention cells using automated samplers collecting grab samples of stormwater runoff influent and effluent for at least six precipitation events during a two-year period. The bioretention cell sites were located in parking lots near the corner of 63rd Street and Platte Avenue in Lincoln, Nebraska. Two automated samplers were installed at each site with different programming schema suited to the sites. Additional research included samplers for two rainfall, six rain garden, two commercial rooftop, two commercial parking lot, and six residential rooftop sites.

Sample Collection and Preservation

Samples needed to be collected and preserved within 24 hours after the conclusion of a rainfall event. Samples were collected in a glass container that was properly cleaned. Stored samples were either refrigerated or frozen depending on the pollutant analysis type. Table 8 shows a breakdown of sample collection detailing container type, minimum sample quantity, sample type, preservation used, and maximum holding time for each of the tested contaminants.

Cleaning of the glassware ensured no residual pollutants or foreign substances contaminating the samples. All glass containers were cleaned in a 0.2 mole Citronox solution three times, then rinsed with distilled water three times. The glass containers were aired dried for at least four hours before being fired in a kiln set to 600 degrees Fahrenheit for at least four hours. Cleaned and fired glassware were covered with aluminum foil to prevent any debris from falling in until the glassware was used for sample collection. All lids were washed three times in a 0.2 mole Citronox solution then rinsed in distilled water three times before being air dried for at least four hours.

Samples were preserved with either nitric acid (HNO_3), sulfuric acid (H_2SO_4) or no preservative, depending on the pollutant analysis. The sample container was gently shaken for approximately thirty seconds to ensure that the sample was completely mixed. Sample preparation and storage took place at the Water Science Laboratory (WSL) at the University of Nebraska-Lincoln, Lincoln, Nebraska. Upon arrival, samples were divided and preserved, then placed into storage until analyses could be completed. Samples were voided if samples were held over their maximum allowable holding time. Table 8 shows the amount of preservative needed, maximum holding time and minimum sample amount required.

Table 8 Sample Handling and Preservation Protocol

Pollutant	Minimum Sample Quantity (mL)	Preservation	Maximum Holding Time
Total Kjeldahl Nitrogen (TKN)	250	Add H_2SO_4 to pH<2 Refrigerate 4ºC	28 days
		Freeze	6 months
Nitrate-N	100	Add H_2SO_4 to pH<2 Refrigerate 4ºC	28 days
		Freeze	6 months
Phosphorus, Total	100	Add H_2SO_4 to pH<2 Refrigerate 4ºC	28 days
		Freeze	6 months
Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)	250	Refrigerate 4ºC	28 days
Conductivity	100	Refrigerate 4ºC	28 days
Selected Metals (Zn)	100	Add HNO_3 to pH<2 Refrigerate at 4ºC	6 months
Oil and Grease	500	Add H_2SO_4 to pH<2 Refrigerate 4ºC	28 days
Total and Fecal Coliforms	200	Refrigerate 4ºC	24 hr.
Pesticides	500	Refrigerate at 4ºC	28 days

Main analysis of the pollutants excluding total fecal coliform and total E.coli was completed at the Water Science Lab (WSL) at the University of Nebraska-Lincoln. Total fecal coliform and total E.coli analysis was completed by the United States Department of Agriculture, Agriculture Research Service, Agro Ecosystems Management Research Unit Laboratory located at the Plant Science Hall room 138, at the University of Nebraska-Lincoln. Analytical methods used to measure pollutants in samples are summarized in Table 9.Table 9 Analytical Sample Methods Used for Analysis

Contaminant	Test Method	Units
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	mg/L
Nitrate Nitrogen	EPA 353.2	mg/L
Total Phosphorus (TP)	EPA 365.1	mg/L
Total Suspended Solids (TSS)	SM2540C	mg/L
Total Dissolved Solids (TDS)	Method 2540C	mg/L
Conductivity	Method 2510B	µS/cm
Selected Metals (zinc)	EPA 200.8	µg/L
Oil and Grease	EPA 1664	mg/L
Total Coliform Bacteria	Method SM9223	mpn/100 mL
Total E.coli Bacteria	Method SM9223	mpn/100 mL
Pesticides	NE Pesticide Scan	µg/L

Constraints/Limitations

Sample collection did not occur with snow or frost on the ground. Sample collection was not completed in the event of continuing lightning, hail or tornado in the immediate area, to ensure the safety of the person(s) collecting the sample were not compromised or placed in a situation that could potentially inflict bodily harm. Each sample had a minimum volume pre-determined for different pollutant tests run on the sample. Samples were voided if not enough volume is collected. Samples were not collected if the site was observed or suspected of being disturbed. Table 10 shows the five different types of sampling sites with pollutants to be analyzed and the minimum volume of sample needed to complete all of the tests.

Table 10 Minimum Volume of Sample Needed for Selected Sites

Sampling Site	Contaminants Tested	Minimum Sample Volume (mL)
Parking Lot	TKN, Nitrate, Total Phosphorus, TSS, TDS, Conductivity, Zinc, Oil/Grease	1650
Rainfall	TKN, Nitrate, Total Phosphorus, Conductivity, and Pesticides	1050
Bioretention Cell	TKN, Nitrate, Total Phosphorus, TSS, TDS, Conductivity, Zinc, Oil/Grease, Coliforms, E. coli, and Pesticides	2350
Rain Garden and Roof Runoff	TKN, Nitrate, Total Phosphorus, - Zinc, Coliforms, E. coli,	750

Bioretention Cells

Site Selection

The two bioretention cells used in the study were located adjacent to different parking lots near the corner of 63rd Street and Platte Avenue in the Havelock area of Lincoln, Nebraska. These cells are referred to as "large" and "small." Each cell was selected because it was constructed in June of 2005 establishing vegetated growth and provided easy access for sample collection. The large bioretention cell had approximately 800 square feet of surface area, while the small bioretention cell had approximately 500 square feet. Each cell had a soil mixture of about 50% compost, 40% sand and 10% topsoil. The large bioretention cell had a depth of 24 inches from the surface to the underdrain, while the small bioretention cell had a depth of 18 inches to the underdrain from the surface. Vegetation planted for both bioretention cells during initial construction has since been harvested, replanted, or replaced with different vegetation. The city of Lincoln confirmed no fertilizer has or was applied to the bioretention cells since being constructed. The large bioretention cell only had parking lot runoff contribution, while the small bioretention cell had parking lot and rooftop runoff

contributions. Both experienced light traffic on the parking lots during the mornings and afternoons during the weekdays and moderate to heavy traffic during the weekends and evenings. Figure 41 and Figure 42 in Appendix B Design Drawings and Figures, show the large and small bioretention design plans respectively.

Site Survey

A total station survey was used to determine the parking lot contributing area for each cell, while satellite imagery was used to estimate rooftop areas. The survey was completed between August 1, 2013 and August 10, 2013. The total stations recorded elevation at a unique parking lot point and using the graphing software SURFER 10.0, all points were gridded using the kriging method and mapped for each cell. The size of the contributing area of the parking lot and the cells was then determined manually using the produced contour map and had the area calculated from it. Figure 55 and Figure 56 in Appendix G Design Drawings and Figures, show the parking lot areas contributing to the large and small bioretention cell, respectively with the contributing area outlined in blue, data points as green crosses and the bioretention cell outlined in magenta. The tabulated area of stormwater contribution to both the large and small bioretention cell can be seen in Table 11, with significant digits to the 10th foot.

Table 11 Stormwater Area of Contribution Bioretention (Large and Small)

Bioretention Cell	Parking Lot Size* (ft^2)	Bioretention Cell* Size (ft^2)	Rooftop** (Estimated) (ft^2)	Total*** Contributing Area
Large Bioretention Cell	19,450	800	-	20,250
Small Bioretention Cell	24,620	500	17,530	42,150

**Calculated using SURFER 10.0*

***Estimated from Satellite Imagery*

****Total Contributing Area=Column 2+Column 4*

Design

The primary means of sampling influent and effluent for each of the two bioretention cells was ISCO Series 6700: Automated Samplers (Teledyne Isco, 2011). These samplers were chosen for their ability to sample at different times during a runoff event and securely store the influent/effluent samples. The samplers were triggered by liquid detection or depth probe programmed into the samplers. Before programming the four samplers (two for each cell), a diagnostic test was performed to ensure the samplers were operating within normal bounds before being placed in the field. Table 29 and Table 30 in Appendix C , lists each of the diagnostic tests along with a brief explanation of the test and normal operating bounds for the four ISCO samplers used as well as serial numbers for each, all samplers used in the research study passed the diagnostic test. Each of the ISCO samplers had unique programming for the influent and effluent, tailored to the bioretention cell site. Each component of the ISCO programming is explained in Table 31 and Table 32 in Appendix C .

Large Bioretention Cell Sampling

Influent collection used an ISCO liquid level actuator series 1640 as the sample collection triggering mechanism. The liquid actuator triggers the sampling program as soon as it detects water though the probe. The 1640 liquid level actuator was set to "latch," meaning once the water is detected, the sampler will continue sampling even if water is not touching the liquid actuator (Teledyne ISCO, 2008). Once the liquid actuator initialized the program for the large bioretention cell influent, 3.6 liters of sample was collected every 15 minutes, resulting in three unique samples for each storm runoff event.

Effluent collection used ISCO series 720 submerged probes as the triggering mechanism. After detecting a water level depth of 3 inches using the submerged probe,

3.6 liters of sample was collected every 10 minutes, resulting in three unique samples for each runoff event. Details of the programming for influent and effluent sampling of the large bioretention cell can be seen in Table 33 in Appendix C .

Small Bioretention Cell Sampling

Influent collection used an ISCO series 720 submerged probe, while the effluent used the 1640 liquid level actuator, set to "latch" as explained in the previous subsection, Large Bioretention Cell Sampling. Once the program for the small bioretention cell influent was initialized after detecting a water level depth of 3.6 inches using the ISCO module series 720 probe, 3.6 liters of sample was collected every 15 minutes, resulting in three unique samples for each storm runoff event. After the effluent was detected in the liquid actuator, 3.6 liters of sample was collected every 10 minutes, resulting in three unique samples for each storm runoff even. Details of the programming in the influent and effluent of the small bioretention cell can be seen in Table 34, Appendix C .

Construction and Site Setup

Locked metal storage boxes, two at each of the bioretention cells, were used to house the ISCO samplers. The metal storage boxes contained a car battery along with various cable and tubing connections to the sampler. Batteries and connection cables were regularly checked in order to maintain the workings of each bioretention cell site. Figure 7 shows a metal storage box with the sampler and all supporting equipment in it.

Figure 7 Locked Metal Storage Box with ISCO Sampler and Components

A mesh strainer sampling probe was attached at the end of the sampling tube at each of the bioretention sites for both the influent and effluent. The mesh strainer provided preliminary screening of the runoff water, by blocking the suction of large debris and grit that could potentially damage the samplers' pumps. Figure 2 shows the typical mesh strainer used for all cell sampling sites.

Figure 8 Stainless Steel and Polypropylene Mesh Strainer (Teledyne ISCO, 2014)

Large Bioretention Cell Construction and Site Setup

The influent sampling location was set up at the west side of the bioretention cell at a curb cut. The curb cut, located at the edge of the bioretention cell, allowed stormwater runoff to flow into the bioretention cell. Only one curb cut was used for sampling while all other curb cuts adjacent to the one used for the influent sampling had 70 lb. sand bags placed in front of the adjacent curbs to divert runoff flow into the influent sampling location. Figure 9 shows two sand bags blocking a curb cut on the right hand side, diverting the flow into the sampling trench located on the left hand side.

Figure 9 Sand Bags Blocking Curb Cuts for Large Bioretention Cell

In order to collect a sufficient sample size while maintaining the first flush, a small trench was dug, lined with landscape fabric. A 10-foot long PVC drainage pipe, 4 inches in diameter, was placed at the top of the trench at the same elevation of the parking lot and partially buried. As the trench fills up and before it reaches the drainage pipe, any additional runoff with be sent away via the drainage pipe, this minimized mixing and preserve the first flush. A liquid actuator and 25 feet of polyethylene tubing was connected to the ISCO sampler, with a meshed sampling strainer placed at the end of the sampler tubing. Figure 10 shows the large bioretention cell sampler setup for the influent location of the cell.

Figure 10 Large Bioretention Cell Influent Sampler Setup

The location of the effluent was in a stormwater junction box with a beehive cover or a mesh grate box to prevent large debris from entering it. The effluent pipe was located about one foot above the bottom of the junction box. Sampling from the bottom of the junction box after a runoff event would be insufficient, as mixing of runoff from the effluent pipe, overland flow and main stormwater sewer pipe could possibly occur. A 90-degree elbow was installed at the end of the effluent pipe that elevated the effluent pipe outlet an additional 6 inches. The elbow allowed the effluent sample to be collected due to ponding in the elbow. Installing the elbow at the end of the effluent pipe did not alter the cells properties/mechanisms and was open to the atmosphere, eliminating any pressurized flow that may occur.

Possible cross contamination of the effluent could also occur from rising water levels in the junction box due to an influx of runoff volume from the street. A water level logger was installed in the junction box to monitor and measure the height of the water in the junction box. If the height of the water recorded, overtopped the height of the elbow

joint at the effluent sample location, the sample collected was voided. If the effluent level was greater than 3 inches, sampling was trigged and a sample was collected at 10-minute increments. Figure 11 shows the setup of the large bioretention cell at the junction box with the effluent riser and the water level logger.

Figure 11 Large Bioretention Cell Effluent Sampling Setup, Effluent Joint Riser and Water Level Logger

An ISCO series 674 automatic rain gage was installed at the site and connected to the influent ISCO sampler for only the large bioretention cell. The rain gage helped assure that the sampler collected precipitation runoff and not extraneous runoff that may occur at the site from a breakdown of public utilities or other unknown sources.

Small Bioretention Cell Construction and Site Setup

A stormwater junction box located toward the north end of the cell housed three pipes; two of the pipes were connected to the underlying pipe network of the cell and the third was connected to the main stormwater sewer. All three pipes in the junction box where at the same level. The junction box had a beehive cover to prevent large objects from falling into it while allowing runoff to flow freely into it. The cell had a pipe

maintenance access point on the southeast corner of the cell. This access point allowed cleanout of the underlying pipe network.

Large deep channels in the cell were observed and was inferred that large and fast amounts of runoff were occurring. This inference was also supported by large amounts of sediment and debris deposited at the curb cuts inflows, indicating ponding around the outside of the cell. Observations during a rainstorm noted the cell could not handle large volumes of water as runoff traversed the cell quickly and emptied into the junction box, resulting in mixing of the influent and effluent.

Two 4-inch flexible rubber caps were placed on effluent pipes in the junction box to prevent mixing of the influent and effluent, allowing collection of influent. The third pipe leading to the main storm drain was left open to allow proper drainage. If the influent water level is greater than 3.6 inches, sampling was triggered as described in the previous section. Figure 12 shows the setup of the cell influent sampling in the junction box with one of the rubber caps and connection to the main storm water line.

Figure 12 Small Bioretention Cell Influent Set Up

The pipe maintenance access point, located in the southeast corner of the cell was used as the effluent sampling location. As the effluent accumulates in the pipe due to the pipe being capped, the water level will rise up and gather enough to pull a sample. A liquid actuator; explained previously, was placed above the bend in the pipe and triggered sampling as explained previously.

Site Collection and Observation

Cells having only an influent or effluent collected; were voided as pollutant comparison between them could not be completed. Cells collecting both an influent and effluent were labeled, stored on ice, before being transported to the lab for further preservation and analysis. Any large debris that has been collected around the beehive cover over the junction box is removed. Any equipment experiencing contamination or dislodgement, appropriate steps were taken to correct the equipment and/or problem. Each of the rubber caps in the small bioretention cell were removed and remaining effluent is discharged. The ISCO samplers were then reset and awaited the next runoff sample event to occur. During the first season/year of sampling, 2013, the small bioretention cell did not have much success collecting effluent samples.

Rainfall

Site Selection

Each rainfall site must be away from any large building to remove any hindrance of any sample collection, be on opposite sides of the city of Lincoln and owner of the property must give consent. Two sites selected that fit all of the criteria were the City of Lincoln Municipality Baldwin Yard located at the corner of Baldwin Avenue and Griffith Street, Lincoln, Ne 68504 and Lincoln Fire Department, Fire Station Number 12, located at South 84th Street, Lincoln, NE 68506.

Design

Rainfall samplers were designed with the criteria that sampling might occur during a drought period, leading to the rainfall sampler having maximum surface area. A 55 gallon plastic deer feed funnel with a 22 ½ inch diameter was selected for collecting rainfall with a surface area of 256,520.7 mm^2 and a collection of 4,267 mL. A 1-gallon carboy was selected to hold the rainfall until collected. Two samplers were constructed and placed at each rainfall sampler if one of the samplers should fail to collect rainfall due to unforeseen circumstances. Table 12 summarizes the values of the sizing as mentioned in this section.

Table 12 Rainfall Collector Sizing

Rainfall Collector Sizing		
Parameter	**Value**	**Units**
Funnel Diameter	571.5	mm
Funnel Area	256,520.7	mm^2
Total Rainfall	16.6	mm
Total Volume Collection For Storm Duration	4267	mL
Volume of 1 gallon Carboy	3,785.41	mL
Minimum Sample Needed	1,050	mL

Construction and Site Setup

Rainfall samplers used an 18 gallon plastic tote with the 22 ½ inch funnel attached to the lid of the tote. The lid of the tote was modified with lumbar support using two twelve-inch pieces of 2 x 4 lumber for the funnel to prevent it from tipping over when the weight of the rain made it top heavy. In order to make sure the rainfall sample collected in the carboy does not change over multiple times during a storm event, the carboy is exposed to the atmosphere using a flow reducer and two inch by ½ inch threaded cut-off riser. A sandbag was placed at the bottom of the tote in order to prevent the tote from being blown over. A complete detailed drawing of the sample set up can be

seen in Appendix B Design Drawings, Figure 43, while pictures of the both the Baldwin Yard and Fire Station 12 sites can be seen in Figure 13.

Figure 13 Fire Station 12 and Baldwin Yard Site Setup

When rainfall was collected, the sample in the carboy was divided into four 1-liter clear glass wide mouth sample bottles. The remaining sample from the other sampler was discarded and new cleaned and kilned fired brown glass carboys were placed in each of the samplers.

Residential Rooftop

Site Selection

Criteria used for the site selection of the residential rooftop runoff included consent from the homeowner and asphalt shingling of said homeowner roof. Six residential roofs fit the criteria at five homes, with one of the homes having two rooftop samplers on different sections of the home. The six rooftop sample sites were at the following residential homes in Lincoln, Nebraska: 3330 Woods Avenue, 3348 Woods Avenue, 3454 Woods Avenue, 3460 Woods Avenue and 2474 South 74th Street with two samplers installed on opposite sides of the South 74th street house.

Design

The Natural Resource Conservation (NRCS) method was used for calculating the roof runoff for the residential homes, this equation was chosen based on its simple relationship between rainfall excess and total rainfall contingent on a 24-hour period of rainfall (Novotny, 2008). The NRCS method equation is listed in Appendix D Equations, Equation 4, Equation 5 and Equation 6 with explanation of the terms along with supplemental equations related to it.

The sampler was designed for a 2-year storm frequency and able to collect enough sample volume for a complete analysis within a 10-minute storm event period. A 2-year storm period was chosen because it was the same amount of time for the duration of the study. The Lincoln Public Works and Utilities Department hydrology design criteria for storm frequency and duration were used to calculate rainfall intensity and total rainfall using two equations and an intensity duration-frequency curve shown in Appendix D Equations, Figure 57 (Utilities, 2000). Using Equation 2 and Equation 3 in Appendix D Equations, first, the frequency value (a) was calculated to be 48.57 using a storm frequency design (F) of 2 years. Using the calculated frequency value (a) and inputting it into Equation 4 and using storm duration value (t) for ten minutes, the calculated storm intensity (i) was 3.93 inches per hour with the total rainfall to be 0.65 inches. Table 13 shows a summary of the calculated values for the rainfall intensity.

Table 13 Two-Year Design Storm with Duration, Intensity and Total Rainfall Depth

Design Storm (years) (F)	Frequency Value (a)	Storm Duration (min) (t)	Intensity (in/hr)	Total Rainfall (in)
2	48.57	10	3.93	0.65

Using Equation 4, the precipitation amount (P) is 0.65 inches, a curve number of 98 associated with impermeable surface or road (Novotny, 2008). Using Equation 5, a total storage (S) of 0.2 inches is used calculated. Calculating from the total storage, an initial abstraction (I_a) of 0.04 inches in calculated using Equation 6. Substituting in all of these previously calculated and assumed values, the excess rainfall amount (Q) to be 0.64 inches of rainfall. Table 14 summarizes the NRCS method values used for the rooftop calculations.

Table 14 NRCS Method Rooftop Summarized Values

NRCS Method Parameters	Value	Units
(Q) Excess Rainfall Volume	0.64	inches
(P) Precipitation Amount	0.65	
(I_a) Initial Abstractions	0.04	
(S) Total Storage	0.2	
(CN) Curve Number	98	N.A.

Using the energy equation for flow between two sections, it was manipulated in order to calculate the flow of the downspout during the design storm and can be seen in Equation 7 and Equation 8 in Appendix D Equations. There was no pump (h_p and h_t =0), a velocity correction factor is turbulent flow (α=1), no pressure differences between each point (P_1 and P_2=0), a height difference is ten feet (z_2=10, z_1=0), and no velocity of flow at the top of the downspout (V_2=0) in when making the assumptions for Equation 7 and Equation 8. Using Equation 8 with a gravity constant (g) of 32.2 ft/sec^2 and a height difference of 10 feet, the average velocity of water in the downspout is 25.38 ft/sec. Each

residential home's downspouts are 2 x 3 inches; the maximum flow is 1.06 ft^3/sec or 7.91 gallons per second using the calculated velocity.

Time of concentration (t_c) is defined as time required runoff to travel from the hydraulically most distance part in the watershed to the outlet (National Resource Conservation Service, 2012). The time of concentration was used to gage the occurrence of the first flush as it takes into account the longest flow path, which accounts for water contacting the entire surface before being collected. The time of concentration equation is shown in Equation 9 and Equation 10 in Appendix D Equations. Using the area of the rooftop contributing the downspout as the watershed area in acres (A), each had approximately an estimated 500 ft^2 via satellite imagery, the longest flow length (L) was calculated to be 14 feet using Equation 10. Time to concentration was calculated to be 5 seconds using the longest flow length (L) of 14 feet, an estimated slope of 10% (Y), a total storage of 0.2 inches (S) calculated previously and a contributing area of 500 ft^2 using Equation 10 and Equation 9. Using the estimated flow calculated previously as 7.91 gps and multiplying it by the t_c, the volume of water passing was 39.4 gallons of water. Table 15 shows a brief summary of all of the values that were calculated to determine the total volume of water passing before the first flush

Table 15 NRCS Time of Concentration Summary for Residential Rooftop Sampling

Time of Concentration Parameter	Value	Units
Rooftop Area (A)	500	ft^2
Longest Flow Length (L)	14.0	ft
Total Storage (S)	0.2	inches
Slope (Y)	10.0	%
Time of Concentration (t_c)	5.0	sec
Flow	7.91	gps
Volume of Water Passing at tc	39.4	gallons

Multiplying the percentage of flow need (2.5%) by the area of each of the residential homes downspout (6 in^2) an approximated area of 0.15 in^2 needed to collect runoff. Using a polyethylene tubing size of ½ inch diameter, with an approximate area of 0.2 in^2, the extra area (0.2 in^2 > 0.15 in^2) will serve as a safety factor in order to compensate for any unknowns. Table 16 shows the sizing parameters for the residential rooftop samplers.

Table 16 Sizing of Residential Rooftop Sampler

Sizing Residential Rooftop Sampler Flow Parameters	Value	Units
Volume of Water Passing at t_c	39.37	gallons
Collection Needed	1.00	gallon
Percent of Flow Needed for t_c	2.5%	NA
Area needed	0.15	inches2
Hole Size	0.50	inches
Hole Area inches 2	0.20	inches2
Safety Factor	1.3	NA

Construction and Site Setup

Samples were collected in 1-gallon brown glass carboy with a rubber stopper on top and an air bleed house so no pressurized flow occurs. The carboy was housed in an 18-gallon plastic tote with a sandbag on the bottom to prevent it from tipping over. A one ½-inch diameter PVC pipe was used for the design of the residential sampler. The PVC used was 4 inches long and attached a PVC 1 ½ inch diameter female adapter with a cleanout plug. Half of the sampler, 2 inches, was milled horizontally allowing the ponding of water in the sampler. A ½ inch hole was then drilled on the bottom as sized in the previous section to attach the polyethylene tubing. The sampler is equipped with a y-branched connection used to divert the overflow in order to keep the first flush runoff. All residential rooftops sample sites used the same sampler design.

Basic construction components of the residential rooftop sampler can be seen in Appendix B Design Drawings, Figure 44 and Figure 45 while Figure 14 below shows the actual setup of one of the residential rooftop samplers in the field.

Figure 14 Residential Roof Sampler Setup

At least four of the six samplers had to collect a sample in order to conduct a pollutant analysis. If a carboy was filled up with rooftop runoff, the sample in the carboy was divided into four 1 liter clear glass wide mouth sample bottles. The remaining sample was discarded and new cleaned and kilned fired brown glass carboys were placed in each of the samplers. Regular maintenance of the samplers was required in order to keep the samplers clean and functioning.

Commercial Parking Lot

Site Selection

Criteria for sampling parking lot runoff included asphalt based, willing cooperators and moderate to heavy thru traffic. Parking lots that were selected for the research study were the Lower Platte South, Natural Resource District (NRD) office at 3125 Portia Street, Lincoln Ne, 68521 and the University of Nebraska-Lincoln Extension

in Lancaster County (Lancaster County Extension Office), located at 444 Cherrycreek Road, Lincoln Ne 68528.

Design

Design of the samplers focused on the collection of the first flush before the t_c was reached. Each parking lot is approximately 5,000 ft^2 with an estimated average slope of 0.5% taken from measurements obtained via satellite imagery. The same 2 year design storm is used with a total rainfall of 0.65 inches as calculated in a previous section, Residential Rooftop, subsection, Design. Using the watershed area of 5,000 ft^2 (A) an estimated longest flow length was calculated to be 57 feet Equation 10. Time of concentration for each parking lot was calculated to be 49 seconds using the longest flow length (L) 57 feet, slope of 0.5% (Y) total storage of 0.2 inches (S) and a watershed area of 5,000 ft^2 (A) using Equation 9. The volume of runoff passing before t_c was calculated using the open channel flow, Equation 11 in Appendix D Equations and Supplemental Material, for each parking lot. Using Equation 11, both parking lots had a Manning's roughness coefficient of 0.012, different runoff areas, hydraulic radiuses and slope, each flow was calculated and summarized in Table 17 along with sizing of tubing needed to collect the runoff.

Table 17 NRCS Time of Concentration Summary for Commercial Parking Lot Sampling

Parking Lot Sizing Parameter	Parking Lot		Units
	NRD	Lancaster County Extension Office	
Longest Flow Path (L)	57.0		ft
Slope (S)	0.5		%
Time of Concentration (tc)	49.0		sec
Manning's Roughness Coefficient (n)	0.012		NA
Area of Outflow (A)	1.8	3.6	ft^2
Area Hydraulic Radius (R_h)	0.5	0.6	ft
Flow (Q)	29.4	72.7	ft^3/sec
Volume of Water Passing at tc	1441	3559	gallons
Collection Needed	1.00		gallon
Percent of Flow Needed for tc	0.04%	0.03%	NA
Minimum Area Needed	0.0005	0.0001	inches2

Construction and Site Setup

Only a small percentage of the runoff coming off the parking lot was needed; the stormwater runoff would need to be ponded slightly by using sandbags or by natural dam formations to collect the first flush coming off the parking lots. Both sites will be using a polyethylene tubing size of ½ inches in diameter. Multiplying the percentage of flow needed by the area of each of the parking lots channel an approximated area of 0.0005 or 0.0001 in^2 needed to collect runoff. Using a polyethylene tubing size of ½ inch diameter, with an approximate area of 0.2 in^2, the extra area will serve as a safety factor in order to compensate for any unknowns for each of the parking lots; in addition, a y branched fitting was used intended for overflow of any excess runoff. The samples were collected in a 1 gallon brown glass carboy with a rubber stopper on top and an air bleed hose so that no pressurized flow occurs. The carboy was housed in an 18 gallon plastic tote with a sandbag on the bottom to prevent it from tipping over.

Each parking lot sampler was designed slightly different to fit the needs of the site. After a storm event, the sample in the carboy was divided into four 1 liter clear glass wide mouth sample bottles. Any remaining sample was discarded and a new cleaned and kilned fired brown glass carboy was placed in each of the samplers. During the course of the project, it was observed that large amount of detritus, would clog the sampler preventing the sampler from function properly. It was observed that heavy and intense storms would cause some debris to puncture the sandbags in the Lancaster County Office parking lot causing the runoff to not pond. Regular maintenance of the samplers was required in order to keep the samplers clean and functioning.

Lancaster County Extension Office Parking Lot Design Sampler

Design of the Lancaster County Extension Office parking lot sampler was a plastic funnel attached to a wooden board placed perpendicular to the parking lot runoff effluent and anchored with 70 lbs. sand bags. The sand bags were situated in a J-hook formation used to slow runoff down and allow the water to pond. Figure 46 and Figure 47 in Appendix B Design Drawings, show the Lancaster Parking Lot sampler design and intended setup and Figure 15 and photos of the actual setup respectively.

Figure 15 Lancaster County Office Parking Lot Sampler Actual Setup

NRD Parking Lot Sampler

The parking lot had a natural dam formation situated on parking lot runoff exit, formed by detritus and debris lead the runoff to pond. A 5 foot long 3 inch diameter PVC pipe with a Wye branch was designed to collect and store the runoff, allowing overflow to occur should the site collect too much sample that would dilute the first flush. Figure 48, in Appendix B Design Drawings show the design of the sampler and the site setup, and Figure 16 shows a photo of the site setup.

Figure 16 NRD Parking Lot Actual Setup

Commercial Rooftop

Site Selection

Criteria for commercial roof runoff sampling included any office complexes, retail facilities and warehouses that do not have metal frame roofs and consent from the owner. The two commercial sites that fit this criterion were Fireworks restaurant located at 5750 South 86th Drive, Lincoln, Ne 68526 and the University of Nebraska-Lincoln Extension in Lancaster County (Lancaster County Extension Office), located at 444 Cherrycreek Road, Lincoln Ne 68528.

Design

Design of the sampler had criteria focused on collection of the first flush before t_c was reached. The NRCS method that used for residential roof calculations was also was used for commercial rooftops. The estimated size of the rooftop at both sites contributing to the downspout is approximately 1,000 ft^2 estimated via satellite imagery. The same 2 year design storm is used with a total rainfall of 0.65 inches as calculated in a previous section, Residential Rooftop, subsection, Design. The longest flow path was calculated to be 21.7 feet using the estimated area of 1,000 ft^2 (A) using Equation 10. The time of concentration was calculated to be 11.6 seconds using a longest flow path of 21.7 feet (L), an estimated slope of 3% (Y), a total storage calculated previously as 0.2 inches (S) and a watershed area of 1,000 ft^2 (A) using Equation 9.

The flow of the Fireworks restaurant was calculated using the energy equations, Equation 7 and Equation 8, from subsection Residential Rooftop, with all assumptions, the average velocity of water in the downspout is 25.38 ft/sec. The downspout was circular with a diameter of 4 inches; the maximum possible flow was then calculated to be 26.6 ft^3/sec or 198.79 gallons per second.

For the Lancaster County Extension office, the downspout was open to the atmosphere, using the open channel flow equation as seen in Equation 11 in Appendix D Equations, substituting in a slope of 1, indicating a vertical surface, a hydraulic radius of 0.153 ft (area =0.21 $feet^2$ and wetted perimeter of 1.4 ft) and a manning's roughness of 0.012 for cast iron, an approximate flow of 35.45 ft^3/s or 265.3 gallons per second was calculated (Novotny, 2008). Table 18 shows the values of the calculations done for both of the rooftops and associated values.

Table 18 Commercial Rooftop Sizing of Samplers

Sizing of Commercial Rooftop Sampler Parameter	Value		Units
	Fireworks	Lancaster County Extension Office	
Longest Flow Length (L)	21.7		ft
Slope (Y)	3.0		%
Time of Concentration t_c	11.6		sec
Volume of Water Passing at tc	2,313.4	3,087.5	gallons
Collection Needed	1.00		gallon
Percent of Flow Needed for tc	0.04%	0.03%	NA
Area needed	0.0005	0.0001	inches2

Construction and Site Setup

Multiplying the percentage of flow needed by the area of each of the parking lots channel an approximated area of 0.0005 or 0.0001 in^2 needed to collect runoff. Using a polyethylene tubing size of ½ inch diameter, with an approximate area of 0.2 in^2, the extra area will serve as a safety factor in order to compensate for any unknowns for each of the parking lots; in addition, a y branched fitting was used intended for overflow of any excess runoff. The samples were collected in a 1-gallon brown glass carboy with a rubber stopper and an air bleed house so no pressurized flow occurs. The carboy was housed in a 18 gallon plastic tote with a sandbag placed on the bottom to prevent from tipping. Each parking lot sampler was designed uniquely to fit the needs of the site.

Lancaster County Extension Office Commercial Rooftop Site Setup

Construction of the sampler was a plastic funnel attached to a three walled wooden boxed placed in the corner of the 3-walled open air downspout approximately 5 feet off the ground. This allowed some ponding before collecting a sample, Figure 51 in Appendix B Design Drawings and Figures show the Lancaster Commercial Roof sampler design and the intended setup while Figure 17 shows photos of the actual setup.

Figure 17 Lancaster County Office Rooftop Sampler Actual Setup

Fireworks Restaurant Commercial Rooftop Site Setup

Construction of the sampler was a plastic funnel attached to a three walled wooden box, placed in a constructed wooden channel approximately 4 feet in length, placed under the downspout. Figure 52 and Figure 53 in Appendix B Design Drawings show the Fireworks Restaurant sampler design and the intended setup while Figure 18 shows the actual site setup.

Figure 18 Fireworks Restaurant Rooftop Sampler Actual Site Setup

After a storm event, the sample in the carboy was divided into four 1 liter clear glass wide mouth sample bottles. The remaining sample from the other sampler was

discarded and new cleaned and kilned fired brown glass carboys were replaced in each of the samplers. Regular maintenance of the samplers was required in order to keep the samplers clean and functioning.

Residential Rain Gardens

Site Selection

Criteria used for the site selection of the residential rain gardens included: consent from the homeowner to be able to disturb the rain garden and each rain garden have at least two years of well-maintained growth. Six residential rain gardens fit the criteria at five homes with one of the homes having two rain gardens located in different areas of the property. The homes used for the study were 3300, 3348, 3454 and 3460 Woods Ave, Lincoln Ne, 68510 while two more rain gardens were used at one residential home located at 1860 Twin Ridge Road, Lincoln, NE 68506.

Design

Design of the sampler centered on being able to collect the ponded runoff; identified as the first flush, before it went over the berm of the rain garden. Other requirements were implemented into the design of the rain garden sampler at the request of the homeowners, these requirements included minimal disturbance and blend into the surroundings of the homeowners' rain garden.

Construction and Site Set Up

The sampler was constructed using a high-density polyethylene (HDPE) 32 oz. (946 mL) oblong spray bottle with a 28/400 mm thread sized cap. The spray bottle had a 2 ½ inch hole drilled in the center fitted with a PVC stand and rain cap. The PVC stand and rain cap allows the spray bottle to be extended slightly so that ponded rain water does not pond on top of the sampler. The PVC stand and rain cap was then glued using epoxy

to the spray bottle and silicon caulk placed around the seams to prevent any rainfall from leaking into the sampler. The sampler was then spray painted dark brown to blend into the rain garden surroundings. Two samplers were placed in each rain garden, should one of the samplers should fail, in a five inch deep depression. Four 3/8 inch diameter 10 inch long metal stakes were then driven into the side of hole and two 12 inch bungee cords where then wrapped around the stakes to hold the rain garden sampler from turning over or floating away during a storm event. Figure 54 in Appendix B Design Drawings and Figure 19 below show the components of the final rain garden sampler and the actual site set up in the field, respectively.

Figure 19 Rain Garden Sampler Actual Set Up

Site Collection and Observation

At least four of the six residential rain garden samplers had to collect sample in order to conduct pollutant analysis. After a storm event, the sample was divided into two 1 liter clear glass wide mouth sample bottles. The remaining sample from the other sampler was discarded and new cleaned rain garden samplers were placed at the sample site. During the course of the project, it was observed that the sampler never fully filled during the sampling period and only small amount of sample were collected.

Chapter 4 Results

Stormwater runoff sample collection occurred from April 21, 2013 to May 22, 2014. Sampling seasons were defined as; spring, March 20 to June 20, early summer, June 21 to August 2, and late summer, August 3 to September 21. Six samples were collected from the influent and effluent for both the large and small bioretention cells. Additional research sites collected the following from: six rain gardens (2 samples each), six residential rooftop (2 samples each), two commercial rooftops (3 samples each), two parking lots (3 samples each), two commercial rooftops (3 samples each) and two rainfall (3 samples each). Table 19 shows the sample event dates for all sites to be used in the analysis section later in this research; cells colored blue, purple and brown in represent spring, summer and late summer sampling, respectively. All samples that were collected, but not necessarily used for the analysis can be seen in Table 35 through Table 40 in Appendix E Data Collection. Green cells in Table 35 through Table 40 represent samples that were used in the analysis, while orange cells represent cells not used and gray cells represent no data collection for that particular sample site and storm event. Table 41 through Table 64 show all of the pollutant concentrations measured for all sites.

Table 19 Samples Used for Analysis

Group	Sample Event Dates					
	1st	*2nd*	*3rd*	*4th*	*5th*	*6th*
Rain Garden	6/1/2014	6/3/2014	N.A.			
Rainfall	7/23/2013	9/10/2013	5/22/2014	N.A.		
Commercial Rooftop	9/10/2013	4/13/2014	5/22/2014	N.A.		
Residential Rooftop	9/10/2013	5/22/2014	6/1/2014	N.A.		
Parking Lot	6/24/2013	9/10/2013	5/22/2014	N.A.		
Large Cell	6/24/2013	9/10/2013	4/13/2014	4/24/2014	4/27/2014	5/22/2014
Small Cell	6/23/2013					
Notes: Cell Colors						
	=Spring Samples					
	=Summer Samples					
	=Late Summer Samples					

Storms used for the analysis of the bioretention cells are summarized in Table 20 showing rainfall intensity, total rainfall and length of storm, thus confirming that rainfall occurred when samples were collected from each of the bioretention cells and not an artificial source. Figure 58 through Figure 63 in Appendix F Graphs, show each of the outputted rainfall intensity graphs corresponding to the storm event along with total amount of rainfall recorded as seen in Table 20.

Table 20 Rainfall and Storm Data for Bioretention Cell Events

Storm Event Date	Maximum Rainfall Intensity (inches/hr)	Total Rainfall (inches)	Storm Length (hh:mm)
6/24/2013	0.16	0.3	0:55
9/10/2013	0.082	1.03	11:05
4/13/2014	0.13	0.69	5:45
4/24/2014	0.09	0.35	9:40
4/27/2014	0.04	0.51	9:50
5/22/2014	0.06	0.5	7:30

Equipment Malfunctions

A water level logger used to measure the water level of the junction box for the large bioretention cell as explained in Chapter 3: Methodology, only recorded data for about a month before it malfunctioned. To validate the effluent results of the large bioretention cell, the submerged probe used to trigger effluent sampler was used in place of the water level logger. The elbow in the large bioretention cell allowed the water to rise 6 inches to collect an uncontaminated sample, Figure 64 through Figure 69, Appendix F Graphs, shows the submerged probe depth did not rise over 6 inches, confirming uncontaminated samples. Figure 70 through Figure 75 show the small bioretention cell influent depth.

Data Spread Comparison Analysis

For each site and for each pollutant, a box and stem plot was constructed to show basic analysis of the dataset. The analysis shows outliers or values located outside of the normal distribution of the data for each pollutant/site. Outliers may occur from the following: sample anomalies, transcription errors, sample contamination, sample preservation or sample storage. The plots show if first flush of any pollutant occurs in each of the cells. The plots were also used to compare the pollutant data spread between the supporting sites and the cells. Each of the box and stem plots have the following five main components: a lower spread, first quartile, median, third quartile and an upper spread. The lower and upper spread represents the third quartile subtracted from the 1st quartile multiplied by 1.5; this value is then subtracted from either the 1st quartile or the 3rd quartile representing the minimum and maximum value that could possibly result from the dataset respectively (Devore, 2008). The first quartile represents the median value of the bottom 50% of the values while the third quartile represents median value of the upper 50% of the dataset. The median value is the center value calculated from the dataset. Any data points in the analysis that fall outside of the box and stem plot is labeled as an outlier, they represent data points that do not follow a normal distribution and are extreme values that might skew the dataset (Devore, 2008). Outliers indicate other external factors are affecting pollutant concentrations levels that do not follow within the norm of the data range. Figure 20 through Figure 34 plots show starting from the top: the large and small cells' individual samples (Influent-1, Influent-2, Influent-3, Effluent-1, Effluent-2 and Effluent-3), and the data spread from all rainfall site, commercial parking lots, commercial rooftops, residential rooftops and residential rain

gardens. It should be noted that not all of the pollutants analyzed had all of the supporting sites, only TKN, nitrate, total phosphorus and zinc did.

TKN

Evidence of first flush is observed in the large cell as each consecutive influent sample had a narrower spread. This was not observed in the small cell. The rainfall measurements had a significant spread as both sites had high levels of TKN measured on 5/22/2014. All other supporting sites have ranges similar to what was seen in both of the cells influent. The TKN data spread is shown below in Figure 20.

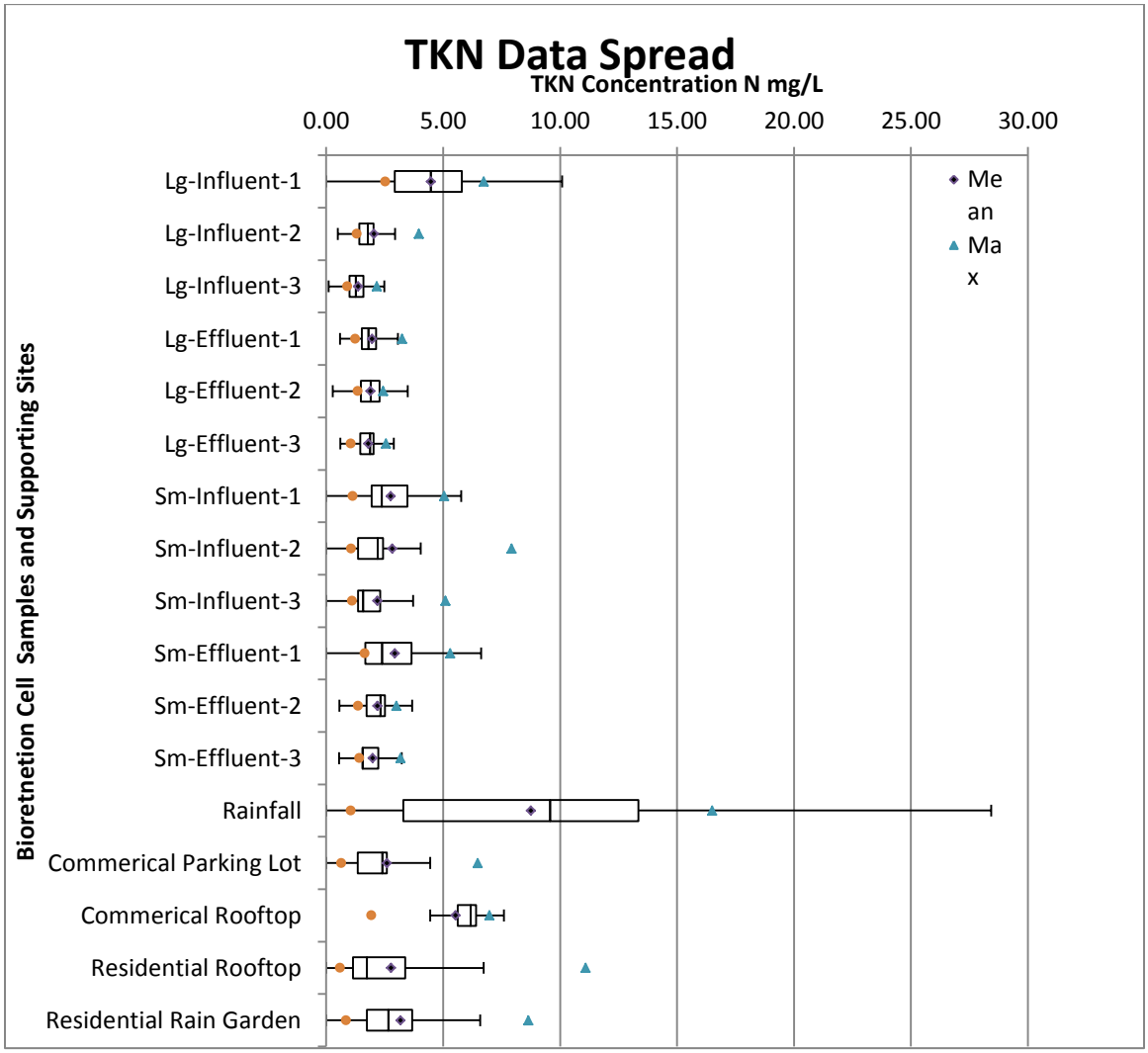

Figure 20 TKN Data Spread

Nitrate

Both cells experienced a wider data spread for the effluent samples than the influent samples. Evidence of first flush is indicated in the large cell as each consecutive influent sample had a narrower spread; this was not observed in the small bioretention cell. The commercial rooftop sites had the greatest nitrate spread similar to the bioretention cells, while all other sites had narrower range. The nitrate data spread is shown below in Figure 21.

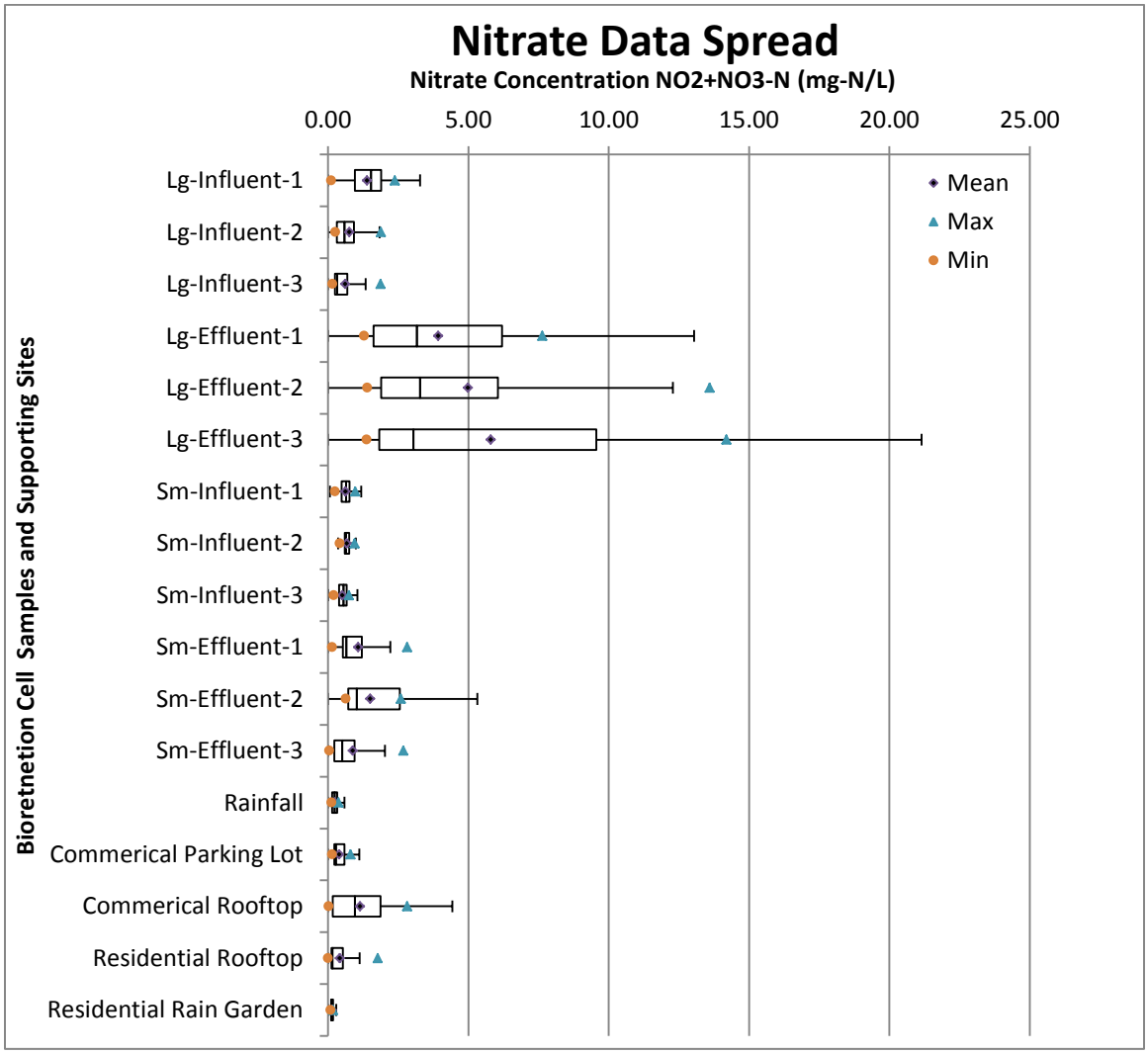

Figure 21 Nitrate Data Spread

Total Phosphorus

The large cell had a wider data spread in the effluent compared to the influent, while the small cell experienced similar data spreads in both the influent and effluent. Evidence of first flush was observed in both cells as each consecutive influent sample had a narrower spread. Rainfall sites found to have a range much wider than both cells, while all other sites had values comparable to each of the cells. The data spread is shown below in Figure 22.

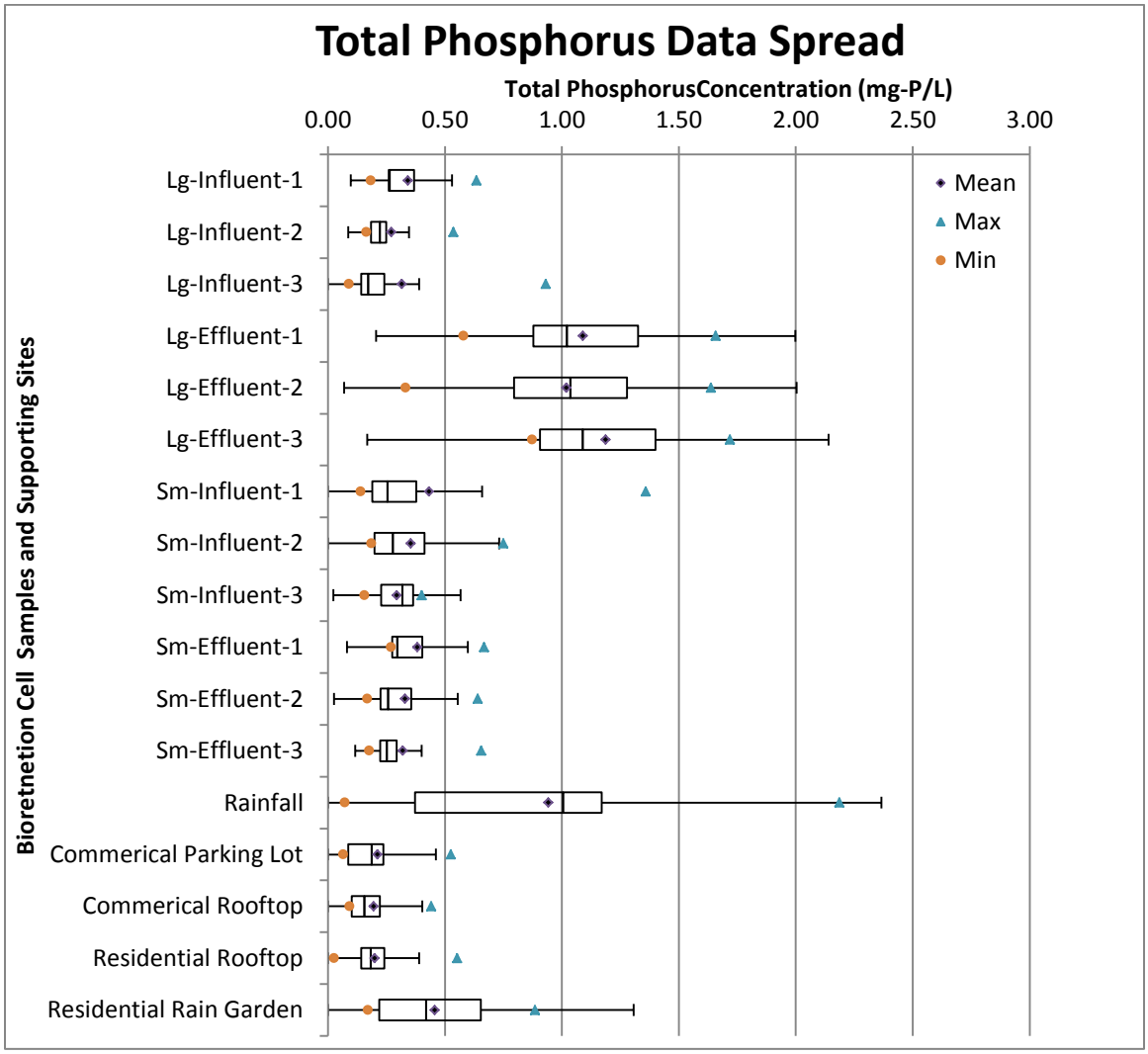

Figure 22 Total Phosphorus Spread

Zinc

The small cell had a wider influent data spread compared to the large cell; however, both had similar data spreads in the effluent. Rainfall and residential rooftop sites accounted for the zinc data spread observed in the small cell influent, while all other sites were similar to data spread large cell influent. The zinc data spread is shown below in Figure 23.

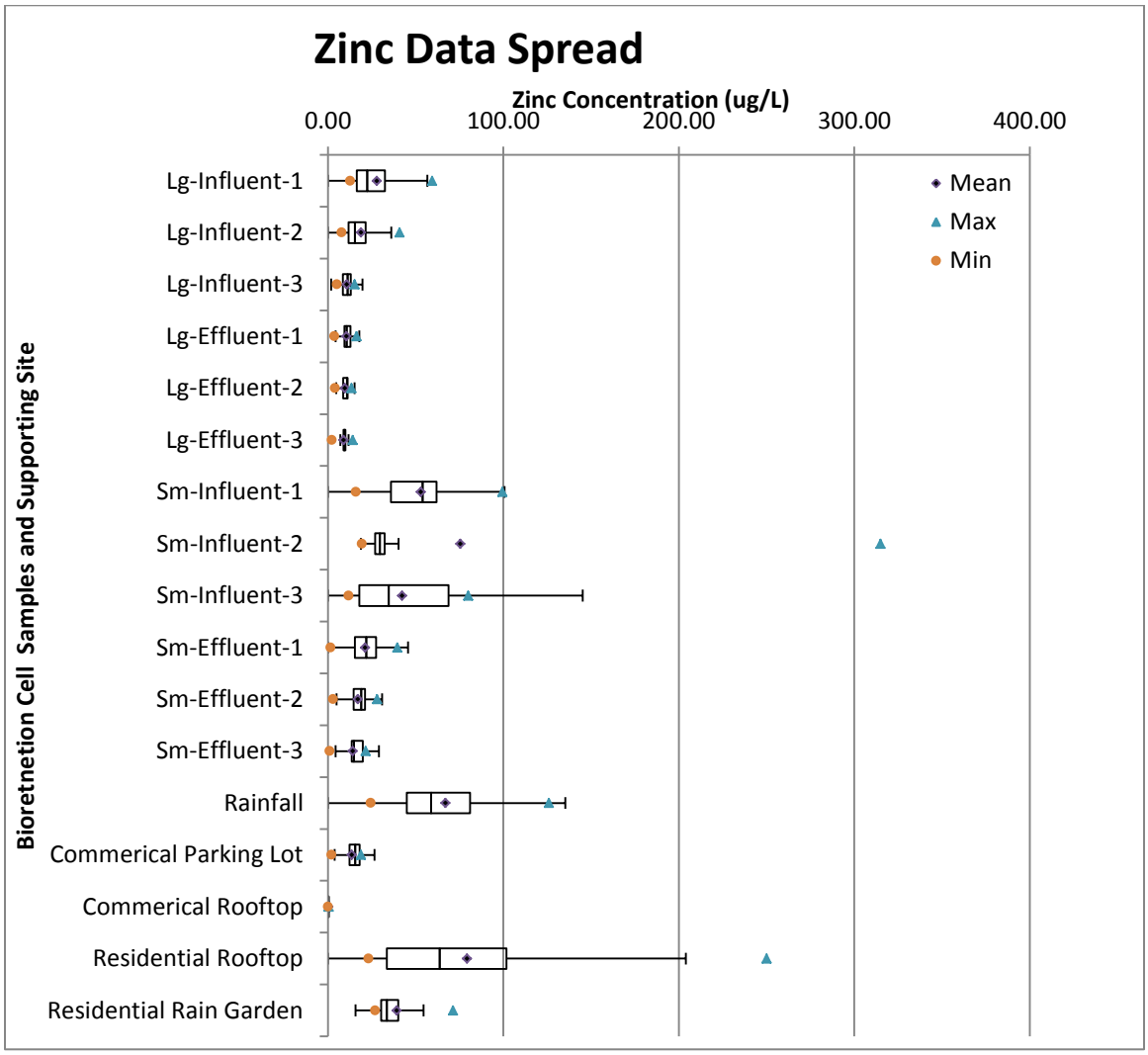

Figure 23 Zinc Data Spread

Total Fecal Coliforms/Total E.coli

Very narrow data spreads were observed for both bioretention cell effluents. The data spread for the influents in both cells were very wide and had many outliners. First flush was shown for total E.coli for the large bioretention cell, but not total fecal coliform. Both residential and commercial rooftops have ranges comparable to the large cell range but not the small cell. The data spread for total fecal coliform and E.coli is shown below in Figure 24 and Figure 25 respectively.

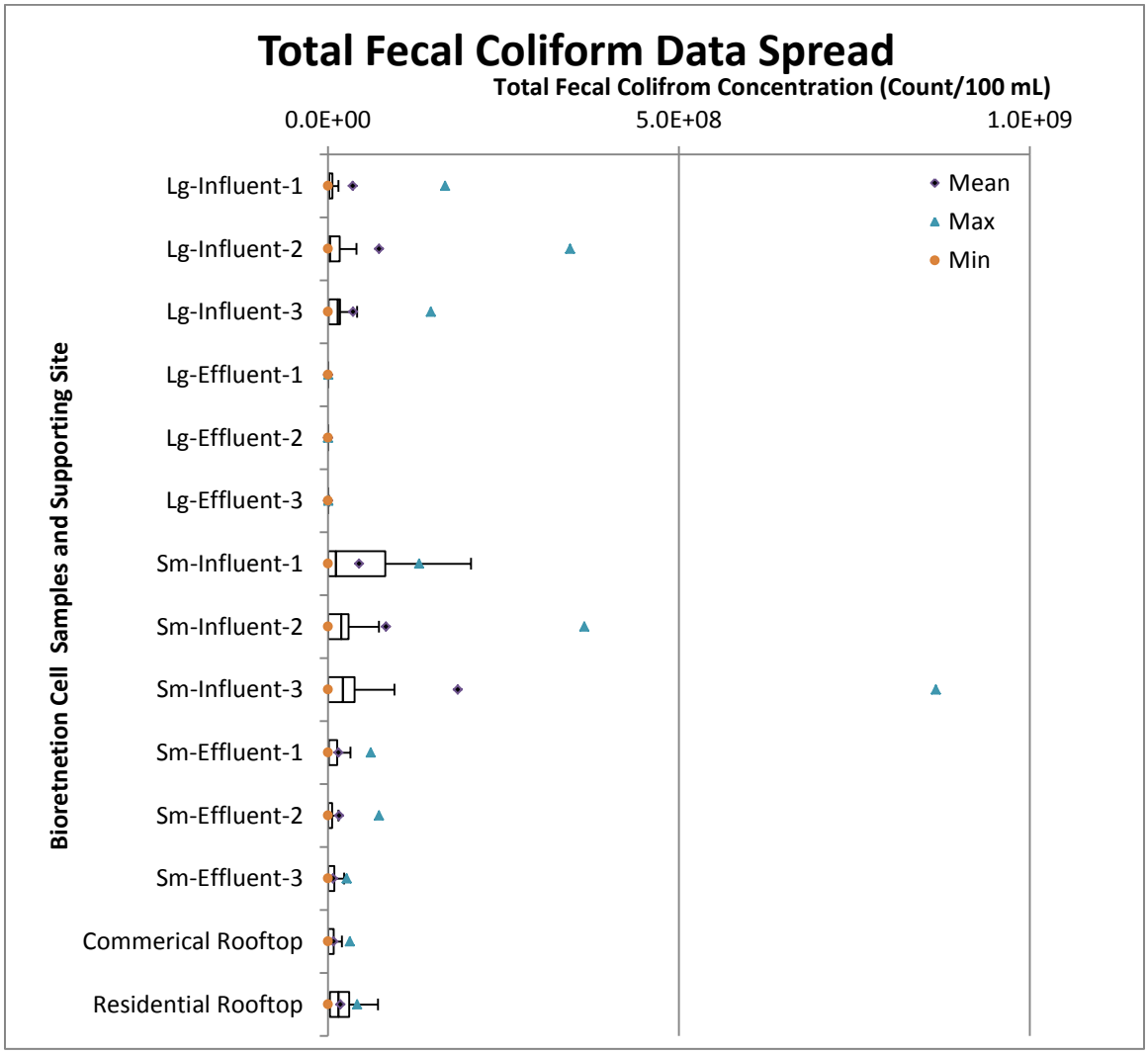

Figure 24 Total Fecal Coliform Data Spread

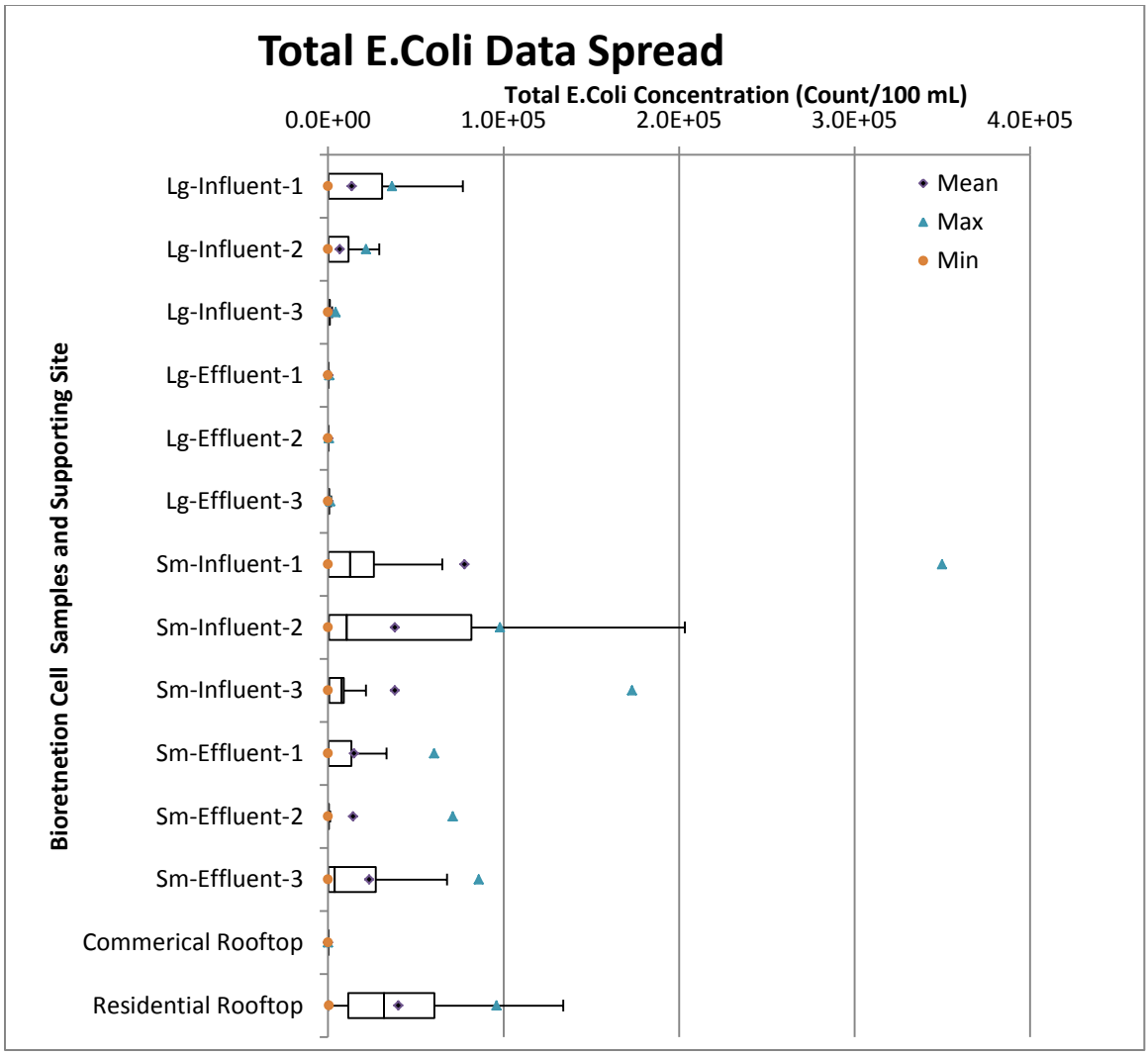

Figure 25 Total E.coli Data Spread

Total Suspended Solids (TSS)

Evidence of first flush was observed in both cells as each consecutive influent sample had a narrower spread. The data spread is shown below in Figure 26.

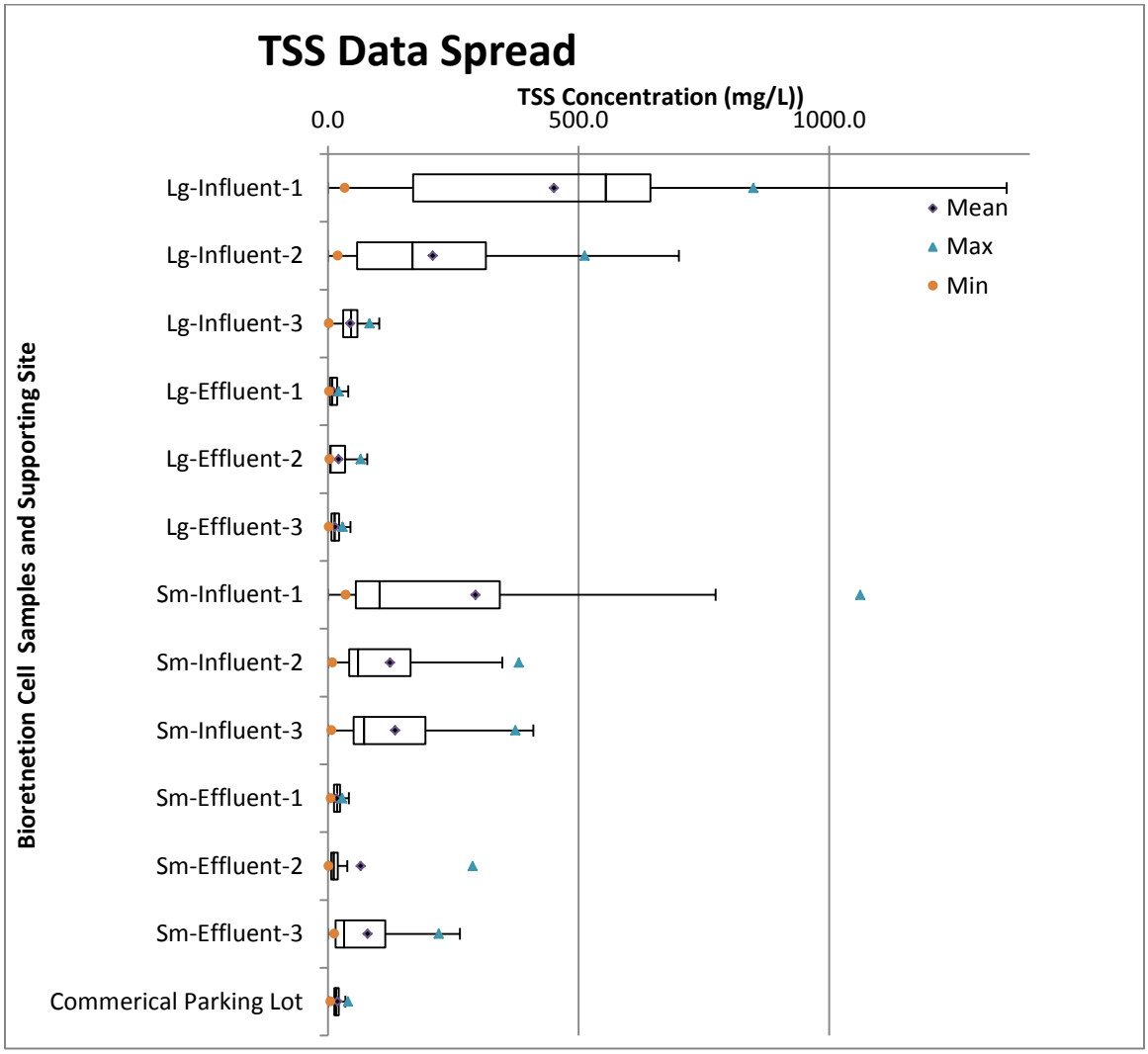

Figure 26 TSS Data Spread

Total Dissolved Solids (TDS)

Evidence of first flush is observed in both cells as each consecutive influent sample had a narrower spread. Sites that measured TDS; parking lots, observed similar concentrations observed at the end of first flush effect in the bioretention cell influent; indicating, first flush may not have been captured from parking lots. The TDS data spread is shown below in Figure 27.

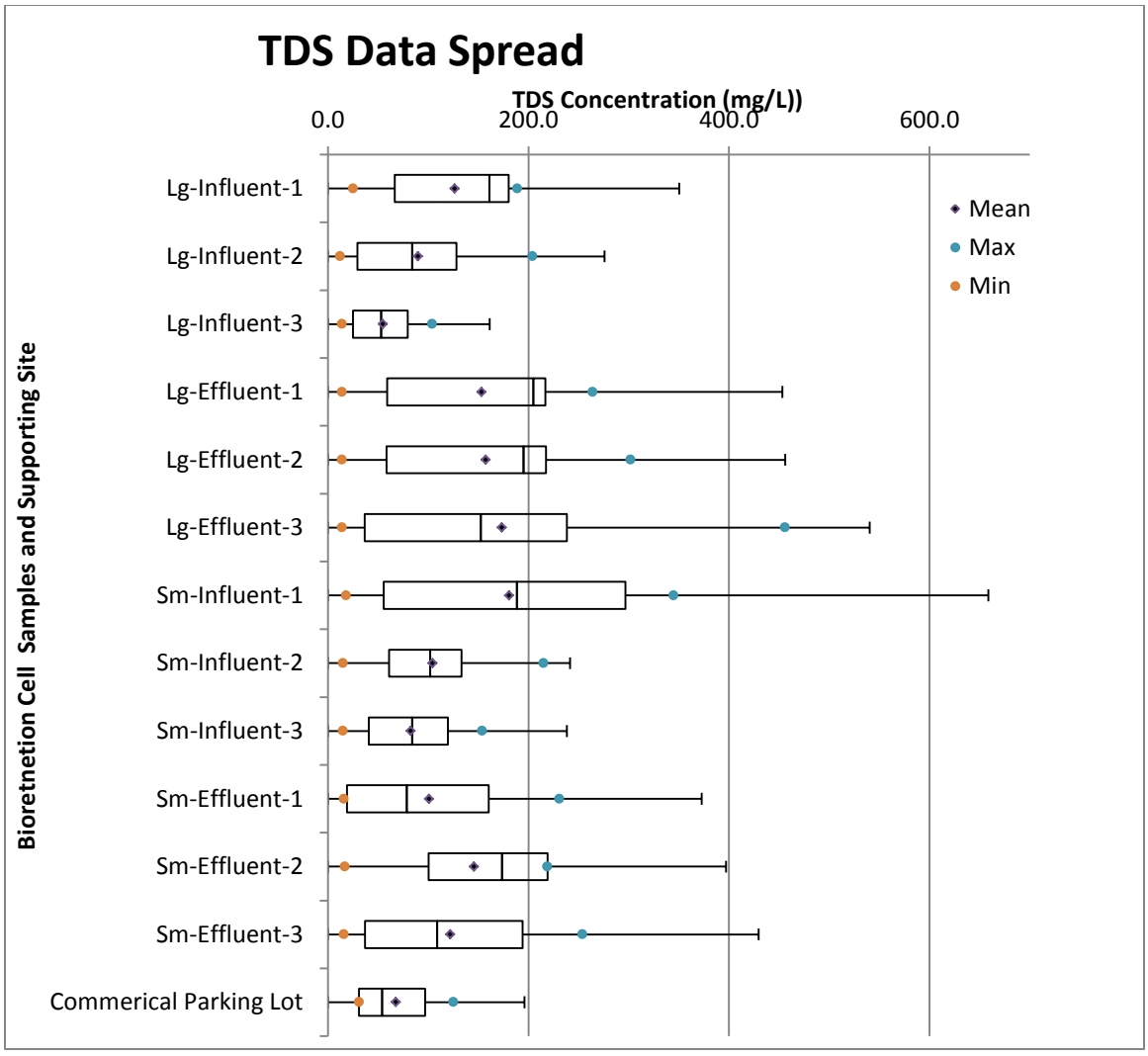

Figure 27 TDS Data Spread

Conductivity

Evidence of first flush is observed in the large cell as each consecutive influent sample had a narrower spread. Both cells saw larger data spreads in the effluent sampling than the influent for conductivity. Sites that measured conductivity; rainfall and parking lots, had similar data spreads to both cells influent. The conductivity data spread is shown below Figure 28.

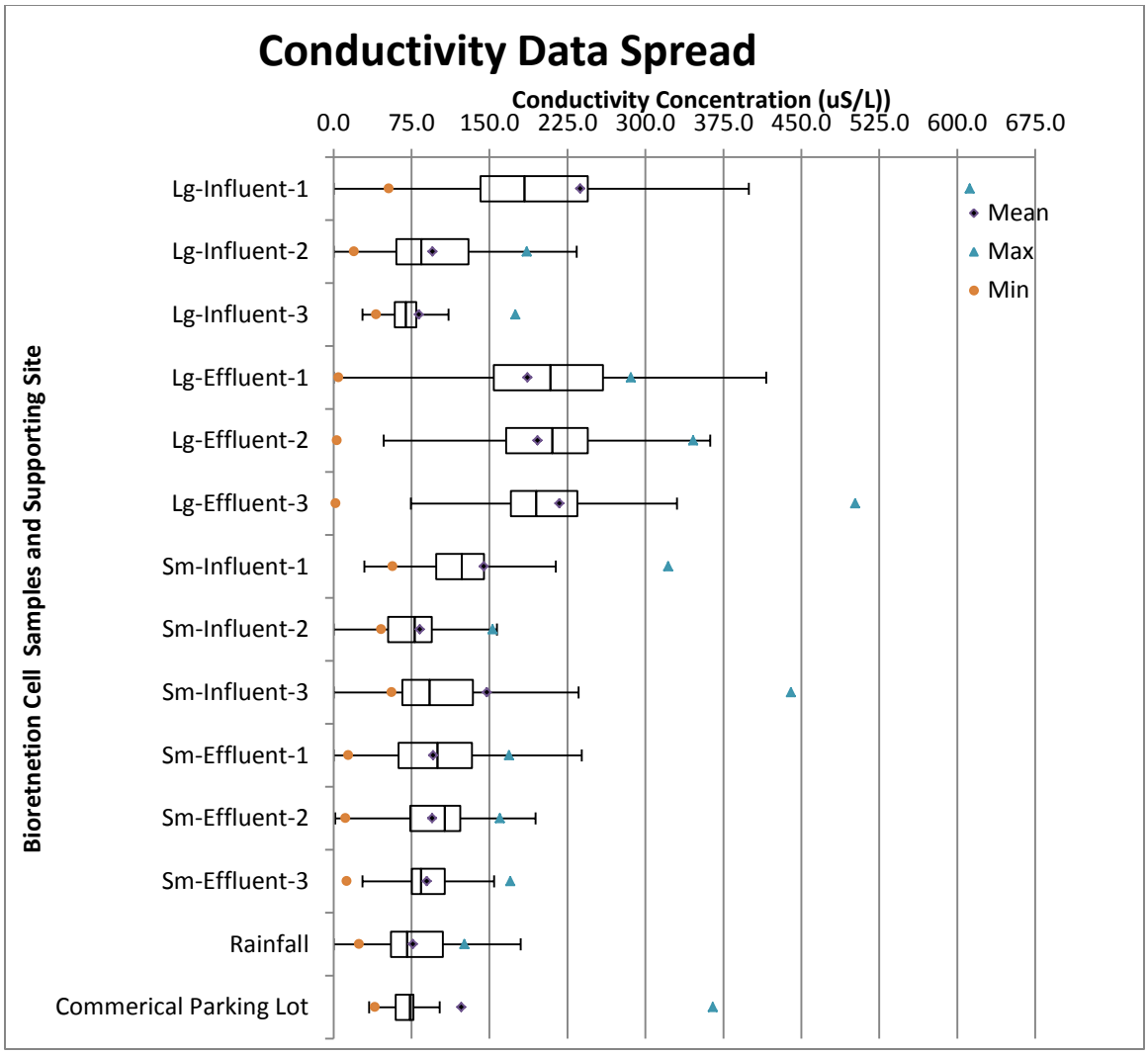

Figure 28 Conductivity Data Spread

Oil/Grease

Data spread for oil and grease saw outliers greater than what was normally collected. This could be the result of errors from mishandling of sample, analysis of sample or transcription errors as a single runoff event occurring on 4/27/2014 found an elevated oil and grease sample only in Lg-Influent-1 to be 8.3 mg/L. A runoff event occurring on 5/22/2014, had measurable levels of oil/grease in both the large and small bioretention cell influent, potentially cause by a vehicle leaking on the parking lot. This would cause oil and samples collected during this runoff event to appear to be outliers when in actuality, it was caused by a single event that would have not occurred in past

sampling events. No influent or effluent trends can be deduced from the data, due to the majority of the samples having undetectable levels. The oil and grease data spread is shown below in Figure 29.

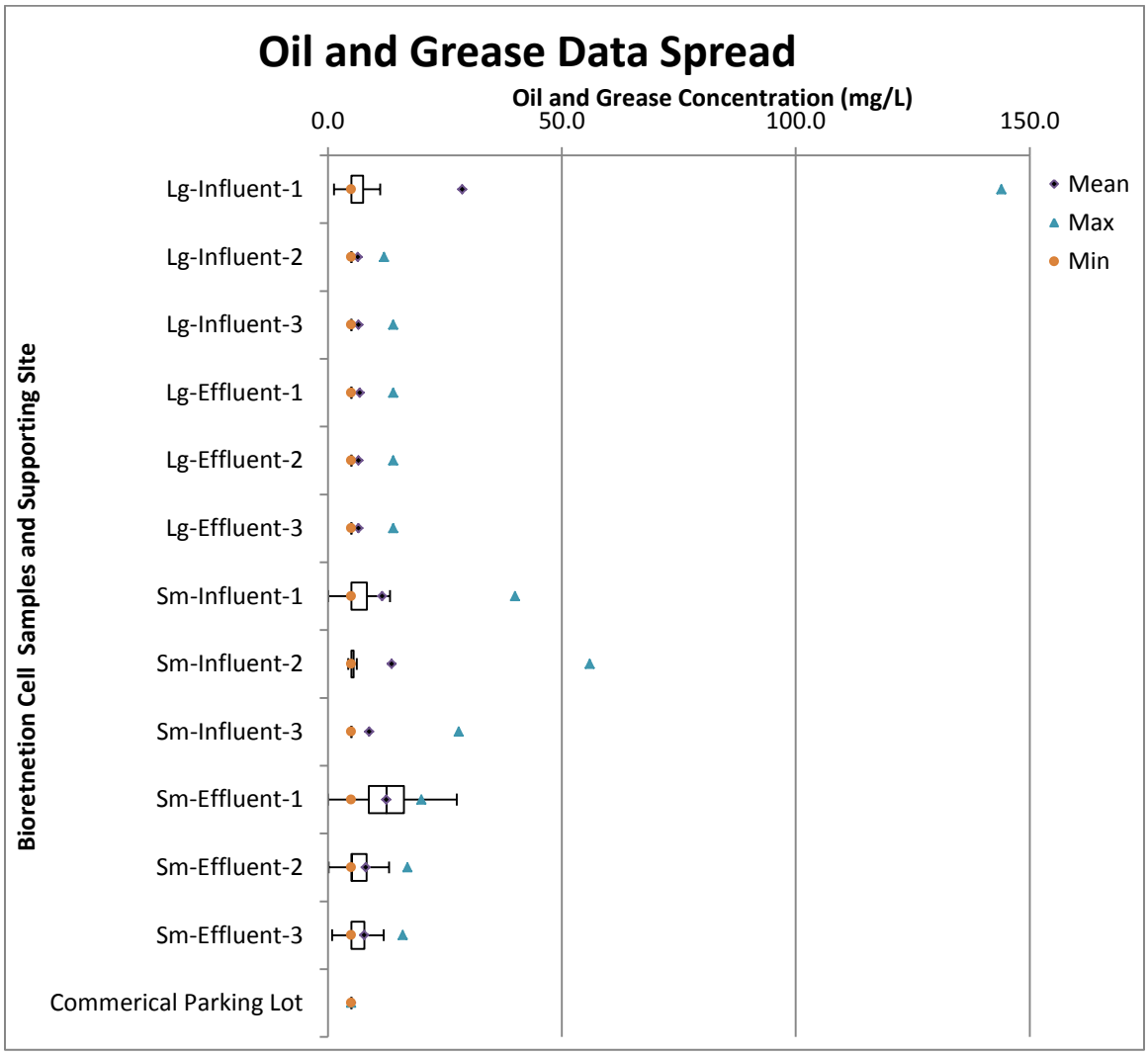

Figure 29 Oil and Grease Data Spread

Pesticides

Of the 21 pesticides that were tested, the following five: acetochlor, atrazine, DEA, metolachlor, and propazine, were found to have measureable levels in both cells. Each of the cells saw evidence of first flush as each consecutive influent sample had a narrower spread. The rainfall sites had data spreads similar to what was observed in both cells. DEA had a significantly increased levels in the data spread in the effluent compared

to the influent for the small bioretention cell. The pesticide data spread is shown below in, Figure 30 through Figure 34.

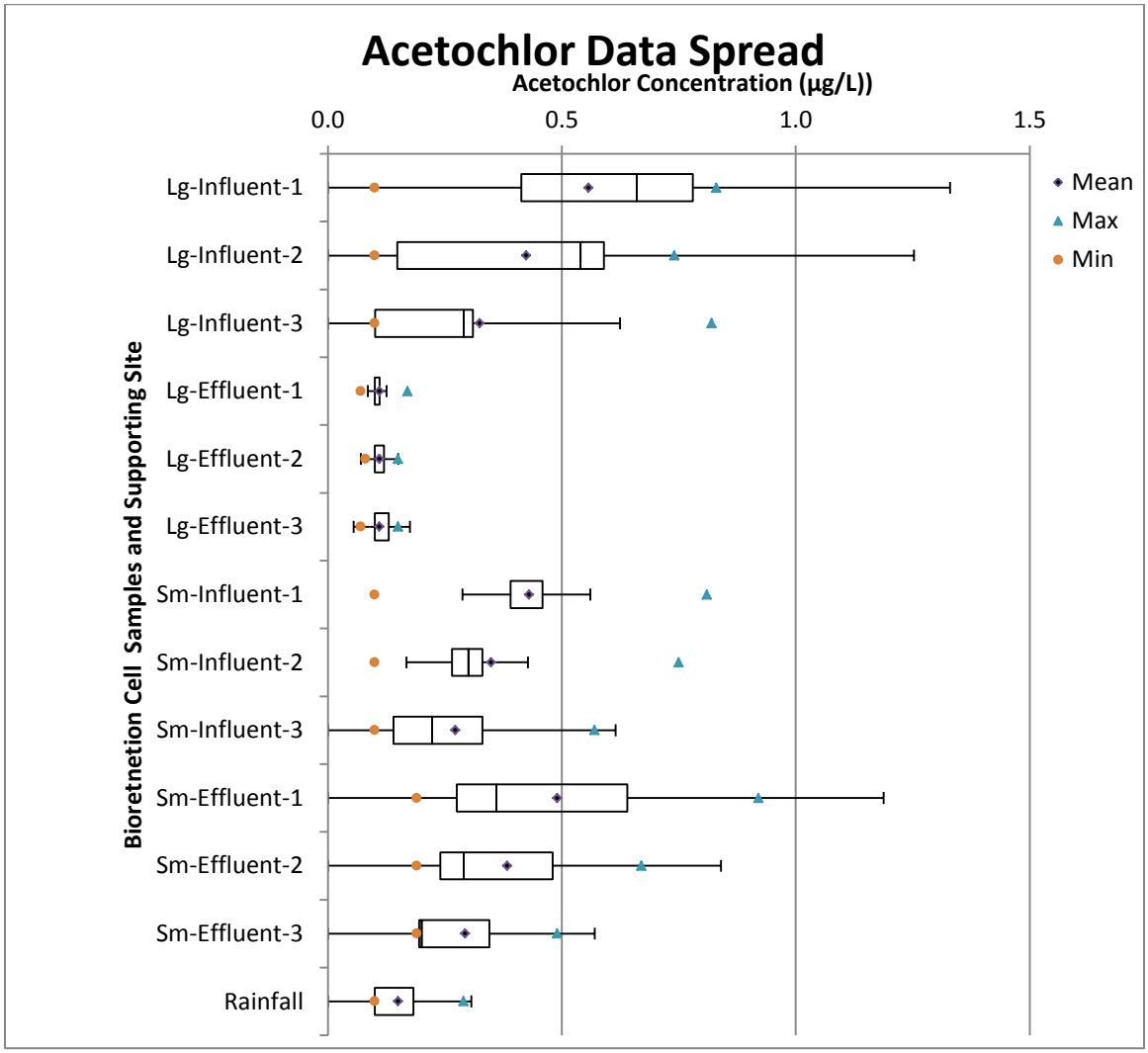

Figure 30 Acetochlor Data Spread

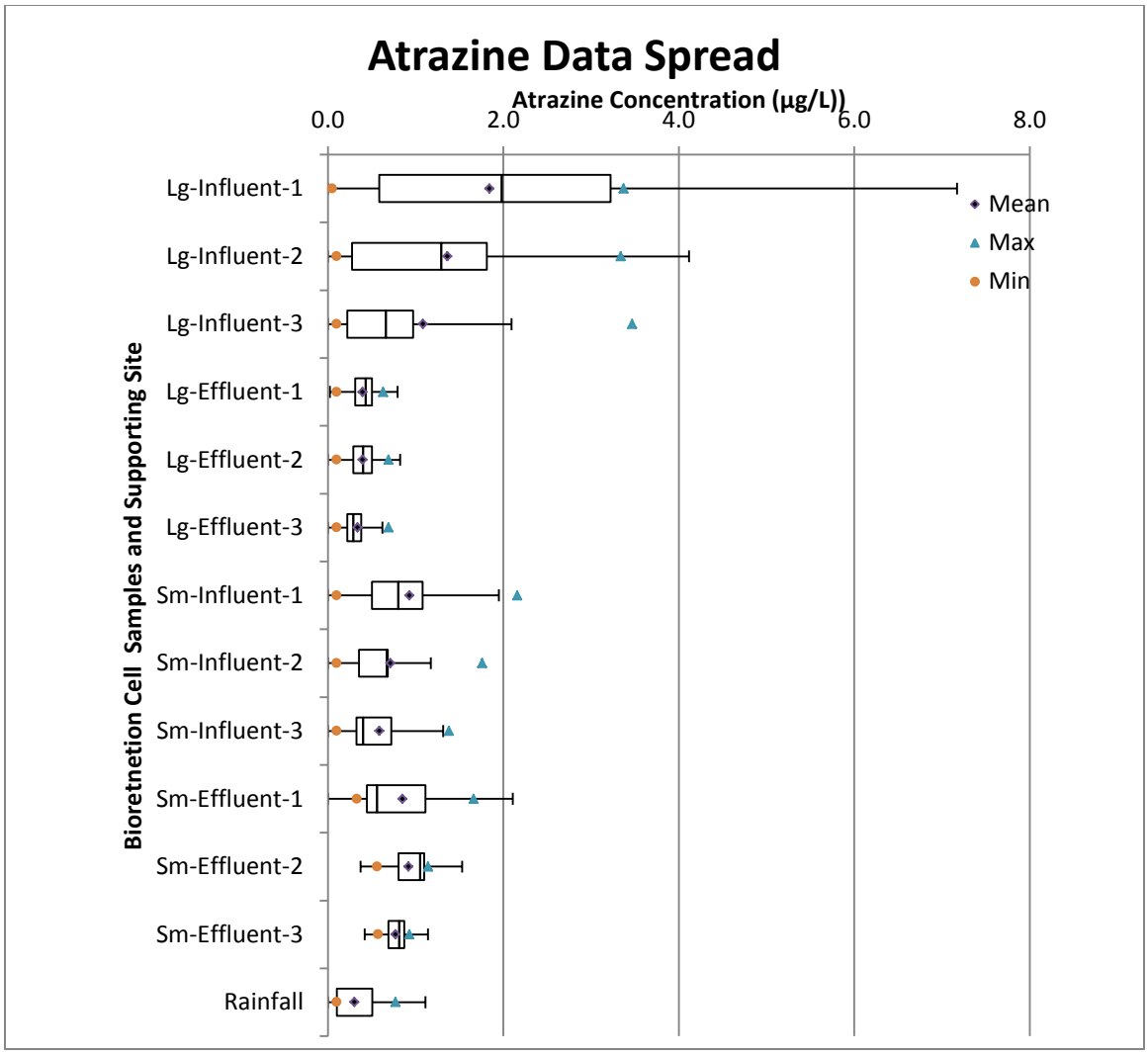

Figure 31 Atrazine Data Spread

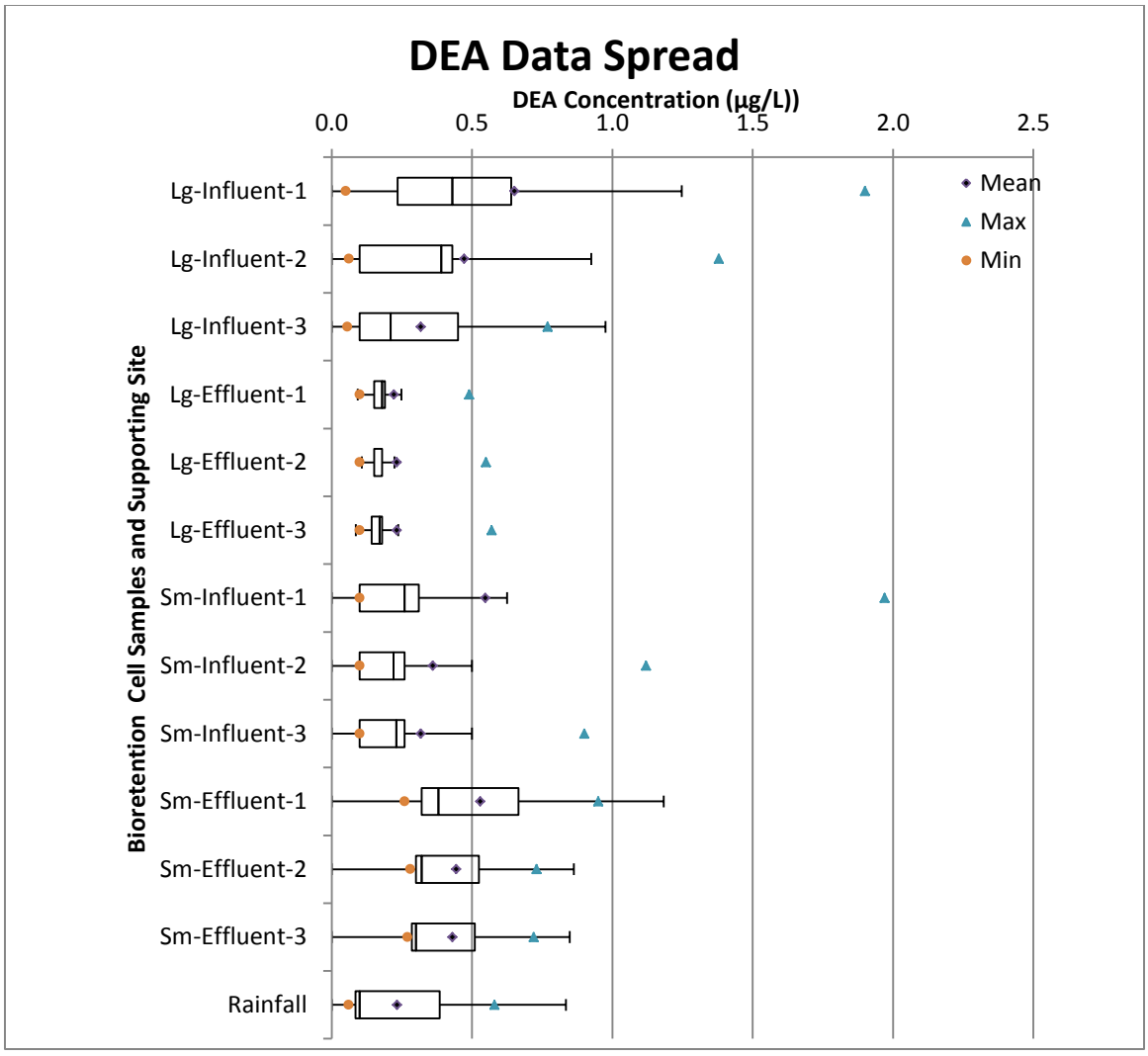

Figure 32 DEA Data Spread

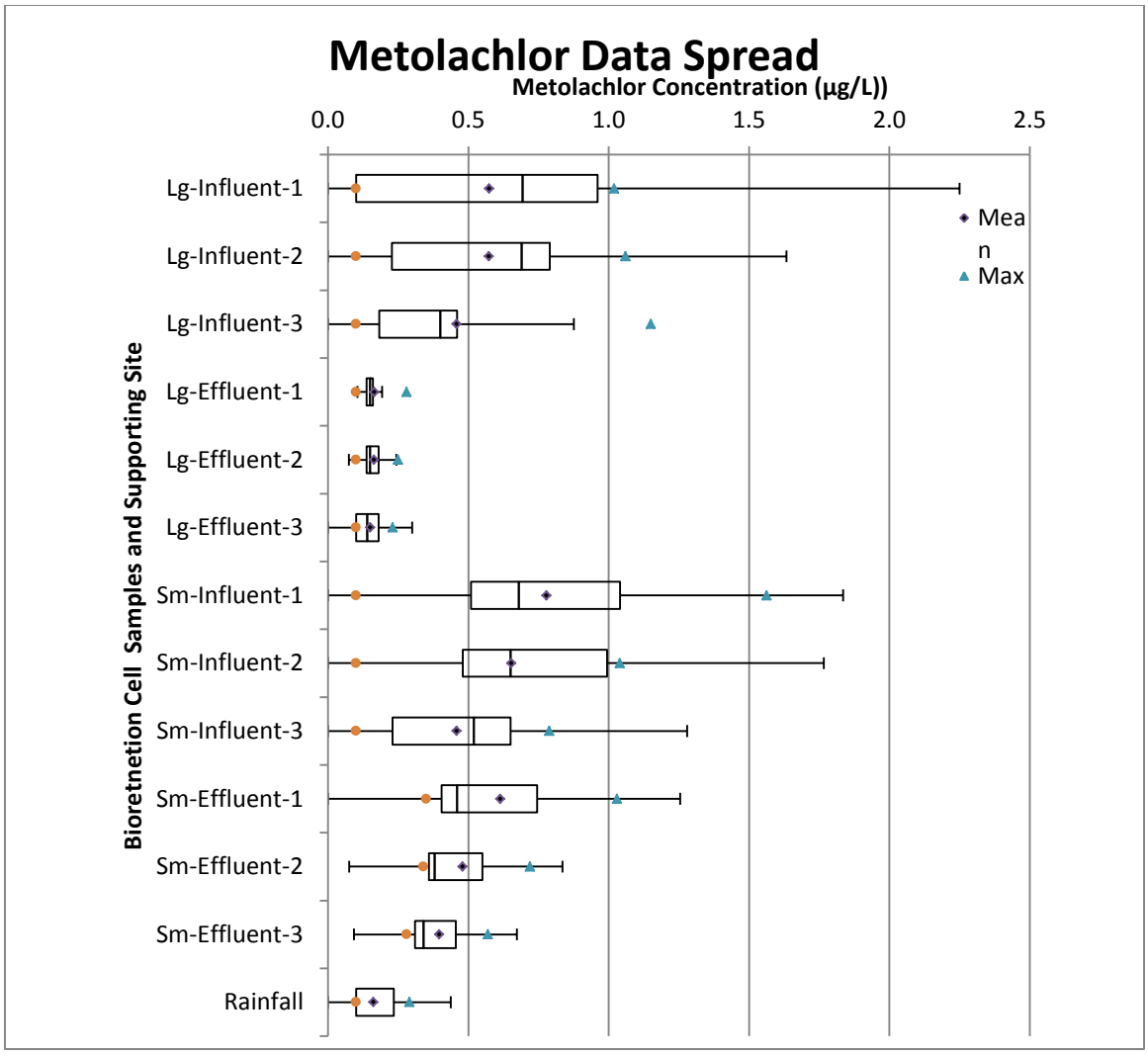

Figure 33 Metolachlor Data Spread

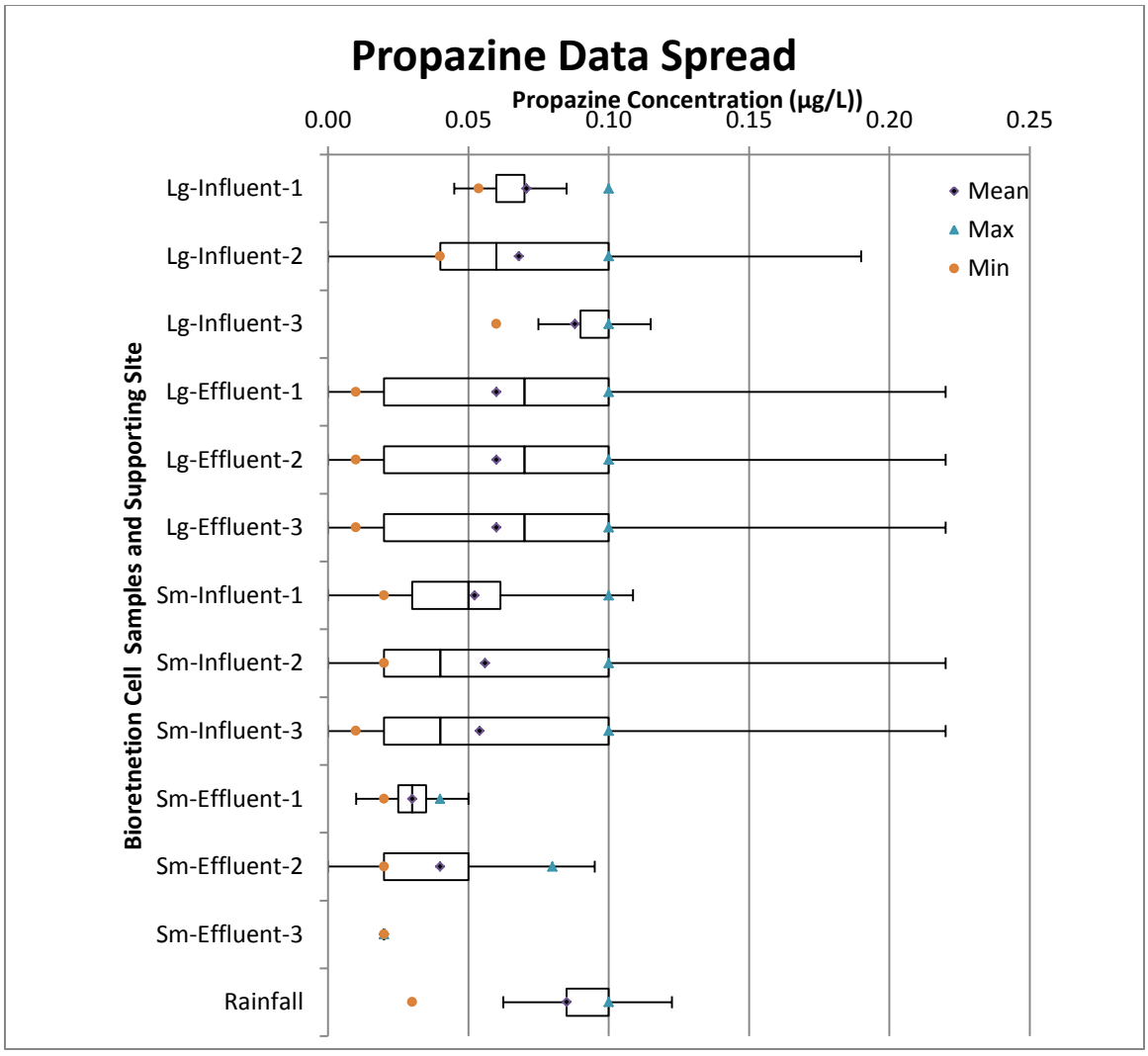

Figure 34 Propazine Data Spread

Chapter 5 Results and Discussion

Abstract

Comparing the average influent against the average effluent, both the large and small bioretention cells had pollutant reductions (+) respectively for metolachlor 70%/21%, propazine 21%/45%, TKN 28%/9%, zinc 49%/69%, total fecal coliform 99.6%/88%, total E.coli 97%/66%, TSS 93%/71%, and oil/grease 52%/17% , while cells were a source(-) for nitrate -431%/-91%, and TDS -79%/-41%. The cells differed in pollutant removal/source for acetochlor, atrazine , DEA, total phosphorus and conductivity as the large cell had pollutants calculated at; 75%, 75%, 52% -255% and -45% respectively, while the small cell measured opposite of what the large cell at; -11%, -14%, -14% 5% and 25% respectively.

Concentrations of pollutants in the rain garden runoff were 51% and 66% less than residential rooftop runoff for zinc and nitrate respectively. Concentrations of pollutants TKN and total phosphorus measured in the rain gardens runoff were 15% and 129% respectively greater than residential rooftop runoff.

Statistical differences calculated between each of the cells influent samples quantified evidence of first flush for some pollutants. Statistical differences calculated between each of the cells influent and effluent quantified evidence that cells were either acting as source or effectively removing certain pollutants. Other quantifiable parameters such as narrow range of pollutant removal, higher pesticide levels in the effluent and observations of high and fast runoff flows, seem to indicate that the small cell was under-designed or exhausted its pollutant removal capabilities.

Additional research supporting sites included samplers for two rainfall, six rain garden, two commercial rooftop, two commercial parking lot, and six residential rooftop

sites. These supporting sites helped determine background concentrations of pollutants for the bioretention cells' influent. Pollutants measured at the rainfall supporting sites indicate that rainfall contributed a majority of pollutants to both cells. This was supported by similarities seen between the rainfall and bioretention cell for seasonal changes and statistically similar pollutant levels during the same storm event. Pollutants measured at all of the sites showed a decreasing trend from spring to late summer, with the exception of zinc.

Recommendations for future study include increased flow monitoring and increasing the stormwater collection points at supporting sites. These changes would allow better elimination of the experimental errors that could arise in the analysis of the data.

Introduction

A statistical analysis for finding differences in treatment groups for each pollutant was completed for the following: influent/effluent, first flush effects, seasonal effects and rainfall sites contributing to the influent. Statistical analysis was completed using SAS programming for all statistical comparisons. All statistical analyses for each site will use the same datasets as seen in Chapter 4 Results, Table 19 Samples Used for Analysis. Oil and grease samples had few outliers, with the majority of samples having no data, a rainfall depth vs. oil and grease concentration was not determined in this study.

Comparison of stormwater makeup found in this research was compared to stormwater makeup reported in previous studies. Conclusions and recommendations will be discussed because of the analyses completed in this section.

Pollutant comparison was calculated by comparing the residential rooftop samples against rain garden samples.

Multiple Comparisons of Treatment Means

Statistical comparison used Tukey's analysis and a 95% confidence level $p < 0.05$. The average mean of the site is used for Tukey's statistical comparison by using a studentized range or the difference between the largest and smallest values in a test sample measured in units of the test samples standard deviation, allowing comparison of all ranges of data against each treatments in order to determine if the two treatments compared are significantly different (Mendenhall & Sincich, 2007). All treatments must have equal treatment sizes using Tukey's method of statistical analysis. The null hypothesis for the statistical analysis if $p<0.05$, reject the null hypothesis and accept the alternative hypothesis. All parts of Tukey's method and model are explained in Equation 12 and Equation 13 in Appendix D. Figure 35 below shows all of the sample sites grouped together to show treatment means for the statistical analysis.

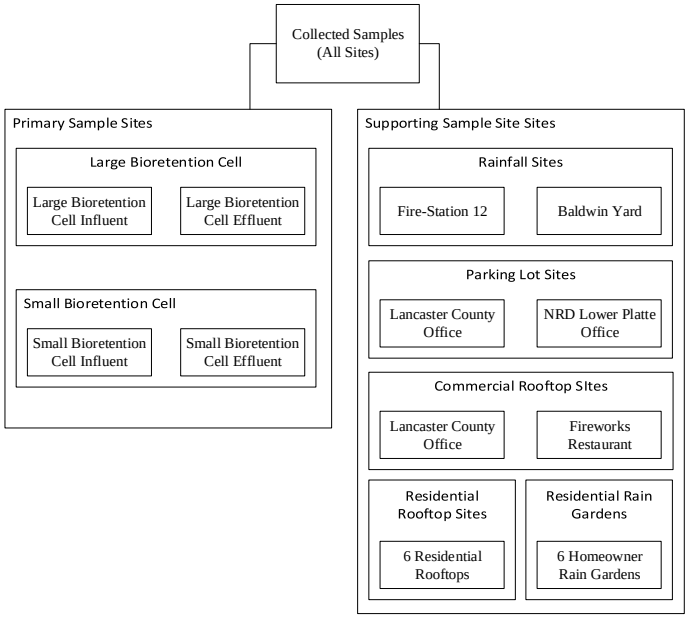

Figure 35 Sample Sites Grouping for Treatment Analysis

Bioretention Cells First Flush

Statistical comparison of each pollutant against each of the three influent samples collected from each cell was calculated to determine if stormwater going into the cell had

a first flush effect. The null hypothesis for this analysis is each individual pollutant does not have a first flush effect on the collection of influent at different times. If the p value was <0.05, the null hypothesis is rejected and state that influent samples for that particular pollutant are statistically different, indicating a possible first flush effect.

The large bioretention cell had calculated statistical differences for TKN, zinc and TSS with measured p values of 0.0024, 0.0044 and 0.0092, respectively. The small bioretention cell experienced no first flush effects for any pollutant. Total fecal coliforms could not be determined in this analysis, as the data spread was too wide to do a complete analysis of the data leading to inconclusive results. All tables associated with the first flush analysis in the bioretention cell are listed in Appendix G SAS Programming p value Tables, Table 66 and Table 67.

Bioretention Cells Influent Composition and Contribution

The rainfall supporting sites were compared to the bioretention cells influent to determine its contribution to pollutants in the cell influent. The null hypothesis stated that rainfall does contribute to the cell influent and if a p value was <0.05, is rejected and the supporting sites samples for that particular pollutant are statistically different indicating the rainfall site does not contribute to the cells stormwater influent makeup. Each rainfall site and bioretention cell compares all collected data points for that particular dataset as seen in Chapter 4 Results, Table 19 Samples Used for Analysis. Other supporting sites were not statistically compared to the bioretention cells, as they did not contribute any stormwater to the bioretention cell; thus, they could not be compared.

Rainfall Vs Bioretention Cells

TKN, total phosphorus, zinc, conductivity, atrazine and DEA for both the Fire-Station 12 and the city of Lincoln Baldwin municipal yard were not statistically different

against bioretention cell influent with statistically measured values of p=0.3085/0.3006, p=0.3853/0.3496, p=0.3908/0.9462, p=0.2304/0.1296, p=0.1574/0.1296 and p=0.1208/0.131 respectively. This analysis concludes that rainfall contributes TKN, total phosphorus, zinc, conductivity, atrazine and DEA to the cells stormwater composition. Each site was indeterminate for propazine as both had differences in statistical analysis for each pollutants, this could possibly mean that vapor drift occurred greater at some areas. All p values tested for the rainfall vs the bioretention cells are listed in Appendix G SAS Programming p value Tables, Table 68.

Bioretention Cell Influent and Effluent Statistical Comparison

Statistical analysis of each pollutant between the influent and effluent of the cells was completed in order to determine if pollutant removal or source capabilities in the cells are significant. The null hypothesis for comparing each of the cells was both the influent and effluent are not statistically different. If $p<0.05$, reject the null hypothesis and accept that the influent and effluent are statistically different.

The large bioretention cell showed statistical difference for nitrate, total phosphorus, zinc, total E.coli, TSS, acetochlor, atrazine and metolachlor with p values measured to be 0.0006, 0.0001, 0.032, 0.0431, 0.0016, 0.0003, 0.071 and 0.0016 respectively with nitrate and total phosphorus acting as a source, while zinc, total E.coli, TSS, acetochlor, atrazine and metolachlor, were removed. All details about the statistical analysis for influent and effluent comparison for the large bioretention cell are listed in Table 65, Appendix G SAS Programming p value Tables.

The small bioretention cell showed statistical difference for only zinc with a measured p value of 0.0229, with suspecting pollutant approaching statistical significance confidence level for nitrate and TSS, with p values measured to be 0.0562 and 0.0591

respectively with nitrate acting as a source, while zinc and TSS were removed. All details about the statistical analysis for influent and effluent comparison for the small bioretention cell are listed in Table 65, Appendix G SAS Programming p value Tables.

Seasonal Pollutant Changes Analysis

Seasonal statistical analysis was completed for each of the sites individually as well as all of sites as a whole to determine if pollutant concentration shift as the seasons progress. The null hypothesis stated that seasons would not affect pollutant concentrations measured at each of the sites; if rejected, seasons do affect the pollutants concentrations. The seasonal statistical analysis broke down samples into treatment groups collected during the spring, summer and late summer. Statistical analysis of the seasonal changes is listed in Appendix G SAS Programming p value Tables, Table 69 through Table 80. In addition to the statistical analysis, graphs of the seasonal trends for each of the pollutants were compiled. Each site took averages for each pollutant over the seasons and graphed the average values against the seasons in which they corresponded. All seasonal graphs are shown in Appendix F Graphs, Figure 76 through Figure 96.

Comparing all the sites as a whole, pollutants were statistically different for, TDS, acetochlor, atrazine, DEA, metolachlor and propazine, and had an overall decreasing trend compared from spring to late summer for the majority of the sites. All p values tested for seasonal analysis are listed in Appendix D: SAS Programming p value Tables, Table 43 All Sites Seasonal Analysis Comparison.

Bioretention Cells Seasonal Changes

Seasonal comparison of the large bioretention cell influent pollutant levels found total phosphorus, TDS, acetochlor, atrazine, DEA, metolachlor and propazine with p values calculated to be 0.0014, 0.0106, 0.0001, 0.0002 and 0.0135 respectively. These

pollutants found, had a decreasing trend when concentrations of the pollutants were compared from spring to late summer. All seasonal trends for pollutants tested in the large bioretention cell are shown in Figure 76 through Figure 80 in Appendix F Graphs.

Statistical seasonal comparison of the small bioretention cell influent found nitrate, total phosphorus, TSS, acetochlor, atrazine, metolachlor and propazine to be statistically different with p values calculated to be 0.0271, 0.0053, 0.0058 and 0.0005 and showed nitrate and total phosphorus increase from spring to late summer while all other pollutants decrease from spring to late summer.

Although total E.coli and total fecal coliforms were inconclusive, these pollutants trended upward from spring to late summer for both cells. All seasonal trends for pollutants tested in the small bioretention cell are shown in Figure 81 through Figure 85 in Appendix F Graphs.

Parking Lot Seasonal Changes

Seasonal comparison of the parking lots found no pollutants to be statistically different as levels stayed static from spring to late summer. All seasonal trends for pollutants measured in the parking lot sites are shown in Figure 86 and Figure 87 in Appendix F Graphs.

Commercial Rooftop Seasonal Changes

Seasonal comparison of the commercial rooftops found no pollutants to be statistically different as levels stayed static from spring to late summer. No samples were collected from the summer sampling period, more of these samples are needed to better solidify conclusions made. Although total E.coli and coliforms were inconclusive statistically, these pollutants trended upward from spring to late summer. All seasonal

trends for pollutants measured for commercial rooftop sites are shown in Figure 88 through Figure 91 in Appendix F Graphs.

Residential Rooftop Seasonal Changes

Seasonal comparison for residential rooftops pollutant found the nitrate statistically different with a p value calculated of 0.0036. Nitrate was shown to trend upward from spring to late summer from residential rooftops. All seasonal trends for pollutants measured for residential rooftop sites are shown in Figure 92 and Figure 93 in Appendix F Graphs.

Rainfall Seasonal Changes

Seasonal comparison of rainfall pollutant found TKN, nitrate, total phosphorus, atrazine, DEA and metolachlor statistically different with calculated p values of 0.0009, 0.0008, 0.0033, 0.0061, 0.0065 and 0.0001 respectively and decreased from spring to late summer. All seasonal trends for pollutants measured for rainfall sites can be seen in Figure 94 through Figure 96 in Appendix F Graphs.

Characterization and Comparison of Stormwater Runoff

Stormwater runoff pollutant concentrations measured at supporting sites were compared to previous field studies. Most of these field studies were limited in what pollutants were analyzed compared to this field study. All values; including this study, had average values calculated in order to simplify the analysis.

Parking Lot vs. Field Studies

Three field studies measured pollutants concentration occurring from parking lots as described in Chapter 2: Literature Review. Pollutants, TDS, conductivity, and oil/grease were not measured in any of these previous studies. Table 21 shows the

parking lot runoff comparison from this study; highlighted in bold, against other the other previous studies as explored in the literature review section.

Table 21 Parking Lot Stormwater Runoff, Collected vs Literature Review Comparison

Pollutants	Units	Average Parking Lot Runoff Values From Literature Review or This Study				
		Reviewed Study				
		This Study	31*	2**	3***	4****
TKN	mg N/L	**2.60**	0.56	0.55		
Nitrate	mg-N/L	**0.40**	0.27	0.28		0.14
Total P	mgP/L	**0.21**	0.11	0.11	0.895	1.51
Zinc	ug/L	**13.65**	45.70	43.80		118.11
TSS	mg/L	**19.12**	11.24	13.45	51.4	39.00

**Rushton, 2001(F1)*
***Rushton, 2001(F2)*
****DeBusk & Wynn, 2011*
*****Davis, 2007*

Total phosphorus, nitrate and TSS pollutants measured in the study had averages comparable to what was observed in the previous three studies. TKN and nitrate, were found to have average values outside of the previous studies, it is unknown as to the nature of why these nutrients have higher levels than previously found in studies.

Commercial/Residential Rooftop vs. Previous Studies

Two field studies measured pollutant concentration for stormwater runoff occurring from residential rooftops and commercial rooftops. Pollutants, zinc, total E.coli and total fecal coliforms, were not measured in any of these previous studies. Table 22 shows the commercial and residential rooftop runoff comparison from this study against other the other previous studies as explored in Chapter 2: Literature Review.

Table 22 Commercial/Residential Rooftop Stormwater Runoff, Collected vs Literature Review Comparison

Pollutant	Units	Average Commercial/Residential Rooftop Runoff Values From Literature Review or This Study				
		Reviewed Study				
		This Study Commercial Rooftop	This Study Residential Rooftop	1*	2**	3***
TKN	mg N/L	**5.53**	**2.78**		0.5	
Nitrate	mg-N/L	**1.14**	**0.42**	0.81	0.5	0.19
Total P	mgP/L	**0.20**	**0.20**	0.1	0.01	0.37

**Carpenter & Kaluvakolanu, 2011-Stone Roof*

***Dietz & Clausen, 2006-Asphalt Roof*

****Carpenter & Kaluvakolanu, 2011-Asphalt Roof*

Total phosphorus and nitrate measured in this study from commercial rooftops and residential rooftops had average values comparable to what was observed in previous field study. TKN was found to have average values outside of the previous studies for both the commercial rooftop and residential rooftop. TKN levels in stormwater runoff may be influenced by geographical location or its surrounding environment.

Rainfall

Only one field study measuring rainfall pollutants (pesticides) was completed in the state of Nebraska (Vogel et al. 2008). Pesticide levels measured in the rainfall along with rainfall amount can be seen in Figure 36 and Figure 37. Each of the five pesticides seen in the USGS study showed elevated levels in the spring, gradually decreasing as the growing season progressed from spring to fall.

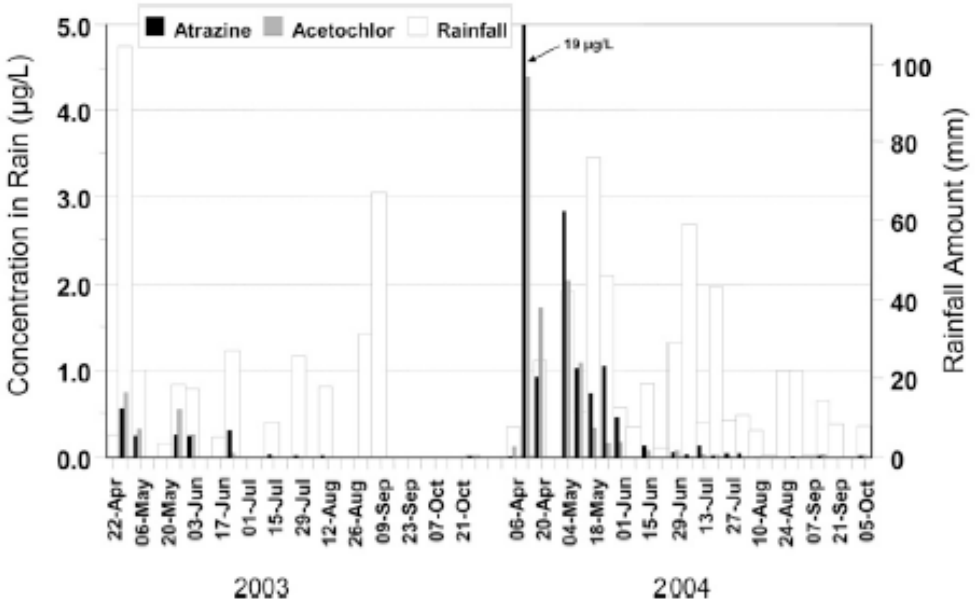

Figure 36 Atrazine and acetochlor concentrations in weekly composite rain samples, plus weekly rainfall amounts, at the rain sampling site in Nebraska during the growing season in 2003 and 2004

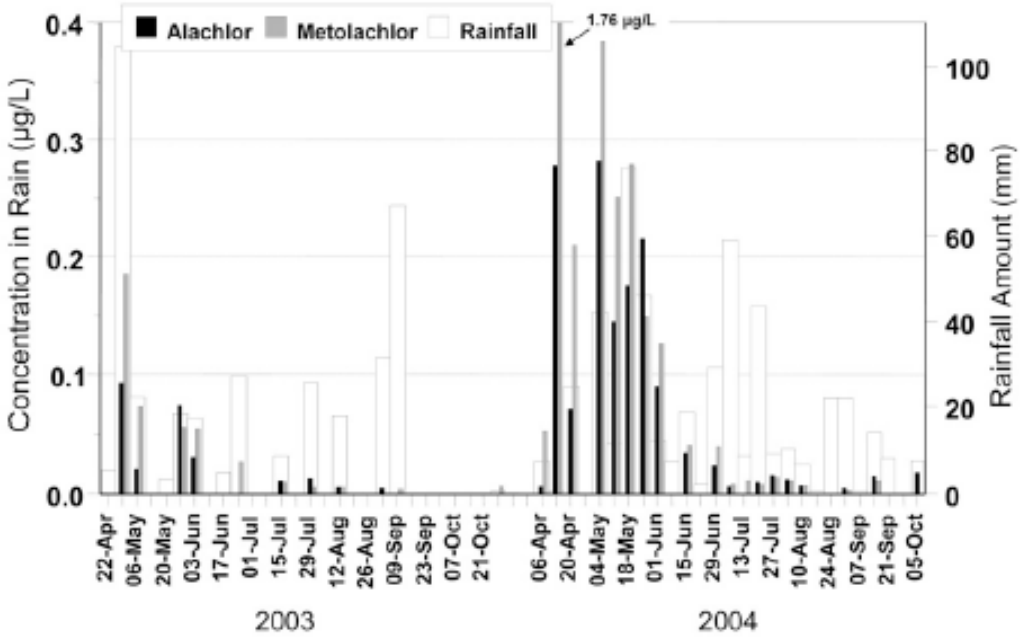

Figure 37 Alachlor and metolachlor concentrations in weekly composite rain samples, plus weekly rainfall amounts, at the rain sampling site in Nebraska during the growing season in 2003 and 2004

Levels of atrazine and acetochlor seen in the USGS study were much greater than pesticide levels detected in this research study; while metolachlor levels were similar. Table 58 and Table 60 show all of the pesticides measured in the rainfall for this study,

Bioretention Cells Influent/Effluent Analysis

Pollutant removal or source analysis for each cell was calculated for the influent and effluent. Averages for both the influent and effluent were calculated over the three samples taken at the same storm event for each of the cells using Equation 1. Calculated pollutant removal or sources for the cells were graphed for non-pesticides and pesticide pollutants shown in Figure 38 and Figure 39, with blue and red bars representing the large and small bioretention cell respectively.

Equation 1 Pollutant Removal

$$Pollutant\ Removal = \frac{Average\ Influent - Average\ Effluent}{Average\ Influent} * 100$$

Where:

Pollutant Removal =Reduction () or increase (+) of selected pollutant

Average Influent=Average selected pollutant influent averaged over the three samples collected (In1, In2 and In3)

Average Effluent= Average selected pollutant effluent averaged over the three samples collected (Out1, Out2 and Out3).

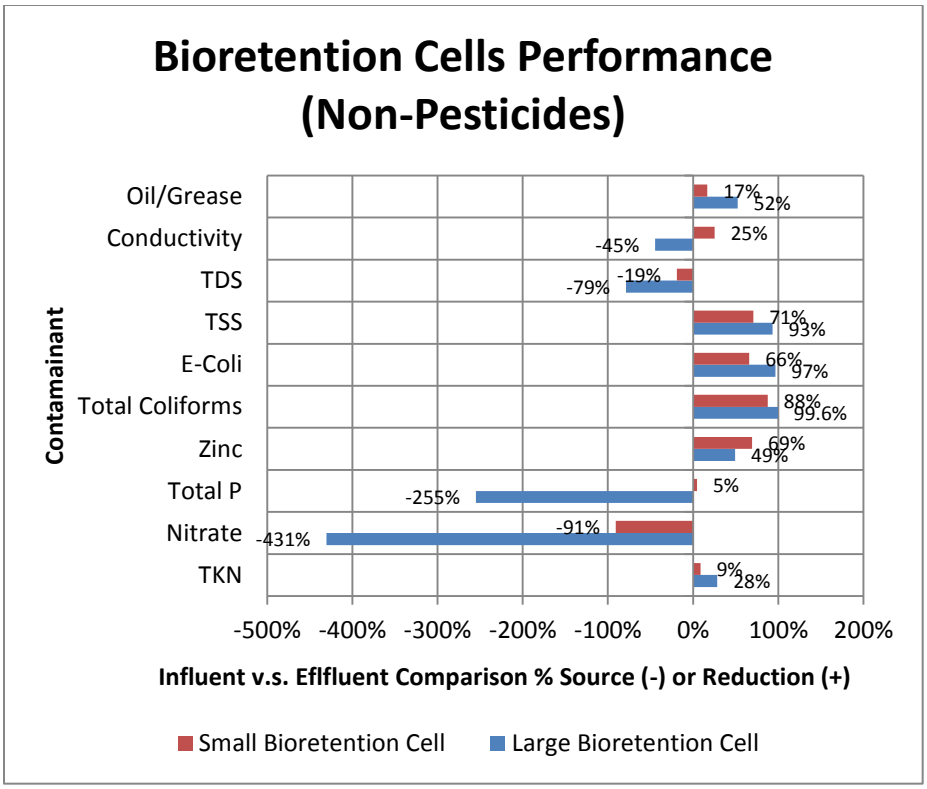

Figure 38 Bioretention Cells Performance (Non-Pesticide Pollutants)

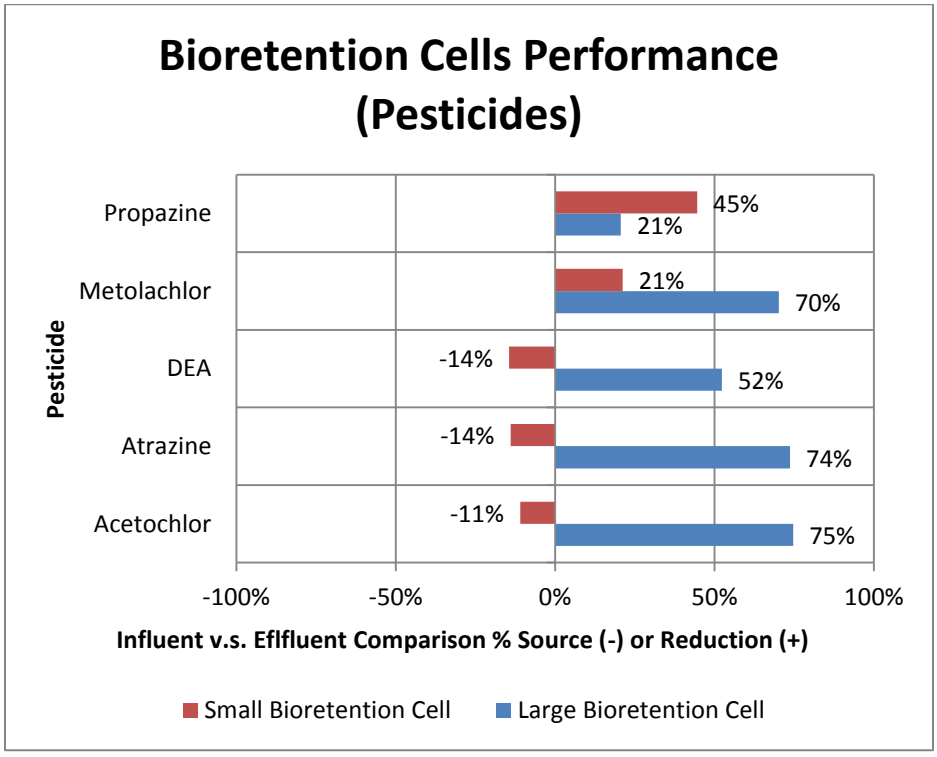

Figure 39 Bioretention Cells Performance (Pesticide Pollutants)

TKN

Minimal pollutant reduction was shown in TKN for both large and small bioretention cells, calculated as 28% and 9% respectively. TKN field studies cited in the literature review showed similar reduction in TKN ranging from 45% to -4.9% in one study, similar to what was observed in this research study. (Hunt et al. 2006). The range of TKN reduction or sources in previous field study's tested different P-index soils, and observed the higher the P-index soil (20-26); characterizes by high organic content, is less likely the bioretention cell is capable of removing TKN from stormwater. This research had a soil composition with high organic content and confirmed this observation, demonstrated through poor TKN removal.

Nitrate

Both cells acted as sources of nitrate for both the large and small bioretention cell, calculated as -431% and -91% respectively. A previous field study had observed nitrate pollutant removal efficiency for bioretention cells to be 86% (Davis, 2007). The Davis, 2007 study used a soil media composition: 50% sand, 30% topsoil and 20% mulch, while the soil media used in this study had closer to 50% compost, 40% sand and 10% topsoil. This difference in soils, could explain the disparity between the study and this research.

Total Phosphorus

Total phosphorus measured in both the large and small bioretention cells showed a disparity between the cells with calculated values of, -255% and 5% respectively. Previous field studies have observed total phosphorus reduction or sources from bioretention cells ranging from 99% to -240%. A field study that used a very high P-index soil (86-100) saw bioretention cells either act as a source or reduce total phosphorus in the stormwater as pollutant removal efficiency was seen between 39% to -

240%, similar to what was observed in this research study (Hunt et al. 2006). Other literature review field studies that had high pollutant removal efficiency had soil media mixtures that were sandier, and having low P-index rating for the soil (University of New Hampshire Stormwater Center, 2010; Davis, 2007). A literature field study that saw a 99% total phosphorus pollutant removal efficiency, completed a cumulative mass removal analysis with few data points, this field study could not be compared to this research study as cumulative mass removal was not completed in the analysis (DeBusk & Wynn, 2011).

Conductivity

Conductivity measured for both the large and small bioretention cells saw a disparity between them with a calculated value of -45% and 25% respectively. No bioretention field studies tested conductivity pollutant removal analysis; therefore, no comparisons of conductivity could be compared. The large cell was a greater source of nutrient pollutants than the small cell and mirrors removal capabilities compared since the more dissolved pollutants affect conductivity.

Total Dissolved Solids (TDS)

TDS acted as a source for both the large and small bioretention cells showed by a calculated -79% and -41% respectively. No bioretention field studies tested TDS pollutant removal analysis; therefore, no comparisons of TDS could be compared. The large cell was a greater source of nutrient pollutants than the small cell and mirrors removal capabilities compared since the more dissolved pollutants affect conductivity.

Total Suspended Solids (TSS)

TSS was reduced for both the large and small bioretention cells at 93% and 71%, respectively. Bioretention field studies saw similar TSS pollutant removal rates

measuring between 97% to 41% removal rates. TSS pollutant removal was affected by the depth of the soil media as one field study noted that TSS was observed to have an 87% and 97% TSS pollutant efficiency rate for soil depths at 30 and 48 inches (University of New Hampshire Stormwater Center, 2010). The city of Lincoln confirmed that the soil depth in the large cell was deeper than the small cell, supporting the field study that had high removal rates for much higher soil depth. The Davis, 2007 study evaluated bioretention cell field performance, found a low TSS removal efficiency rate with a media composition of 50% sand, 30% topsoil and 20% mulch, topsoil.). The soil media used in this research was closer to 50% compost, 40% sand and 10% topsoil, the different soils used in the research and the study mentioned in the previous sentence could explain the disparity between the TSS removal rates.

Zinc

Zinc removal was observed to be much higher in the small cell than the large cell calculated at, 69% and 49% respectively. A field study saw a 63% removal of zinc over a 2-year study testing the field performance of bioretention cells (Davis, 2007). The field study and this research study had similar Zinc removal rates even though soil media composition and zinc influent concentrations were different. Another possible explanation of similar removal rates is zinc degradation is not affected by different soil media compositions.

Oil and Grease

Both the large and small bioretention cell showed some oil and grease removal calculated as 52% and 17% respectively. No bioretention field studies tested oil/grease pollutant removal analysis; therefore, no comparisons of oil/grease could be done. All sites measured the majority of oil and grease samples below the detectable limit.

Total E.coli/Fecal Coliform

Total E.coli and total fecal coliform removal in the large bioretention cell saw a 97% and 96.2% removal respectively, while the small bioretention cell had a 66% and 88% removal respectively. These removal rates were similar to what was found in a field study, finding 92% to 89% pollutant removal for E.coli and fecal coliforms. The lower removal rates seen in the small bioretention cell could be the result of the high flow rates diluting the influent sample.

Acetochlor

Acetochlor was removed in the large bioretention cell calculated having a 75% reduction; however, the small bioretention cell showed it acted as a source having an -11% increase. No bioretention field studies tested acetochlor pollutant removal analysis; therefore, no comparisons of acetocholor could be done.

Atrazine/DEA

Atrazine was removed in the large bioretention cell calculated having a 74% reduction; however, the small bioretention cell showed it acted as a source having an -14% increase. DEA; a byproduct of atrazine breaking down, similarly was found to have pollutant removal in the large bioretention cell having a 52% reduction with the small bioretention having it act as a source with a 14% increase. The Yang at al., 2013 field study saw 90% atrazine removal, similar to atrazine removal in the large bioretention cell; 74%, in this study. All other pesticides that were tested in this research study had no field studies on bioretention cell removal efficiency.

Metolachlor

Metolachlor was removed in the large bioretention cell calculated having a 70% reduction; however, the small bioretention cell showed it acted as a source having an -

21% increase. No bioretention field studies tested metolachlor pollutant removal analysis; therefore, no comparisons of metolachlor could be done.

Propazine

Propazine was removed in the small bioretention cell having a 45% reduction; however, the large bioretention cell showed it acted as a source having a -21% increase. No bioretention field studies tested propazine pollutant removal analysis; therefore, no comparisons of propazine could be done.

Rain Garden Pollutant Removal

Comparison of the pollutant differences between the rain gardens and residential rooftop used the same equation for the bioretention cells; Equation 1 Pollutant Removal. Figure 40 shows the average pollutant removal efficiencies for the four pollutants tested.

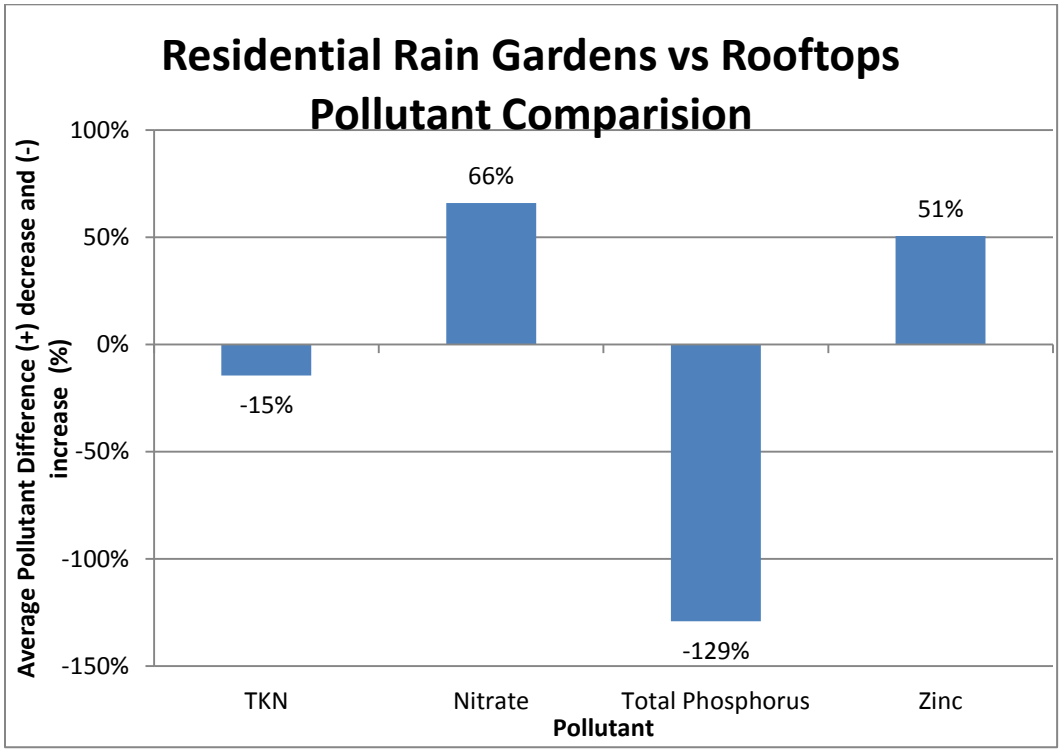

Figure 40 Residential Rain Gardens Pollutant Comparison

TKN

TKN in the residential rain gardens showed an increase pollutant difference of 15% when comparing to residential rooftops levels. A field study of rain gardens showed a 35.4% reduction in TKN when tested over a 2-year study that took influent directly from a residential rooftop downspout, citing that mass retention of total nitrogen is poor in rain gardens due to possible disturbance (Dietz & Clausen, 2005).

Nitrate

Nitrate in the residential rain gardens showed an decrease pollutant difference of 66% when compared to the residential rooftops. A field study of rain gardens showed a 31.2% reduction in TKN when tested over a 2-year study that took influent directly from a residential rooftop downspout, citing that mass retention of total nitrogen is poor in rain gardens due to possible disturbance (Dietz & Clausen, 2006). The field study concluded that installation of an underdrain in the tested rain garden could have hindered nitrate removal; however, this research observed a higher nitrate comparison without an underdrain in any of the sampled rain gardens.

Total Phosphorus

Total phosphorus in the residential rain gardens showed an increase pollutant difference of 129% when compared to residential rooftops. Field studies of rain gardens have observed total phosphorus reduction and sources 60% to -110.6%, similar to what was observed in this study. A similar study that observed -110.6% pollutant removal efficiency cited, disturbance in the rain garden as a likely source for the excess total phosphorus (Dietz & Clausen, 2005).

Zinc

Zinc in the residential rain gardens showed an increase pollutant difference of 51% when compared to the residential rooftops. No rain garden field studies tested zinc pollutant removal analysis; therefore, no comparisons of zinc could be done. Rooftop sources may have built up in the rain garden and may not have the capabilities to reduce zinc effectively like the bioretention cells.

Conclusions

Table 23 and Table 24 show the summary for percent mitigated (- or +), influent/effluent statistically different, influent statistically seasonally different, first flush statistically measured and pollutant source/removal for the large and small bioretention cell respectively. Table 25 shows the summary of supporting sites that contribute pollutants to bioretention cells influent pollutant makeup.

Pollutant makeup of stormwater runoff measured in this study from parking lots, commercial rooftops and residential rooftops were similar to what was measured in field studies quantifying runoff. TKN measured in field studies for parking lots and rooftops, was less than what was measured in this research study. This disparity shows that TKN pollutant levels are subject to the geographical location or that some form of TKN production might exists on the research sampling sites. Zinc measured from the parking lot and compared to field studies was found to be different in the field studies; this is likely due to different traffic patterns, supported by the fact that parking lots sampled for this research were significantly lower than what was observed in the bioretention cells influent. The traffic patterns at these multiple locations were different and may have had an impact on zinc concentrations. More information from field studies is needed help quantify the pollutant makeup of stormwater for Zinc and TKN.

Statistically comparing the influent and effluent showed zinc the only different pollutant for the small cell, while the large cell had different pollutants nitrate, total phosphorus, zinc, acetochlor, atrazine and metolalchor statistically different. The similarity in zinc removal from each cell lead to conclude that zinc was the only pollutant removed effectively that was not affected by the runoff's contributing area, flow rate and size of the bioretention cell and could be dependent on the soil media. Each pollutant in both cells was measured to statistically change seasonally, with the exception of nitrate in the large cell. This similarity between the cells concludes that rainfall greatly contributes to the pollutant makeup into the cells shown by seasonal changes in the cells. The evidence is supported in Table 25 showing rainfall sites having pollutants statistically changed seasonally, similar to what was shown for each bioretention cell and supported by other sites' pollutant measurements did not statistically change seasonally. If the bioretention cells had these sites contribute to the pollutant makeup of the cells influent, no seasonal change would have been observed, which was not seen in Table 25.

Possible sources of errors in the statistical analysis could be the result of pollutants that were measured below the detectable limit. The statistical analysis model used for the analysis did not take into account the weight of these pollutants that were measured below the detectable limit; mainly, pesticides. This could have caused some of the pesticides determined to be not statistically different in being efficiently removed in the bioretention cells to actually have been removed. Future investigations of how to properly weight the data in a statistical analysis should be completed in the future.

The differences in removal or sources between the cells lead to conclude that the small cell was under designed and had a fast flow leading to a small retention time. This

claim is supported by the large cell having multiple pollutants removed, while the small cell had a narrower range of pollutant removed for the same pollutants removed in the large cell. If both bioretention cells had similar flow rates, similar removal patterns would be seen for each cell. An example of this claim is shown in the pesticide removal in the large cell compared to the small cell, as the large cell saw high pesticide removal rates, while the small cell had instances where the effluent had a higher pesticide concentration compared to the influent. This disparity between the two cells is the result of that fast flow of runoff entering the small cell dilutes the pesticides in the runoff, leading to a much lower concentration than what was measured in the effluent. The conclusion about the small cell having a short retention time is also supported by no statistical evidence showing any first flush detected for the small cell while the large cell measured multiple instances of it. A fast runoff flow would dilute the pollutants quickly, leading to no observable first flush.

Pollutants measured at rainfall sites showed little variation compared to bioretention cells influent, with the expectation of nitrate, concluding that rainfall accounts for the vast majority of pollutant makeup in stormwater runoff.

Rain gardens compared to residential rooftop samples showed lower concentrations of nitrate and zinc, while TKN and total phosphorus had higher concentrations compared to the rooftops. Possible explanations for increases in TKN and total phosphorus could be the result private application of lawn fertilizer, organic matter in the rain garden from decaying biomass or some type of nutrient supplement for plants. The seasonal changes between residential rooftop could not be ascertained due to only

spring samples were collected for the rain gardens. Further evaluation of seasonal sample collection for the rain gardens needs to be completed in order for future analysis.

Table 23 Large Bioretention Cell Analysis Summary Table

Pollutants	% Mitigated	Influent Effluent Statistically Different?	Influent Seasonally Statistically Different?	First Flush Statistically Measured?	Pollutant Source or Removed?
TKN	28%	-	-	Yes	-
Nitrate	-431%	Yes	-	-	Source
Total Phosphorus	-255%	Yes	Yes	-	Source
Conductivity	-45%	-	-	-	-
TDS	-79%	-	Yes	-	-
TSS	93%	-	-	Yes	-
Zinc	49%	Yes	-	Yes	Removed
Oil/Grease	52%	-	-	-	-
Total E.coli	97%	-	-	-	-
Total Fecal Coliform	99.60%	-	-	-	-
Acetochlor	75%	Yes	Yes	-	Removed
Atrazine	74%	Yes	Yes	-	Removed
DEA	52%	-	-	-	-
Metolachlor	70%	Yes	Yes	-	Removed
Propazine	21%	-	Yes	-	-

Table 24 Small Bioretention Cell Analysis Summary

Pollutants	Mitigated	Influent Effluent Statistically Different?	Influent Seasonally Statistically Different?	First Flush Statistically Measured?	Pollutant Source or Removed?
TKN	9%	-	-	-	-
Nitrate	-91%	-	Yes	-	-
Total Phosphorus	5%	-	Yes	-	-
Conductivity	25%	-	-	-	-
TDS	-41%	-	-	-	-
TSS	71%	-	Yes	-	-
Zinc	69%	Yes	-	-	Removed
Oil/Grease	17%	-	-	-	-
Total E.coli	66%	-	-	-	-
Total Fecal Coliform	88%	-	-	-	-
Acetochlor	-11%	-	Yes	-	-
Atrazine	-14%	-	Yes	-	-
DEA	-14%	-	-	-	-
Metolachlor	21%	-	Yes	-	-
Propazine	45%	-	Yes	-	-

Table 25 Summary of Supporting Sites That Contribute Pollutants to Bioretention Cells Influent Pollutant Makeup

Pollutants	Commercial Parking Lot		Commercial Rooftop		Residential Rooftops	Rainfall	
	Lancaster Office	NRD Office	Lancaster Office	Fireworks Restaurant		Baldwin	Fire Station 12
TKN	Yes	Yes	-	Yes	Yes	Yes	Yes
Nitrate	Yes	-	Yes	Yes	-	-	-
Total Phosphorus	-	Yes	Yes	-	-	Yes	Yes
Conductivity	-	Yes				Yes	Yes
TDS	Yes	-					
TSS	-	-					
Zinc	-	-	**-	-	-	Yes	Yes
Oil/Grease	*-	*-					
Total E.coli			*-	*-	Yes		
Total Fecal Coliform			*-	*-	*-		
Acetochlor						-	-
Atrazine						Yes	Yes
DEA						Yes	Yes
Metolachlor						-	-
Propazine						Yes	-

**Statistical difference undetermined*

***Suspected statistical difference, p value approaches 0.05*

****Gray cells represent pollutants not tested for site*

Recommendation for Future Research

One of the main conclusions that this study determined, were differences in pollutant removal and pollutant sources for each bioretention cell. Factors such as stormwater flow and ratio between contributing area and bioretention area may have influence the analysis of the data statistically. Another recommendation would be to have similar bioretention cells tested as well in terms of catchment area, ponding area, similar

vegetation, soil depth/composition and total underdrain pipe; this would reduce the experimental error in the analysis.

All of the supporting sites had one location collecting the stormwater runoff, limiting to a small portion of both the area (i.e. only one downspout collecting sample) and the stormwater runoff volume itself (i.e. only could collect a small percentage of that flow). This could have possible lead to an improper representation of the pollutant concentration makeup of the supporting sites stormwater runoff, as well as falsely identifying the first flush time of concentration at these sites when designing sampling equipment. By placing multiple samplers at one site and forming a composite sample, a better representation of the pollutant in the stormwater runoff from the supporting site.

To further reduce any statistical errors and create a better bioretention cell pollutant profile, an increased data set by sampling more frequently and collecting a set amount of samples from the different seasons will better solidify conclusions made in this research study. This increased data set will help explore gaps in the research such as uncertainty of total fecal coliform supporting site contribution, as well as confirming a better link that commercial parking lots and commercial rooftops contribute nutrients to bioretention cell influent.

Better sampling techniques need to be evaluated for rain garden sampling as very few samples were collected during this research period. In addition, more rain garden samples need to be collected from different seasons in order to better quantify the effectiveness of rain garden mitigation.

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Appendix A Pesticide Profiles

Table 26 Basic Summary of Pesticides Tested in Study (1/3)

Pesticide Name	Type	Carcinogen*	Ecological Toxicity**	Half Life (Days)***	Source
Acetochlor	Herbicide	Likely	Moderate	14	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 2006)
Alachlor	Herbicide	Likely	Slight to Moderate	5 to 20	(Pesticide Action Network (PAN), 2014; United States Environemntal Protection Agency, 1998)
Atrazine	Herbicide	Not Likely	Slight to Highly	30 to 159	(Pesticide Action Network (PAN), 2014; United States Department of Health and Human Services, 2003)
Butylate	Herbicide	Not Likely	Slight	64 to 533	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1993)
Chlorothalonil	Fungicide	Likely	Moderate to Highly	8 to 49	(Pesticide Action Network (PAN), 2014)
Cyanazine	Herbicide	Possible	Slight	15 to 3680	(Pesticide Action Network (PAN), 2014; World Health Organization, 2003)

**EPA carcinogen levels-Known/Likely/Possible/Unclassifiable/Not Likely*

***Ecological Toxicity Levels-Mortality/Very Highly/Highly/Moderate/Slight/Acute/None*

****Half-life represents degradation from hydrolysis, anaerobic and aerobic conditions*

Table 27 Basic Summary of Pesticides Tested in Study (2/3)

Pesticide Name	Type	Carcinogen*	Ecological Toxicity**	Half Life (Days)***	Source
DEA	Parent-Atrazine	Unknown	Moderate	45	(Pesticide Action Network (PAN), 2014)
DIA	Parent-Atrazine	Unknown	None	Unknown	(Pesticide Action Network (PAN), 2014)
Dimethenamid	Herbicide	Possible	Moderate	13	(California Department of Pesticide Regulation (DPR), 2007; Pesticide Action Network (PAN), 2014)
EPTC	Herbicide	Not Likely	Slight	30 to 65	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1999)
Metolachlor	Herbicide	Possible	Slight to Moderate	61 to 200	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1995)
Metribuzin	Herbicide	Unclassifiable	Slight	140 to 4760	(United States Environmental Protection Agency, 1998; Pesticide Action Network (PAN), 2014)
Norflurazon	Herbicide	Possible	Slight to Moderate	172 to 2650	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1996)
Pendimethalin	Herbicide	Possible	Moderate	30 to 90	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1997)

**EPA carcinogen levels-Known/Likely/Possible/Unclassifiable/Not Likely*

***Ecological Toxicity Levels-Mortality/Very Highly/Highly/Moderate/Slight/Acute/None*

****Half-life represents degradation from hydrolysis, anaerobic and aerobic conditions*

Table 28 Basic Summary of Pesticides Tested in Study (3/3)

Pesticide Name	Type	Carcinogen*	Ecological Toxicity**	Half Life (Days)***	Source
Permethrin	Insecticide	Likely	Slight to Very Highly	30 to 3597	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 2009)
Prometon	Herbicide	Unclassifiable	Slight	61 to 1130	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 2008)
Propachlor	Herbicide	Likely	Slight to Highly	5 to 28	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1998)
Propazine	Herbicide	Not Likely	Slight to Moderate	83 to 131	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 2006)
Simazine	Herbicide	Unclassifiable	Slight to Highly	28 to 110	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 2006)
Tefluthrin	Insecticide	Unclassifiable	Very Highly	38	(Pesticide Action Network (PAN), 2014)
Trifluralin	Herbicide	Possible	Slight to Highly	181	(Pesticide Action Network (PAN), 2014; United States Environmental Protection Agency, 1996)

**EPA carcinogen levels-Known/Likely/Possible/Unclassifiable/Not Likely*

***Ecological Toxicity Levels-Mortality/Very Highly/Highly/Moderate/Slight/Acute/None*

****Half-life represents degradation from hydrolysis, anaerobic and aerobic conditions*

Appendix B Design Drawings and Figures

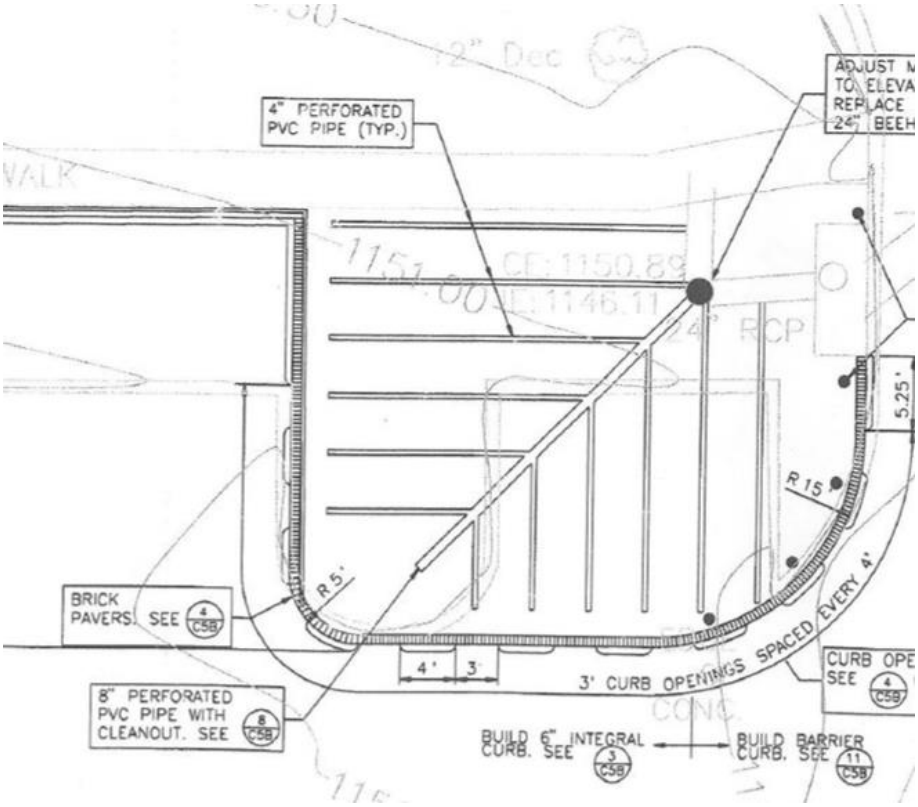


Figure 41 Large Bioretention Cell Design Plan (Provided by the City of Lincoln)

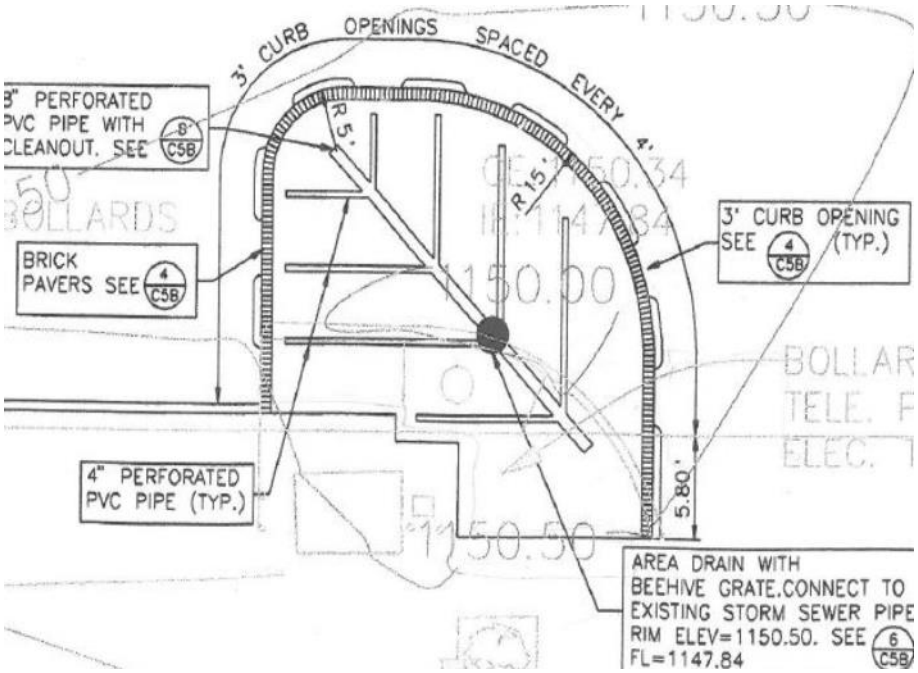


Figure 42 Small Bioretention Cell Design Plan (Provided by the City of Lincoln)

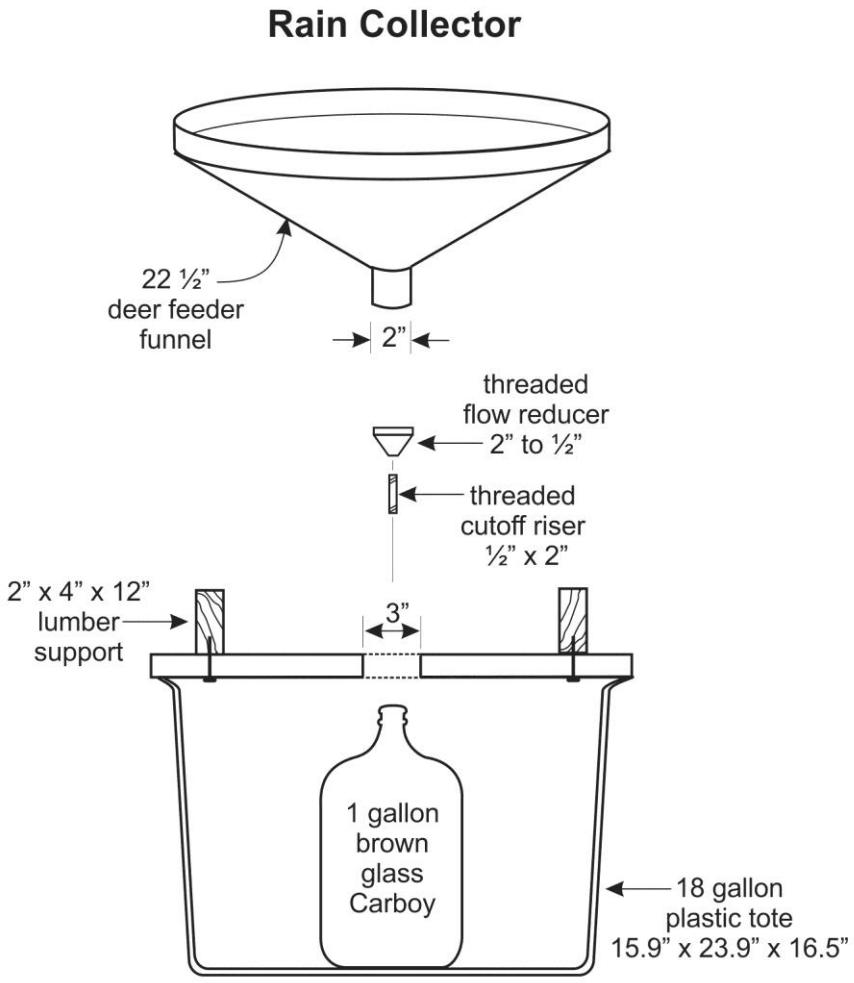


Figure 43 Drawing of Rainfall Collector

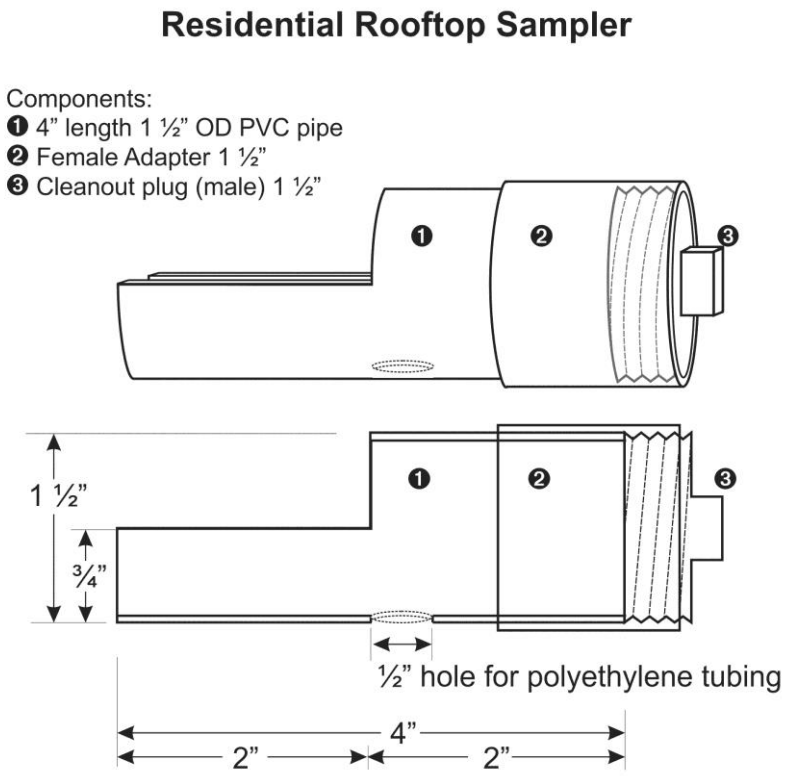


Figure 44 Residential Rooftop Sampler Construction Parts

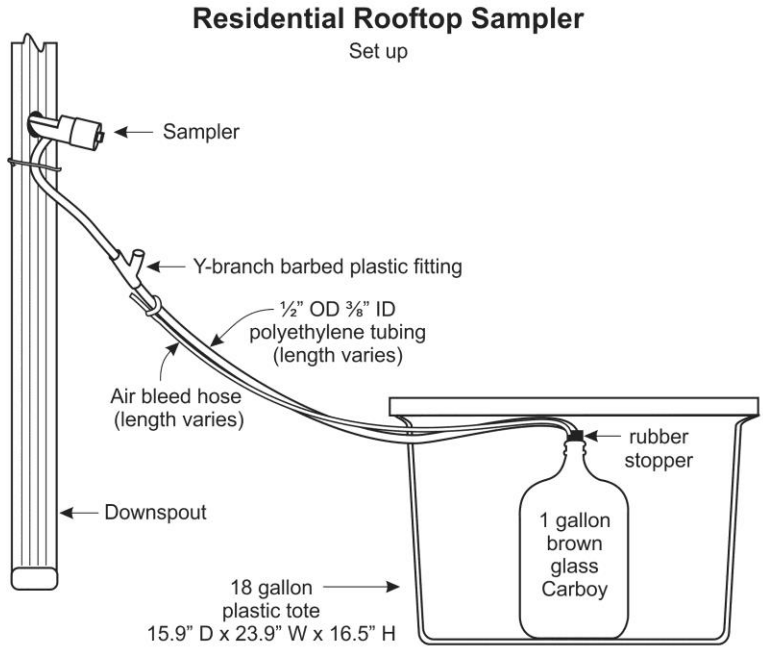


Figure 45 Diagram of Residential Rooftop Sampler Set Up

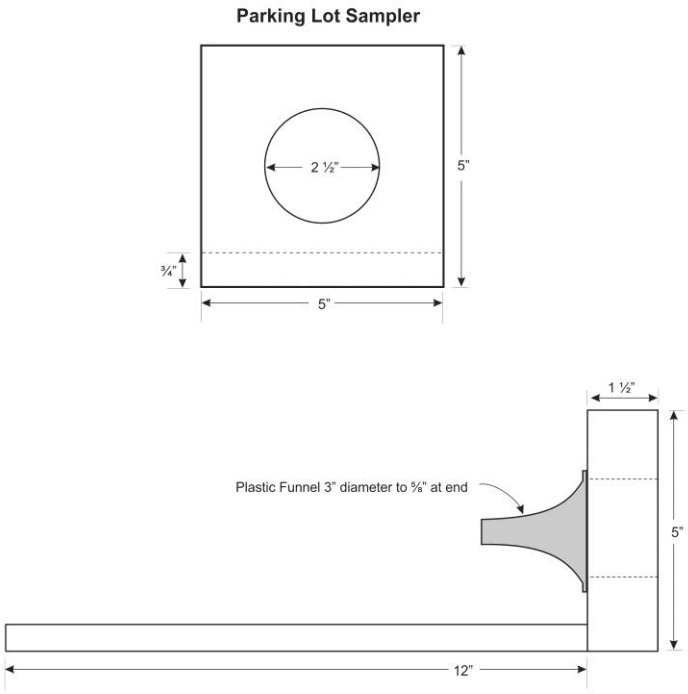


Figure 46 Lancaster County Office Parking Lot Sampler Design

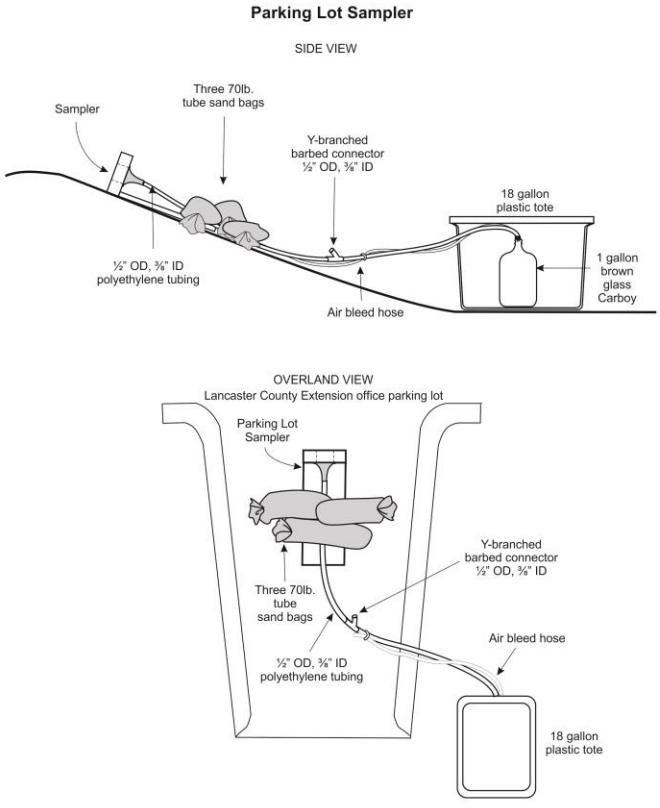


Figure 47 Lancaster County Office Parking Lot Sampler Setup

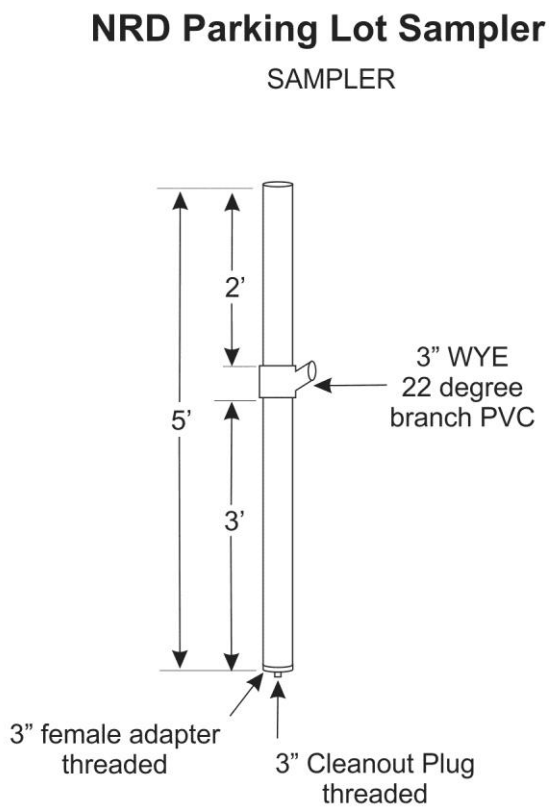


Figure 48 NRD Parking Lot Sampler

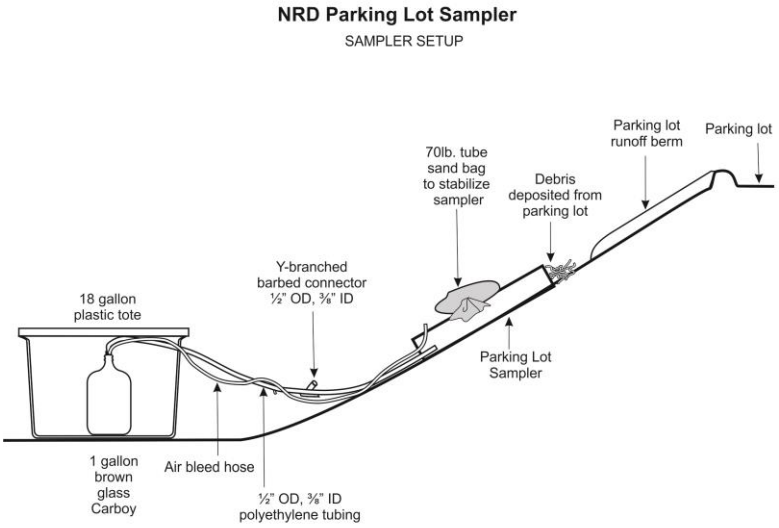
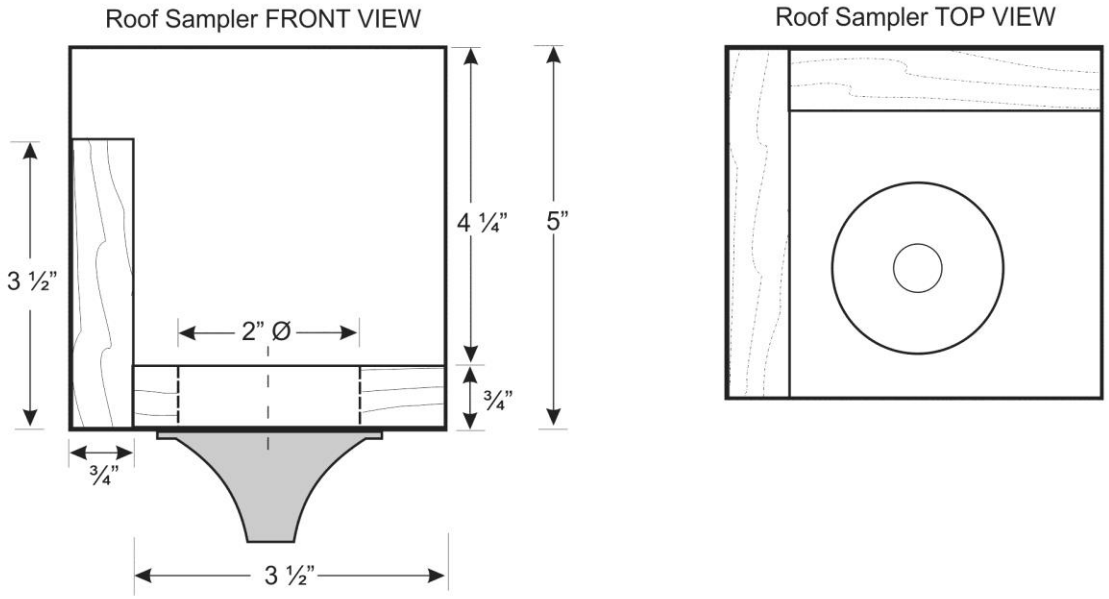


Figure 49 NRD Parking Lot Sampler Set Up



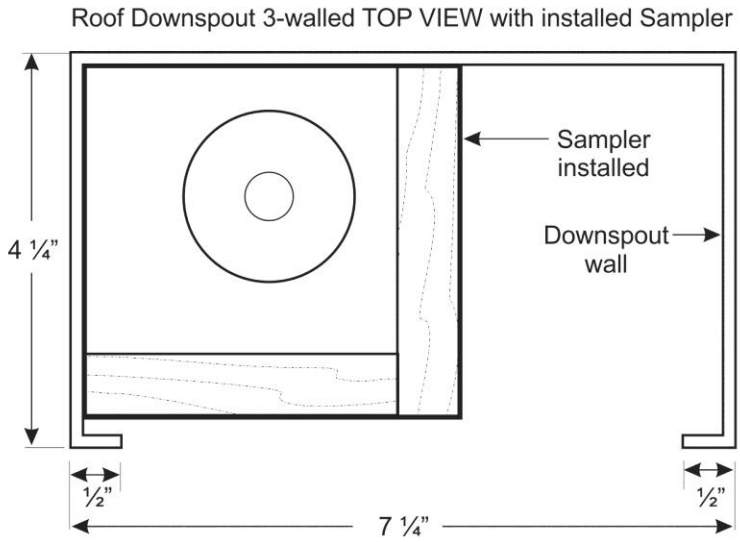


Figure 50 Lancaster County Office Rooftop Sampler

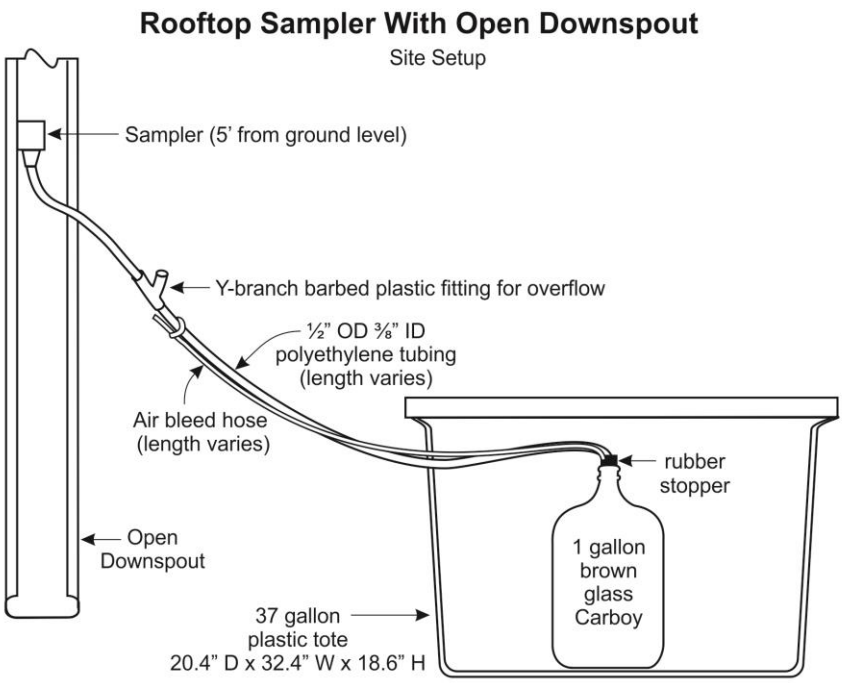


Figure 51 Lancaster County Office Rooftop Sampler Setup

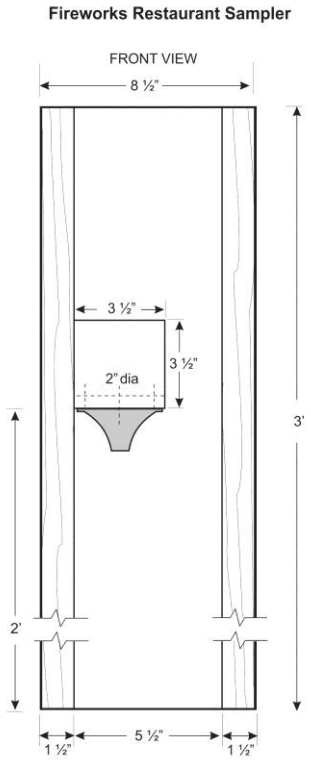


Figure 52 Fireworks Restaurant Commercial Rooftop Sampler

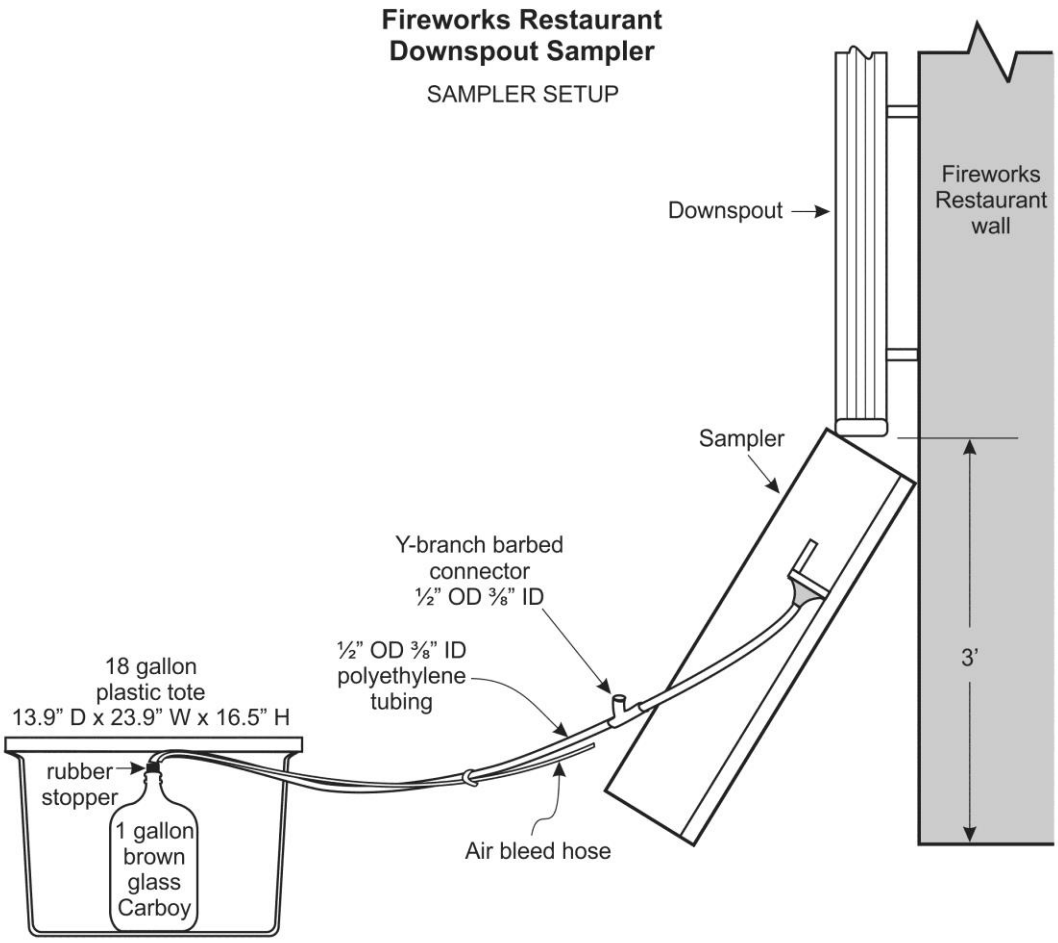


Figure 53 Fireworks Restaurant Commercial Rooftop Sampler Setup

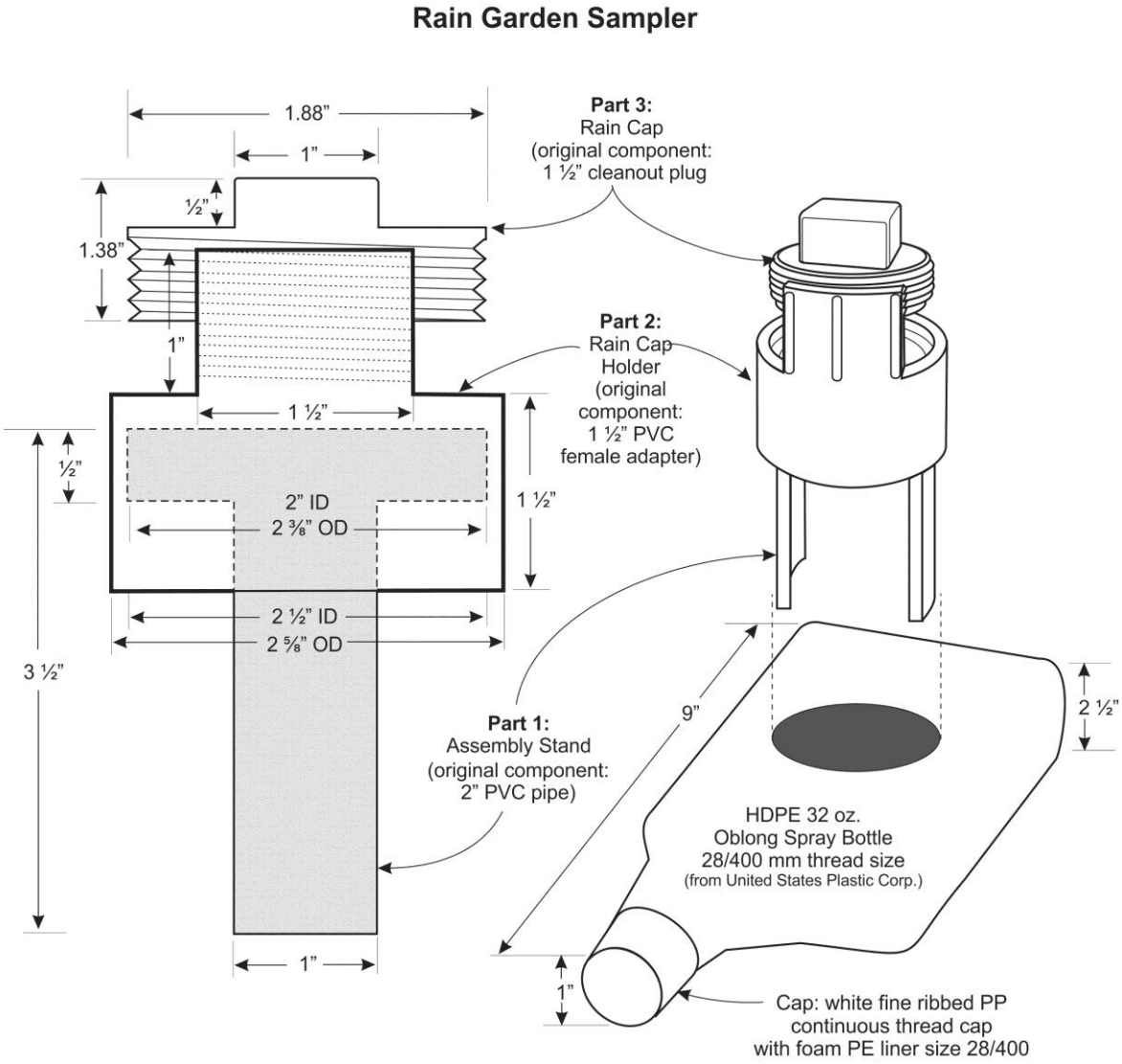


Figure 54 Final Rain Garden Sampler Design

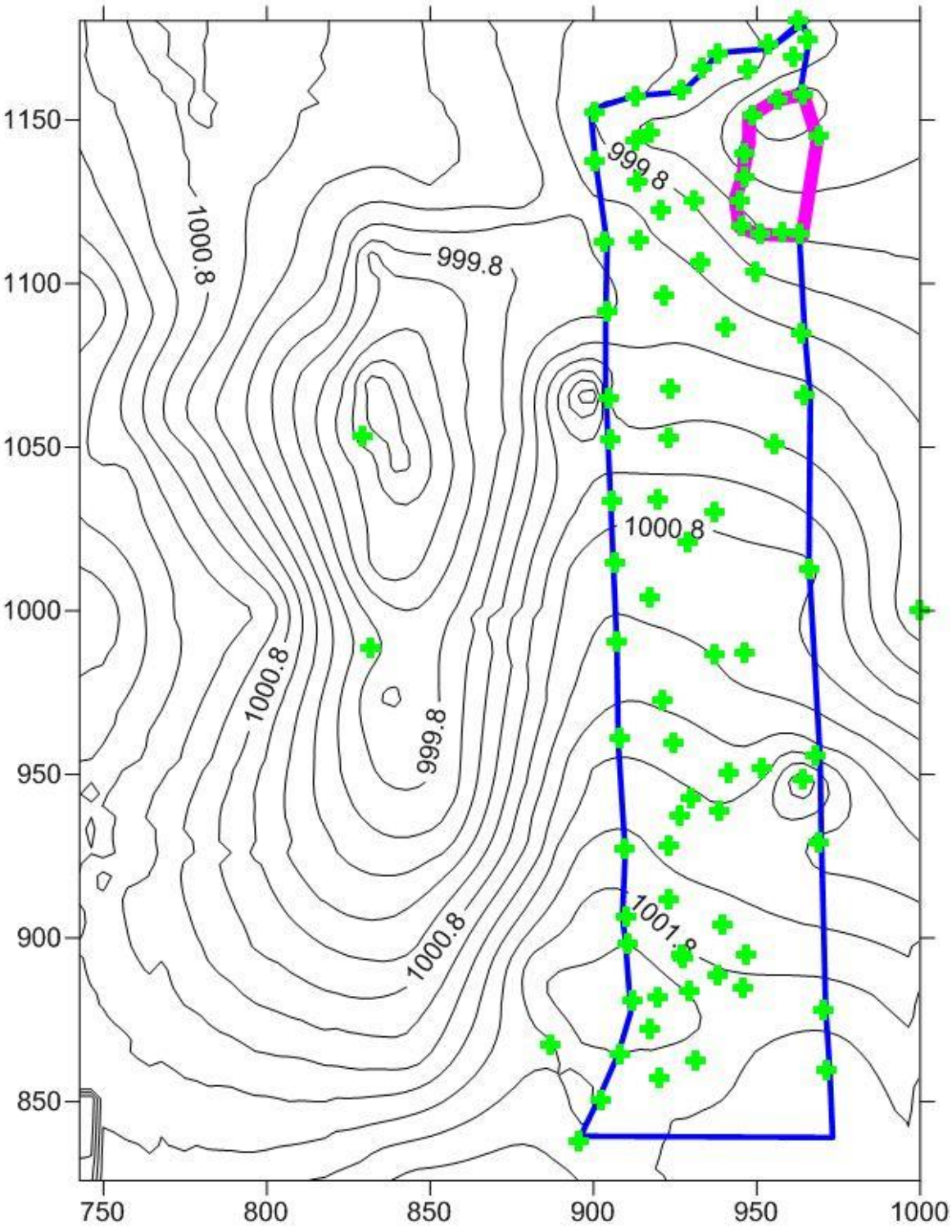


Figure 55 Large Bioretention Cell Parking Lot Contributing Area

T

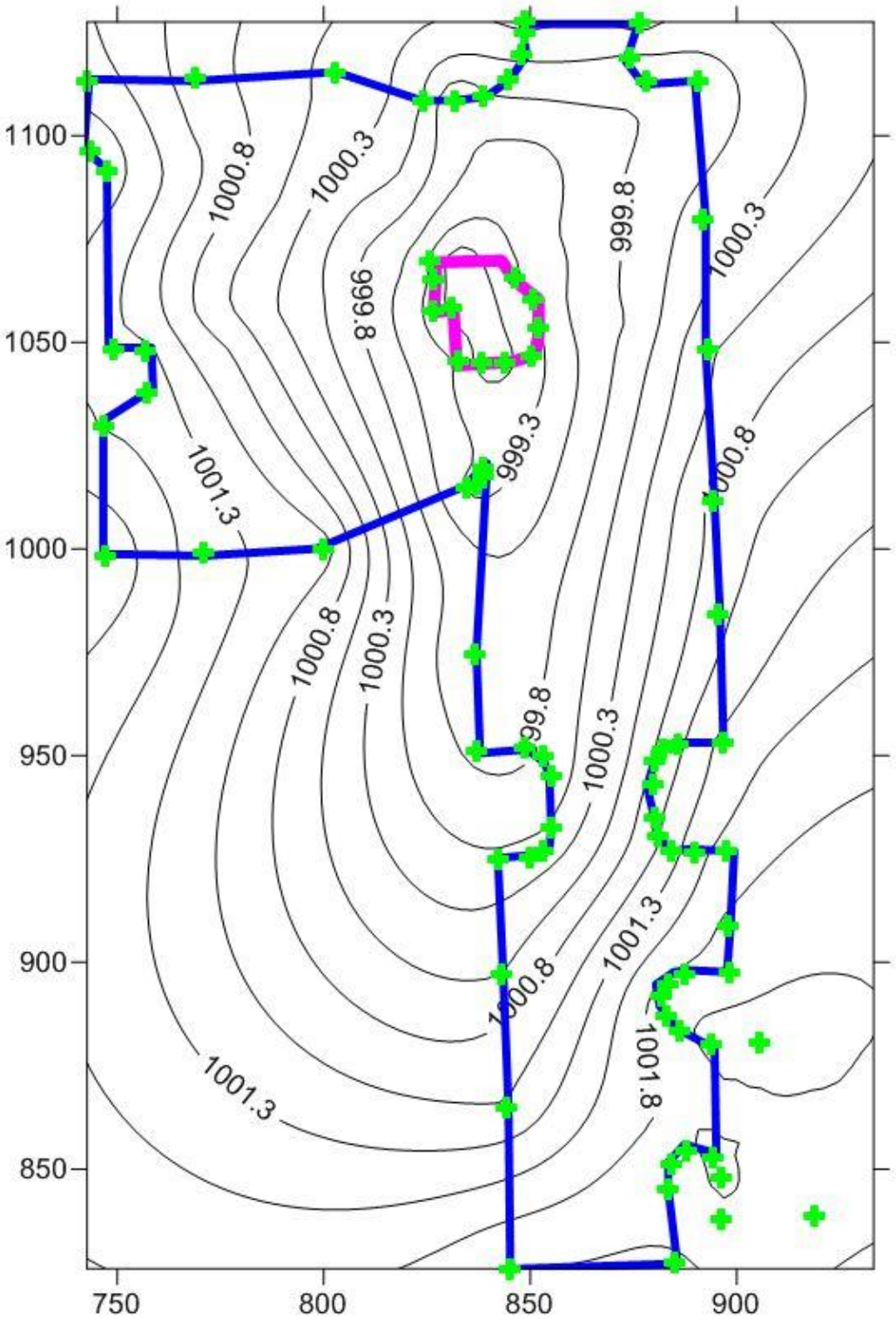


Figure 56 Large Bioretention Cell Contributing Area

Appendix C ISCO Samplers Programming

Table 29 Diagnostic Test of ISCO Samplers Used in Research Study (1/2)

Diagnostic Test	Diagnostic Prompt	Large Bioretention Cell		Small Bioretention Cell	
		Influent Sampler ISCO Serial#: 199H01753	**Effluent Sampler ISCO Serial#: 199H01763**	**Influent Sampler ISCO Serial#: 199H01766**	**Effluent Sampler ISCO Serial#: 199H01770**
RAM Test	Test makes sure the random access memory (RAM) is properly functioning	Passed	Passed	Passed	Passed

Table 30 Diagnostic Test of ISCO Samplers Used in Research Study (2/2)

Diagnostic Test	Diagnostic Prompt	Large Bioretention Cell		Small Bioretention Cell	
		Influent Sampler ISCO Serial#: 199H01753	Effluent Sampler ISCO Serial#: 199H01763	Influent Sampler ISCO Serial#: 199H01766	Effluent Sampler ISCO Serial#: 199H01770
ROM Test	Test makes sure the read only memory (ROM) is properly functioning	Passed	Passed	Passed	Passed
Screen Test	Test makes sure the read out screen on the ISCO sampler is functioning	Passed	Passed	Passed	Passed
Pump Test	Test ON/OFF ratio number of the pump. The acceptable range is between 0.80 and 1.25.	1.00 1.00	0.93 0.95	1.00 1.00	0.94 0.91
Distributor Test	The distributor test is provided for factory personnel to verify the distributor's position as it rotates through the 24 positions.	Passed	Passed	Passed	Passed
Arm Flexure Score	Displays the values of the distributor test. Error appears if arm is not working properly.	13	12	11	12
Re-Initialize?	Erases all memory of the programming	No	No	No	No
Pump Count	Displays the number of times the pump has been used	16544	353532	166733	233498
Warning at Pump Count	Displays the maximum number of times the pump can be used before servicing	1000000	1000000	1000000	1000000
Pump Count Reset	Resets the pump count displayed previously	Yes	Yes	Yes	Yes

Table 31 ISCO Programming Prompts Descriptions (1/2)

ISCO Programming Prompt	Programming Prompt Details
Program Name	Names the current program in a text entry format
Site Description	A site description is commonly a number, address, or other short note that helps identify the monitoring site.
Units	Allows you to choose and set different systems of measurement for length, flow rate and flow volume
Submerged Probe	If a 720 Submerged Probe Module for monitoring a flow level and/or flow rate with a submerged probe. The option to select either level or flow becomes available
Current Level	If a 720 Submerged Probe Module is used, the current reading is outputted in the program creation. This is to ensure that the probe is not damaged in any way and is current with the water level when programming.
Data Interval	Allows you the option to choose the pace at which a reading is taken. The lower the interval the quicker the ISCO memory bank will fill.
Bottles	Choose type and amount of bottles used in the ISCO sampler
Suction Line	Input the length of the sampling line used
Auto suction head or Fixed Suction Head	Choose between an auto generated suction head calculation by the ISCO sampler or manually input the suction head
Rinses	Input the number of rinses completed before the sampling program initiates
Retries	Input the number of retries if a sampling program has an error during sampling
One part program or two part program	Choose between one part or two-part program. One part meaning sampling starts on one set of criteria and two part meaning sampling starts when two criteria are met
Pacing Time	Sets the time between samples when a sample is drawn

Table 32 ISCO Programming Prompts Descriptions (2/2)

ISCO Programming Prompt	Programming Prompt Details
Distribution	Choose the amount of bottles per sample
Volume	Choose the volume of each bottle when the sample is drawn
Enable	Sets the enable conditions, determined on what module is or is not installed on the ISCO sampler
Once Enabled Stay Enabled/ repeatable Enable no sample at disable and countdown continues	Choose between either: Once Enabled Stay Enabled, once the sampler is enable the program finishes and is not interrupted Repeatable enable no sample at disable and continue at countdown, the sampler will pull a sample and if the enable is disable, will be able continuing sampling when the enable is activated, the sampler will not grab a sample if the program is disable. The pacing time is not disabled when the program is disabled.
Sample at Enable?	Allows the user to sample when the program is activated or has a delay until the sampler is programmed.
Pauses and Resumes	A program with pauses and resumes begins sampling at its programmed start time, continuing until the first pause time and day of the week. It then suspends sampling until the first resume time, when it begins sampling again.
No Delay to Start	Select NO DELAY TO START when you want the sampler to start as soon as you select RUN. Select DELAYED START when you want the sampler to delay from 1 to 999 minutes before starting the program.

Table 33 Havelock Site Large Bioretention Cell Influent and Effluent Programming

Large Bioretention Cell Programming		
ISCO Programming Prompt	**Influent Programming**	**Effluent Programming**
Program Name	" Large- In"	" Large- Out"
Site Description	"Havelock-I"	"Havelock-O"
Units	ft, ft3/s, ft3	ft, ft3/s, ft3
Submerged Probe	-	Level Only
Current Level	-	-
Data Interval	10 minutes	10 minutes
Bottles	12, 1000 mL	12, 1000 mL
Suction Line	25 ft	15 ft
Auto suction head or Fixed Suction Head	Auto Suction Head	Auto Suction Head
Rinses	1	1
Retries	1	1
One part program or two part program	One part Program	One part Program
Pacing Time	15 minutes	10 minutes
Distribution	4 Bottles/Sample	4 Bottles/Sample
Volume	900 mL/Sample	900 mL/Sample
Enable	None Programmed	> 0.250 ft
Once Enabled Stay Enabled/ repeatable Enable no sample at disable and countdown continues	Once Enabled Stay Enabled	Repeatable Enable No Sample at Disable Countdown Continuous while Disabled
Sample at Enable?	Yes	Yes
Pauses and Resumes	0 pauses and 0 Resumes	0 pauses and 0 Resumes
No Delay to Start	Yes	Yes

Table 34 Havelock Site Small Bioretention Cell Influent and Effluent Programming

Small Bioretention Cell Programming		
ISCO Programming Prompt	**Influent Programming**	**Effluent Programming**
Program Name	" Small- In"	" Small- Out"
Site Description	"Havelock-S"	"Havelock-S"
Units	ft, ft3/s, ft3	ft, ft3/s, ft3
Submerged Probe	Level Only	-
Current Level	-	-
Data Interval	10 minutes	10 minutes
Bottles	12, 1000 mL	12, 1000 mL
Suction Line	10 ft	15 ft
Auto suction head or Fixed Suction Head	Auto Suction Head	Auto Suction Head
Rinses	1	1
Retries	1	1
One part program or two part program	One part Program	One part Program
Pacing Time	15 minutes	10 minutes
Distribution	4 Bottles/Sample	4 Bottles/Sample
Volume	900 mL/Sample	900 mL/Sample
Enable	> 0.300 ft	None Programmed
Once Enabled Stay Enabled/ repeatable Enable no sample at disable and countdown continues	Repeatable Enable No Sample at Disable Countdown Continuous while Disabled	Once Enabled Stay Enabled
Sample at Enable?	Yes	Yes
Pauses and Resumes	0 pauses and 0 Resumes	0 pauses and 0 Resumes
No Delay to Start	Yes	Yes

Appendix D Equations and Supplemental Material

Equation 2-Intensity Curve (Utilities, 2000)

$$i = \frac{a}{(t+14)^{0.7912}}$$

Where:
a=frequency value (unitless)
i=rainfall intensity (in/hr)
t=storm duration (minutes)

Equation 3-Frequency Curve Value (Utilities, 2000)

$$a = 42.45F^{0.1943}$$

Where:
a=frequency value (unitless)
F=Storm frequency design (years)

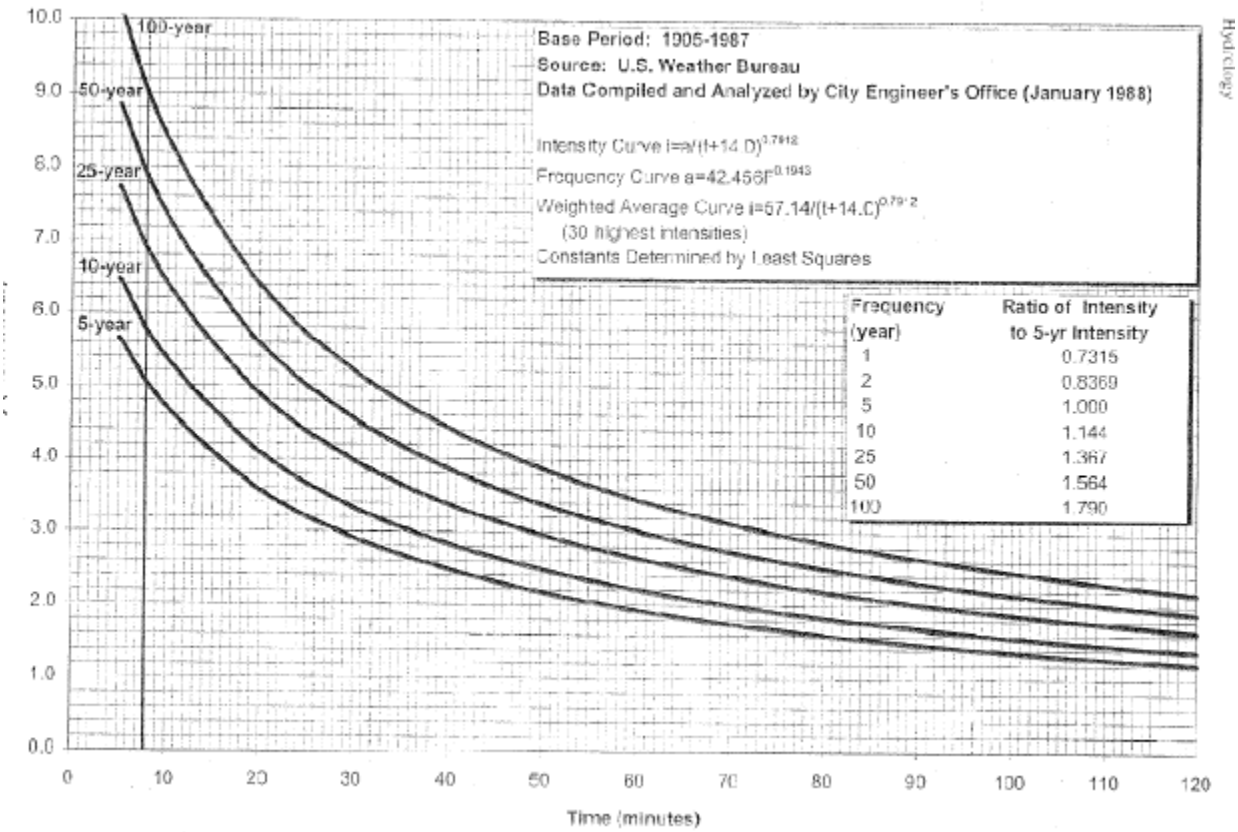


Figure 57 Intensity Duration Frequency Curves for Lincoln Nebraska (Utilities, 2000)

Equation 4 NRCS Method

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where:

Q=Excess rainfall volume
P=Precipitation amount
I_a=Initial abstractions
S=Total storage

Equation 5 Total Storage (S)

$$S = \frac{1000}{CN} - 10$$

Where:

CN=Curve number value
S=Total storage

Equation 6 Initial Abstractions (I_a)

$$I_a = 0.2S$$

Where:

I_a=Initial abstractions
S=Total storage

Equation 7 One Dimensional Pipe Flow Energy Equation

$$h_p + \alpha_1 \frac{V_1^2}{2g} + z_1 + \frac{P_1}{\delta} = h_t + \alpha_2 \frac{V_2^2}{2g} + z_2 + \frac{P_2}{\delta}$$

Where:

h_p=Head delivered by pump (ft)
α=Velocity correction (dimensionless)
V=Velocity of water (ft/sec)
g=gravity constant (32.2. ft/sec^2)
z=Height at point (ft)
P= Pressure (psi)
δ=Weight of water (62.4 lbs./ft^3)
h_t=head removed by turbine (ft)

Equation 8 Rearranged Rooftop One Dimensional Pipe Flow Energy Equation

$$\frac{V_1^2}{2g} = z_2$$

Where:
V_1=Velocity of water at top of downspout (ft/sec)
g=gravity constant (32.2. ft/sec^2)
z_2=Height difference at bottom of downspout (ft)

Equation 9 NRCS Time of Concentration Equation (tc)

$$t_c = \frac{L^{0.8}[(S+1)]^{0.7}}{1140Y^{0.5}}$$

Where:
T_c=time of concentration (hr)
L=Flow Length (ft)
Y=Average watershed land slope (%)
S=Total storage

Equation 10 NRCS Flow Length (L)

$$L = 209A^{0.6}$$

Where:
L=Flow Length (ft)
A=Watershed Area (acres)

Equation 11 Open Channel Equation

$$V = \frac{K_n}{n} R_h^{2/3} S_0^{1/2}$$

Where:
V=Velocity (ft/s)
K_n=1.486
R_h=Hydraulic Radius (area divide by wetted perimeter)
S_0=Slope (ft/ft)
n=manning's roughness coefficient

Equation 12 Tukey's Method

$$\omega = q_{\propto}(p, v)\frac{s}{\sqrt{n_t}}$$

Where:

ω=Calculated value of Tukeys method for both treatments of sample mean

$q_{\alpha}(p,v)$=Critical value of the studentized ranged using confidence error α

p=number of sample means

s=$MSE^{1/2}$

v=Number of degrees of freedom associated with the MSE

n_t=Number of observations in each of the p samples

Equation 13 Tukey's Statistical Model

$$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

Where:

y_{ij} =measurement for the j^{th} observations in location i

μ=overall mean

α_i=fixed effect for the i^{th} location

ε_{ij}=experimental error.

Appendix E Data Collection

Table 35 2013 Bioretention Cells Samples Used for Analysis

Site Name/Location	Bioretention Cells 2013 Sampling Event Dates													
	18-Apr	1-May	19-May	25-May	27-May	13-Jun	23-Jun	24-Jun	23-Jul	29-Jul	1-Aug	11-Aug	10-Sep	20-Sep
Large Cell-Influent	1	1			1									
Large Cell-Effluent			1											
Small Cell-Influent		1												
Small Cell-Effluent							2	2		3			3	

Notes 3

Collected Sample Used for Analysis

Collected Sample Not Used for Analysis

1-Not Sent to Bio Lab

2-Ony Sent to Bio Lab

3-Partial Pollutant Analysis

Table 36 2014 Bioretention Cells Samples Used for Analysis

Site Name/Location	Bioretention Cells 2014 Sampling Event Dates								
	13-Apr	24-Apr	27-Apr	8-May	11-May	12-May	22-May	1-Jun	3-Jun
Large Cell-Influent									
Large Cell-Effluent									
Small Cell-Influent									
Small Cell-Effluent									

Notes

Collected Sample Used for Analysis

Collected Sample Not Used for Analysis

1-Not Sent to Bio Lab

2-Ony Sent to Bio Lab

3-Partial Pollutant Analysis

Table 37 2013 Rain Garden Samples Used for Analysis

Site Name/Location	Rain Garden 2013 Sampling Event Dates													
	18-Apr	1-May	19-May	25-May	27-May	13-Jun	23-Jun	24-Jun	23-Jul	29-Jul	1-Aug	11-Aug	10-Sep	20-Sep
(1)Twin Ridge House #1860														
(2)Twin Ridge House #1860														
Woods Ave #3460														
Woods Ave #3454														
Woods Ave #3348														
Woods Ave #3300														

Notes 3

Collected Sample Used for Analysis

Collected Sample Not Used for Analysis

1-Not Sent to Bio Lab

2-Ony Sent to Bio Lab

3-Partial Pollutant Analysis

Table 38 2014 Rain Garden Samples Used for Analysis

Site Name/Location	Rain Garden 2014 Sampling Event Dates								
	13-Apr	24-Apr	27-Apr	8-May	11-May	12-May	22-May	1-Jun	3-Jun
(1)Twin Ridge House #1860									
(2)Twin Ridge House #1860									
Woods Ave #3460									
Woods Ave #3454									
Woods Ave #3348									
Woods Ave #3300									

Notes

1-Not Sent to Bio Lab
2-Ony Sent to Bio Lab
3-Partial Pollutant Analysis

HH

Table 39 2013 Rainfall, Rooftops and Parking Lot Samples Used for Analysis

Site Name/Location	Rainfall, Rooftops and Parking Lot 2013 Sampling Event Dates													
	18-Apr	1-May	19-May	25-May	27-May	13-Jun	23-Jun	24-Jun	23-Jul	29-Jul	1-Aug	11-Aug	10-Sep	20-Sep
Baldwin														
Fire Station 12														
Fireworks Restaurant						2					2			
Lancaster County Extension Office														
SW 74th (1)														
SW 74th (2)														
Woods Ave #3460														
Woods Ave #3454														
Woods Ave #3348														
Woods Ave #3300														
Lancaster County Extension Office														
NRD Building														

Notes 3

Collected Sample Used for Analysis

Collected Sample Not Used for Analysis

1-Not Sent to Bio Lab

2-Ony Sent to Bio Lab

3-Partial Pollutant Analysis

Table 40 2014 Rainfall, Rooftops and Parking Lots Samples Used for Analysis

Site Name/Location	Rainfall, Rooftops and Parking Lot 2014 Sampling Event Dates								
	13-Apr	24-Apr	27-Apr	8-May	11-May	12-May	22-May	1-Jun	3-Jun
Baldwin									
Fire Station 12									
Fireworks Restaurant									
Lancaster County Extension Office									
SW 74th (1)									
SW 74th (2)									
Woods Ave #3460									
Woods Ave #3454									
Woods Ave #3348									
Woods Ave #3300									
Lancaster County Extension Office									
NRD Building									

Notes

Collected Sample Used for Analysis

Collected Sample Not Used for Analysis

1-Not Sent to Bio Lab

2-Ony Sent to Bio Lab

3-Partial Pollutant Analysis

Table 41 Bioretention Cell Havelock, Large, Influent 1, 2 and 3 Non-Pesticide Pollutants

Date	Location	Time Collected	Pollutants (Non-Pesticide)									
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*	*TSS*	*TDS*	*Conductivity*	*Oil/Grease*
		hh:mm	*TKN mg N/L*	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*	*mg/L*	*mg/L*	*uS/cm*	*mg/L*
6/24/2013	Havelock Large-In-1	18:00	3.91	0.787		35.6	1.99E+06	3.08E+04	496	41	53.2	<5.0
9/10/2013		19:37	5.02	1.48	0.635	59.5	1.67E+08	3.65E+04	848.5	181	132	<5.0
4/13/2014		8:22	6.05	2.38	0.26	21.7	3.36E+03	1.69E+01	654	189	169	<5.0
4/24/2014		2:23	2.53	1.99	0.264	12.8	7.42E+05	2.03E+01	61.2	25	260	<5.0
4/27/2014		8:15	2.6	1.59	0.183	14.7	6.42E+06	6.13E+01	33.7	178	198	8.3
5/22/2014		4:15	6.74	0.12	0.368	23.2			612	144	612	144
6/24/2013	Havelock Large-In-2	18:15	1.31	0.317		22.7	2.48E+06	1.17E+04	356	58	60.2	<5.0
9/10/2013		19:55	2.03	0.957	0.536	40.8	3.45E+08	2.16E+04	512.2	134	108	<5.0
4/13/2014		8:37	1.37	0.327	0.184	11.2	1.10E+03	7.20E+00	192	110	61.1	<5.0
4/24/2014		2:38	2.02	1.89	0.222	17.6	7.52E+05	4.10E+00	29.4	20	186	<5.0
4/27/2014		8:30	1.55	0.837	0.164	7.9	1.66E+07	2.94E+01	145	204	137	
5/22/2014		4:30	3.96	0.264	0.249	13.1			19.6	12	19.6	12
6/24/2013	Havelock Large-In-3	18:30	0.91	0.245		13.3	1.41E+07	9.33E+02	51	43	80.4	<5.0
9/10/2013		21:10	1.37	0.773	0.932	7.9	1.47E+08	4.32E+03	2	85	58.1	<5.0
4/13/2014		8:52	1.15	0.244	0.09	5.2	1.22E+03	5.00E+00	83.3	104	41.1	<5.0
4/24/2014		2:53	2.16	1.88	0.172	10.4	9.34E+05	1.34E+01	40.7	19	175	<5.0
4/27/2014		8:45	0.938	0.415	0.142	15.3	1.72E+07	2.00E+00	26.5	63	77.5	<5.0
5/22/2014		4:45	1.66	0.158	0.241	12.1			61.6	14	61.6	14

KK

Table 42 Bioretention Cell Havelock, Large, Influent 1, 2 and 3 Pesticide Pollutants (1/3)

Date	Location	Time Collected	Pesticides								
			Acetochlor	*Alachlor*	*Atrazine*	*Butylate*	*Chlorthalonil*	*Cyanazine*	*DEA*	*DIA*	*Dimethenamid*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-In-1	18:00	0.41	0.08	0.58	<0.05	<0.05	<0.10	0.24	<0.10	<0.05
9/10/2013		19:37	<0.05	<0.05	0.05	<0.05	<0.05	<0.10	0.05	<0.10	<0.05
4/13/2014		8:22									
4/24/2014		2:23	0.66	<0.10	3.22	<0.10	<0.10	<0.10	0.43	<0.10	<0.10
4/27/2014		8:15	0.78	<0.05	1.98	<0.05	<0.05	<0.05	0.64	0.43	<0.05
5/22/2014		4:15	0.83	<0.05	3.37	<0.05	<0.05	<0.05	1.9	1.02	<0.05
6/24/2013	Havelock Large-In-2	18:15	0.15	<0.05	0.27	<0.05	<0.05	<0.10	0.06	<0.10	<0.05
9/10/2013		19:55	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
4/13/2014		8:37									
4/24/2014		2:38	0.74	<0.10	3.34	<0.10	<0.10	<0.10	0.43	<0.10	<0.10
4/27/2014		8:30	0.54	<0.05	1.29	<0.05	<0.05	<0.05	0.39	<0.05	<0.05
5/22/2014		4:30	0.59	<0.05	1.81	<0.05	<0.05	<0.05	1.38	0.63	<0.05
6/24/2013	Havelock Large-In-3	18:30	0.1	<0.05	0.22	<0.05	<0.05	<0.10	0.06	<0.10	<0.05
9/10/2013		21:10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
4/13/2014		8:52									
4/24/2014		2:53	0.82	<0.10	3.47	<0.10	<0.10	<0.10	0.45	<0.10	<0.10
4/27/2014		8:45	0.29	<0.05	0.66	<0.05	<0.05	<0.05	0.21	<0.05	<0.05
5/22/2014		4:45	0.31	<0.05	0.97	<0.05	<0.05	<0.05	0.77	<0.05	<0.05

Table 43 Bioretention Cell Havelock, Large, Influent 1, 2 and 3 Pesticide Pollutants (2/3)

Date	Location	Time Collected	Pesticides					
			EPTC	*Metolachlor*	*Metribuzin*	*Norflorazon*	*Pendamethalin*	*Permethrin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-In-1	18:00	<0.05	0.69	<0.05	<0.05	<0.05	<0.05
9/10/2013		19:37	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:22						
4/24/2014		2:23	<0.10	0.96	<0.10	<0.10	<0.10	<0.10
4/27/2014		8:15	1.12	<0.05	<0.05	<0.05	<0.05	<0.05
5/22/2014		4:15		1.02	<0.05	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-In-2	18:15	<0.05	0.23	<0.05	<0.05	<0.05	<0.05
9/10/2013		19:55	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:37						
4/24/2014		2:38	<0.10	1.06	<0.10	<0.10	<0.10	<0.10
4/27/2014		8:30	<0.05	0.79	<0.05	<0.05	<0.05	<0.05
5/22/2014		4:30	<0.05	0.69	<0.05	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-In-3	18:30	<0.05	0.18	<0.05	<0.05	<0.05	<0.05
9/10/2013		21:10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:52						
4/24/2014		2:53	<0.10	1.15	<0.10	<0.10	<0.10	<0.10
4/27/2014		8:45	<0.05	0.46	<0.05	<0.05	<0.05	<0.05
5/22/2014		4:45	<0.05	0.4	<0.05	<0.05	<0.05	<0.05

MM

Table 44 Bioretention Cell Havelock, Large, Influent 1, 2 and 3 Pesticide Pollutants (3/3)

Date	Location	Time Collected	Pesticides					
			Prometon	*Propachlor*	*Propazine*	*Simazine*	*Telfluthrin*	*Trifluralin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-In-1	18:00	<0.05	<0.05	0.05	<0.05	<0.05	<0.05
9/10/2013		19:37	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:22						
4/24/2014		2:23	<0.10	<0.10	0.06	0.01	<0.10	<0.10
4/27/2014		8:15	<0.05	<0.05	0.07	0.01	<0.05	<0.05
5/22/2014		4:15	<0.05	<0.05	0.07	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-In-2	18:15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		19:55	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:37						
4/24/2014		2:38	<0.10	<0.10	0.06	0.02	<0.10	<0.10
4/27/2014		8:30	<0.05	<0.05	0.04	<0.05	<0.05	<0.05
5/22/2014		4:30	<0.05	<0.05	0.04	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-In-3	18:30	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		21:10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		8:52						
4/24/2014		2:53	<0.10	<0.10	0.06	0.01	<0.10	<0.10
4/27/2014		8:45	<0.05	<0.05	0.09	<0.05	<0.05	<0.05
5/22/2014		4:45	<0.05	<0.05	0.09	<0.05	<0.05	<0.05

NN

Table 45 Bioretention Cell Havelock, Large, Effluent 1, 2 and 3 Non-Pesticide Pollutants

Date	Location	Time Collected	Pollutants (Non-Pesticide)									
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*	*TSS*	*TDS*	*Conductivity*	*Oil/Grease*
		hh:mm	*TKN mg N/L*	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*	*mg/L*	*mg/L*	*uS/cm*	*mg/L*
6/24/2013	Havelock Large-Out-1	10:12	1.43	7.01	1.383	3.7	4.28E+04	-	3	216	263	<5.0
9/10/2013		20:02	3.25	3.75	1.658	<0.2	5.63E+05	7.27E+02	21.9	264	247	<5.0
4/13/2014		9:30	1.83	7.64	0.58	16.4	2.01E+04	2.38E+01	3.1	194	286	<5.0
4/24/2014		4:56	1.25	1.29	0.875	10.7	2.49E+04	1.75E+01	20.5	14	149	<5.0
4/27/2014		9:50	1.78	1.31	0.887	12.8	1.12E+05	1.87E+01	11.4	217	170	
5/22/2014		4:53	2.24	2.58	1.156	9.4			4.7	14	4.7	14
6/24/2013	Havelock Large-Out-2	10:22	1.35	6.9	1.323	4	7.61E+04	-	5.6	222	243	<5.0
9/10/2013		20:12	2.37	3.5	1.637	<0.2	4.25E+05	5.17E+02	65.3	204	245	<5.0
4/13/2014		9:40	2.44	13.6	0.75	13.4	1.86E+04	8.50E+00	4.7	302	346	<5.0
4/24/2014		5:06	1.39	1.51	0.332	11.2	3.65E+04	1.48E+01	43.4	16	162	<5.0
4/27/2014		10:05	1.76	1.4	1.144	10.9	1.41E+05	1.71E+01	4.2	186	178	<5.0
5/22/2014		5:03	2.03	3.05	0.929	8.6			3.2	14	3.2	14
6/24/2013	Havelock Large-Out-3	10:32	1.06	11.7	1.46	2.3	7.27E+05	1.20E+03	9.4	245	246	<5.0
9/10/2013		20:22	2.56	3.12	1.719	<0.2	4.79E+05	6.87E+02	5.8	87	190	<5.0
4/13/2014		9:50	1.84	14.2	0.89	8.8	2.36E+04	6.30E+00	23.7	456	502	<5.0
4/24/2014		5:16	1.33	1.38	0.873	10	2.61E+04	9.70E+00	16.6	20	164	<5.0
4/27/2014		10:20	1.9	1.44	1.221	9.3	1.67E+05	3.93E+01	29.3	218	200	<5.0
5/22/2014		5:13	2.07	2.97	0.958	14.2			2	14	2	14

Table 46 Bioretention Cell Havelock, Large, Effluent 1, 2 and 3 Pesticide Pollutants (1/3)

Date	Location	Time Collected	Pesticides								
			Acetochlor	*Alachlor*	*Atrazine*	*Butylate*	*Chlorthalonil*	*Cyanazine*	*DEA*	*DIA*	*Dimethenamid*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12	<0.05	<0.05	0.5	<0.05	<0.05	<0.10	0.15	<0.10	<0.05
9/10/2013		20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
4/13/2014		9:30									
4/24/2014		4:56	0.17	<0.10	0.43	<0.10	<0.10	<0.10	0.18	<0.10	<0.10
4/27/2014		9:50	0.07	<0.05	0.31	<0.05	<0.05	<0.05	0.19	<0.05	<0.05
5/22/2014		4:53	0.11	<0.05	0.63	<0.05	<0.05	<0.05	0.49	<0.05	<0.05
6/24/2013	Havelock Large-Out-2	10:22	<0.05	<0.05	0.5	<0.05	<0.05	<0.10	0.15	<0.10	<0.05
9/10/2013		20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
4/13/2014		9:40									
4/24/2014		5:06	0.15	<0.10	0.4	<0.10	<0.10	<0.10	0.18	<0.10	<0.10
4/27/2014		10:05	0.08	<0.05	0.29	<0.05	<0.05	<0.05	0.18	<0.05	<0.05
5/22/2014		5:03	0.12	<0.05	0.69	<0.05	<0.05	<0.05	0.55	<0.05	<0.05
6/24/2013	Havelock Large-Out-3	10:32	<0.05	<0.05	0.22	<0.05	<0.05	<0.10	0.14	<0.10	<0.05
9/10/2013		20:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
4/13/2014		9:50									
4/24/2014		5:16	0.15	<0.10	0.38	<0.10	<0.10	<0.10	0.17	<0.10	<0.10
4/27/2014		10:20	0.07	<0.10	0.29	<0.10	<0.10	<0.10	0.18	<0.10	<0.10
5/22/2014		5:13	0.13	<0.10	0.69	<0.10	<0.10	<0.10	0.57	<0.10	<0.10

PP

Table 47 Bioretention Cell Havelock, Large, Effluent 1, 2 and 3 Pesticide Pollutants (2/3)

Date	Location	Time Collected	Pesticides					
			EPTC	*Metolachlor*	*Metribuzin*	*Norflorazon*	*Pendamethalin*	*Permethrin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12	<0.05	0.14	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:30						
4/24/2014		4:56	<0.10	0.28	<0.10	<0.10	<0.10	<0.10
4/27/2014		9:50	<0.05	0.15	<0.05	<0.05	<0.05	<0.05
5/22/2014		4:53	<0.05	0.16	<0.05	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-Out-2	10:22	<0.05	0.14	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:40						
4/24/2014		5:06	<0.10	0.25	<0.10	<0.10	<0.10	<0.10
4/27/2014		10:05	<0.05	0.15	<0.05	<0.05	<0.05	<0.05
5/22/2014		5:03	<0.05	0.18	<0.05	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-Out-3	10:32	0.06	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:50						
4/24/2014		5:16	<0.10	0.23	<0.10	<0.10	<0.10	<0.10
4/27/2014		10:20	<0.10	0.14	<0.10	<0.10	<0.10	<0.10
5/22/2014		5:13	<0.10	0.18	<0.10	<0.10	<0.10	<0.10

Table 48 Bioretention Cell Havelock, Large, Effluent 1, 2 and 3 Pesticide Pollutants (3/3)

Date	Location	Time Collected	Pesticides					
			Prometon	*Propachlor*	*Propazine*	*Simazine*	*Telfluthrin*	*Telfluthrin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:30						
4/24/2014		4:56	<0.10	<0.10	0.01	<0.10	<0.10	<0.10
4/27/2014		9:50	<0.05	<0.05	0.02	0.01	<0.05	<0.05
5/22/2014		4:53	<0.05	<0.05	0.07	<0.05	<0.05	<0.05
6/24/2013	Havelock Large-Out-2	10:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:40						
4/24/2014		5:06	<0.10	<0.10	0.01	<0.10	<0.10	<0.10
4/27/2014		10:05	<0.05	<0.05	0.02	<0.05	<0.05	<0.05
5/22/2014		5:03	<0.05	<0.05	0.07	0.01	<0.05	<0.05
6/24/2013	Havelock Large-Out-3	10:32	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013		20:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4/13/2014		9:50						
4/24/2014		5:16	<0.10	<0.10	0.01	<0.10	<0.10	<0.10
4/27/2014		10:20	<0.10	<0.10	0.07	<0.10	<0.10	<0.10
5/22/2014		5:13	<0.10	<0.10	0.02	<0.10	<0.10	<0.10

RR

Table 49 Bioretention Cell Havelock, Small, Influent 1, 2 and 3 Non-Pesticide Pollutants

Date	Location	Time Collected	Pollutants (Non-Pesticide)									
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*	*TSS*	*TDS*	*Conductivity*	*Oil/Grease*
		hh:mm	*TKN mg N/L*	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*	*mg/L*	*mg/L*	*uS/cm*	*mg/L*
6/23/2013	Havelock Small-In-1		2.68	0.729	0.14	52.6	1.12E+07	1.26E+04	96.4	102	56.8	<5.0
9/10/2013		19:37	3.74	0.564	1.359	99.4	8.16E+07	3.50E+05	420.6	275	138	<5.0
4/13/2014		8:22	5.04	0.773	0.237	55.2	1.25E+04	4.10E+00	1062	345	147	9.4
4/24/2014		2:23	1.14	0.457	0.174	15.9	6.13E+04	3.64E+01	42.1	18	95.2	<5.0
4/27/2014		8:15	1.9	0.97	0.271	30.3	1.30E+08	2.60E+04	35.7	304	322	<5.0
5/22/2014		4:15	2.07	0.252	0.413	64			109	40	109	40
6/23/2013	Havelock Small-In-2		1.14	0.781	0.192	26.1	1.90E+07	1.06E+04	70.4	76	45.9	<5.0
9/10/2013		19:48	2.03	0.957	0.75	32.9	3.65E+08	8.16E+04	195.8	135	61.6	<5.0
4/13/2014		8:37	2.46	0.676	0.186	19.3	2.62E+03	5.48E+02	381	128	94.2	5.6
4/24/2014		2:38	1.07	0.593	0.222	30.1	8.66E+04	3.23E+01	9	15	94.5	<5.0
4/27/2014		8:30	2.36	0.419	0.332	29	2.91E+07	9.80E+04	39.5	215	153	<5.0
5/22/2014		4:30	7.93	0.618	0.439	315			49.6	56	49.6	56
6/23/2013	Havelock Small-In-3		1.32	0.744	0.201	27.2	2.11E+07	9.04E+03	47.6	130	440	<5.0
9/10/2013		20:03	1.68	0.361	0.331	77.7	8.66E+08	7.67E+03	373.9	89	56.1	<5.0
4/13/2014		8:52	1.47	0.584	0.156	11.9	3.55E+03	7.27E+02	232	79	77.9	<5.0
4/24/2014		2:53	1.11	0.687	0.306	14.7	7.27E+04	4.55E+01	7.2	15	143	<5.0
4/27/2014		8:45	2.51	0.517	0.374	41.9	3.78E+07	1.73E+05	82.1	154	107	<5.0
5/22/2014		4:45	5.1	0.212	0.401	80			62.3	28	62.3	28

SS

Table 50 Bioretention Cell Havelock, Small, Influent 1, 2 and 3 Pesticide Pollutants (1/3)

Time Collected	Pesticides								
	Acetochlor	*Alachlor*	*Atrazine*	*Butylate*	*Chlorthalonil*	*Cyanazine*	*DEA*	*DIA*	*Dimethenamid*
hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
10:12	0.46	0.48	0.5	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
9:30									
4:56	0.39	<0.10	0.8	<0.10	<0.10	<0.10	0.26	<0.10	<0.10
9:50	0.39	<0.10	1.08	<0.10	<0.10	<0.10	0.31	<0.10	<0.10
4:53	0.81	<0.10	2.16	<0.10	<0.10	<0.10	1.97	0.78	<0.10
10:22	0.26	0.13	0.35	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
9:40									
5:06	0.33	<0.10	0.68	<0.10	<0.10	<0.10	0.26	<0.10	<0.10
10:05	0.3	<0.10	0.67	<0.10	<0.10	<0.10	0.22	<0.10	<0.10
5:03	0.75	<0.10	1.76	<0.10	<0.10	<0.10	1.12	0.57	<0.10
10:32	0.22	0.17	0.32	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
20:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10	<0.05
9:50									
5:16	0.14	<0.10	0.4	<0.10	<0.10	<0.10	0.23	<0.10	<0.10
10:20	0.33	<0.10	0.72	<0.10	<0.10	<0.10	0.26	<0.10	<0.10
5:13	0.57	<0.10	1.38	<0.10	<0.10	<0.10	0.9	0.5	<0.10

Table 51 Bioretention Cell Havelock, Small, Influent 1, 2 and 3 Pesticide Pollutants (2/3)

Time Collected	Pesticides					
	EPTC	*Metolachlor*	*Metribuzin*	*Norflorazon*	*Pendamethalin*	*Permethrin*
hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
10:12	<0.05	1.56	<0.05	<0.05	<0.05	<0.05
20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9:30						
4:56	<0.10	0.51	<0.10	<0.10	<0.10	<0.10
9:50	<0.10	0.68	<0.10	<0.10	<0.10	<0.10
4:53	<0.10	1.04	<0.10	<0.10	<0.10	<0.10
10:22	<0.05	0.99	<0.05	<0.05	<0.05	<0.05
20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9:40						
5:06	<0.10	0.65	<0.10	<0.10	<0.10	<0.10
10:05	<0.10	0.48	<0.10	<0.10	<0.10	<0.10
5:03	<0.10	1.04	<0.10	<0.10	<0.10	<0.10
10:32	<0.05	0.79	<0.05	<0.05	<0.05	<0.05
20:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9:50						
5:16	<0.10	0.23	<0.10	<0.10	<0.10	<0.10
10:20	<0.10	0.52	<0.10	<0.10	<0.10	<0.10
5:13	<0.10	0.65	<0.10	<0.10	<0.10	<0.10

Table 52 Bioretention Cell Havelock, Small, Influent 1, 2 and 3 Pesticide Pollutants (3/3)

Time Collected	Pesticides					
	Prometon	*Propachlor*	*Propazine*	*Simazine*	*Telfluthrin*	*Trifluralin*
hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
10:12	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
20:02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9:30						
4:56	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
9:50	<0.10	<0.10	0.03	<0.10	<0.10	<0.10
4:53	<0.10	<0.10	0.05	0.01	<0.10	<0.10
10:22	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
20:12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9:40						
5:06	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
10:05	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
5:03	<0.10	<0.10	0.04	<0.10	<0.10	<0.10
10:32	< 0.05	<0.05	<0.05	<0.05	<0.05	<0.05
20:22	0.14	<0.05	<0.05	<0.05	<0.05	<0.05
9:50						
5:16	<0.10	<0.10	0.01	<0.10	<0.10	<0.10
10:20	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
5:13	<0.10	<0.10	0.04	0.01	<0.10	<0.10

Table 53 Bioretention Cell Havelock, Small, Effluent 1, 2 and 3 Non-Pesticide Pollutants

Date	Location	Time Collected	Pollutants (Non-Pesticide)									
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*	*TSS*	*TDS*	*Conductivity*	*Oil/Grease*
		hh:mm	*TKN mg N/L*	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*	*mg/L*	*mg/L*	*uS/cm*	*mg/L*
6/23/2013	Havelock Small-Out-1						1.12E+06	1.20E+02				
9/10/2013		20:02	3.1	2.82	0.667	1.5	6.13E+07	1.33E+04	5.9	231	169	
4/13/2014		9:30					2.23E+04	1.30E+01				
4/24/2014		4:56	1.65	0.662	0.276	23.5	3.28E+05	1.83E+01	28.6	16	78.7	<5.0
4/27/2014		9:50	1.68	0.648	0.27	20	1.30E+07	6.05E+04	22.3	137	121	
5/22/2014		4:53	5.31	0.155	0.316	39.5			14.3	20	14.3	20
6/23/2013	Havelock Small-Out-2						1.67E+05	4.80E+02				
9/10/2013		20:17	2.51	2.6	0.64	2.9	7.27E+07	1.34E+01	1.7	219	160	
4/13/2014		9:45	2.32	1.03	0.224	21.1	1.99E+04	1.71E+01	289	128	107	5.3
4/24/2014		5:05	1.37	0.718	0.168	14.6	3.87E+05	2.72E+01	19.3	<10	73.8	<5.0
4/27/2014		10:05	1.73	0.635	0.257	19	6.02E+06	7.12E+04	6.3	219	122	<5.0
5/22/2014		5:03	3	2.56	0.356	28			11.4	17	11.4	17
6/23/2013	Havelock Small-Out-3						1.61E+05	-				
9/10/2013		20:32	3.18	2.69	0.656	0.9	2.70E+07	7.54E+03	114.5	254	170	
4/13/2014		10:00	1.56	0.505	0.177	14.7	1.99E+04	1.48E+01	221	44	75.3	<5.0
4/24/2014		5:15	1.42	0.947	0.223	13.6	2.60E+05	1.93E+01	15.4	<10	84.1	<5.0
4/27/2014		10:20	1.55	0.046	0.252	21.6	9.21E+06	8.60E+04	32	174	107	<5.0
5/22/2014		5:13	2.22	0.222	0.294	19.8			12.8	16	12.8	16

WW

Table 54 Bioretention Cell Havelock, Small, Effluent 1, 2 and 3 Pesticide Pollutants (1/3)

Date	Location	Time Collected	Pesticides								
			Acetochlor	*Alachlor*	*Atrazine*	*Butylate*	*Chlorthalonil*	*Cyanazine*	*DEA*	*DIA*	*Dimethenamid*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12									
9/10/2013		20:02									
4/13/2014		9:30									
4/24/2014		4:56	0.92	<0.10	1.66	<0.10	<0.10	<0.10	0.38	<0.10	0.02
4/27/2014		9:50	0.19	<0.10	0.56	<0.10	<0.10	<0.10	0.26	<0.10	<0.10
5/22/2014		4:53	0.36	<0.10	0.33	<0.10	<0.10	<0.10	0.95	0.54	<0.10
6/24/2013	Havelock Large-Out-2	10:22									
9/10/2013		20:12									
4/13/2014		9:40									
4/24/2014		5:06	0.67	<0.10	1.14	<0.10	<0.10	<0.10	0.32	<0.10	<0.10
4/27/2014		10:05	0.19	<0.10	0.56	<0.10	<0.10	<0.10	0.28	<0.10	<0.10
5/22/2014		5:03	0.29	<0.10	1.05	<0.10	<0.10	<0.10	0.73	<0.10	<0.10
6/24/2013	Havelock Large-Out-3	10:32									
9/10/2013		20:22									
4/13/2014		9:50									
4/24/2014		5:16	0.49	<0.10	0.93	<0.10	<0.10	<0.10	0.3	<0.10	<0.10
4/27/2014		10:20	0.19	<0.10	0.57	<0.10	<0.10	<0.10	0.27	<0.10	<0.10
5/22/2014		5:13	0.2	<0.10	0.81	<0.10	<0.10	<0.10	0.72	<0.10	<0.10

Table 55 Bioretention Cell Havelock, Small, Effluent 1, 2 and 3 Pesticide Pollutants (2/3)

Date	Location	Time Collected	Pesticides					
			EPTC	*Metolachlor*	*Metribuzin*	*Norflorazon*	*Pendamethalin*	*Permethrin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12						
9/10/2013		20:02						
4/13/2014		9:30						
4/24/2014		4:56	<0.10	1.03	<0.10	<0.10	<0.10	<0.10
4/27/2014		9:50	<0.10	0.35	<0.10	<0.10	<0.10	<0.10
5/22/2014		4:53	<0.10	0.46	<0.10	<0.10	<0.10	<0.10
6/24/2013	Havelock Large-Out-2	10:22						
9/10/2013		20:12						
4/13/2014		9:40						
4/24/2014		5:06	<0.10	0.72	<0.10	<0.10	<0.10	<0.10
4/27/2014		10:05	<0.10	0.34	<0.10	<0.10	<0.10	<0.10
5/22/2014		5:03	<0.10	0.38	<0.10	<0.10	<0.10	<0.10
6/24/2013	Havelock Large-Out-3	10:32						
9/10/2013		20:22						
4/13/2014		9:50						
4/24/2014		5:16	<0.10	0.57	<0.10	<0.10	<0.10	<0.10
4/27/2014		10:20	<0.10	0.34	<0.10	<0.10	<0.10	<0.10
5/22/2014		5:13	<0.10	0.28	<0.10	<0.10	<0.10	<0.10

Table 56 Bioretention Cell Havelock, Small, Effluent 1, 2 and 3 Pesticide Pollutants (3/3)

Date	Location	Time Collected	Pesticides					
			Prometon	*Propachlor*	*Propazine*	*Simazine*	*Telfluthrin*	*Trifluralin*
		hh:mm	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
6/24/2013	Havelock Large-Out-1	10:12						
9/10/2013		20:02						
4/13/2014		9:30						
4/24/2014		4:56	<0.10	<0.10	0.04	<0.10	<0.10	<0.10
4/27/2014		9:50	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
5/22/2014		4:53	<0.10	<0.10	0.03	<0.10	<0.10	<0.10
6/24/2013	Havelock Large-Out-2	10:22						
9/10/2013		20:12						
4/13/2014		9:40						
4/24/2014		5:06	<0.10	<0.10	0.08	<0.10	<0.10	<0.10
4/27/2014		10:05	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
5/22/2014		5:03	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
6/24/2013	Havelock Large-Out-3	10:32						
9/10/2013		20:22						
4/13/2014		9:50						
4/24/2014		5:16	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
4/27/2014		10:20	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
5/22/2014		5:13	<0.10	<0.10	0.02	0.01	<0.10	<0.10

Table 57 Rainfall Sites Non-Pesticide Pollutants

Rainfall Sites Non-Pesticide Pollutants							
Date	**Location**	**Sample Type**	**Pollutants (Non-Pesticide)**				
			TKN	*Nitrate*	*Total P*	*Zinc*	*Conductivity*
			TKN mg N/L	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*uS/cm*
7/23/2013	Firestation 12 Rainfall Site	Rainfall	8.93	0.381	0.944	66	66
9/10/2013			1.42	0.314	0.182	24.5	24.5
5/22/2014			14.4	0.149	1.065		115
7/23/2013	Baldwin Rainfall Site		10.2	0.142	2.187	126	126
9/10/2013			1.06	0.324	0.073	51.6	51.6
5/22/2014			16.5	0.133	1.205		75.5

Table 58 Rainfall Sites Pesticide Pollutants (1/3)

Rainfall Sites Pesticide Pollutants (1/2)									
Date	**Location**	**Sample Type**	**Pesticides**						
			Acetochlor	*Alachlor*	*Atrazine*	*Butylate*	*Chlorthalonil*	*Cyanazine*	*DEA*	*DIA*
			ug/L	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
7/23/2013	Firestation 12 Rainfall Site	Rainfall	<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	0.08	<0.10
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10
5/22/2014			0.21	<0.05	0.64	<0.05	<0.05	<0.05	0.58	<0.05
7/23/2013	Baldwin Rainfall Site		<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	0.06	<0.10
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.10	<0.05	<0.10
5/22/2014			0.29	<0.05	0.77	<0.05	<0.05	<0.05	0.48	<0.05

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Table 59 Rainfall Sites Pesticide Pollutants (2/3)

Rainfall Sites Pesticide Pollutants (2/3)								
Date	**Location**	**Sample Type**	**Pesticides**					
			Dimethenamid	*EPTC*	*Metolachlor*	*Metribuzin*	*Norflorazon*	*Pendamethalin*	*Permethrin*
			ug/L	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
7/23/2013	Firestation 12 Rainfall Site	Rainfall	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
5/22/2014			<0.05	<0.05	0.28	<0.05	<0.05	<0.05	<0.05
7/23/2013	Baldwin Rainfall Site		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
5/22/2014			<0.05	<0.05	0.29	<0.05	<0.05	<0.05	<0.05

Table 60 Rainfall Sites Pesticide Pollutants (3/3)

Rainfall Sites Pesticide Pollutants (3/3)								
Date	**Location**	**Sample Type**	**Pesticides**					
			Prometon	*Propachlor*	*Propazine*	*Simazine*	*Telfluthrin*	*Trifluralin*
			ug/L	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
7/23/2013	Firestation 12 Rainfall Site	Rainfall	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
5/22/2014			<0.05	<0.05	0.08	0.01	<0.05	<0.05
7/23/2013	Baldwin Rainfall Site		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
9/10/2013			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
5/22/2014			<0.05	<0.05	0.03	0.01	<0.05	<0.05

BBB

Table 61 Commercial Parking Lot Pollutants

Commercial Parking Lot Pollutants										
Date	**Location**	**Sample Type**	**Pollutants**							
			TKN	*Nitrate*	*Total P*	*Zinc*	*TSS*	*TDS*	*Conductivity*	*Oil/Grease*
			TKN mg N/L	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*mg/L*	*mg/L*	*uS/cm*	*mg/L*
7/23/2013	Lancaster Office Parking Lot	Commercial Parking Lot	2.23	0.663	0.23	17.2	16.4	97	59.7	<0.05
9/10/2013			2.58	0.803	0.239	11.8	40	125	73.6	<0.05
5/22/2014			2.59	0.228	0.144	18.2	5.2	<10	76.7	<0.05
6/24/2013	NRD Building Parking Lot		1.06	0.335	0.065	13.7		31		
9/10/2013			0.653	0.149	0.068	2.1	12.6	54	39.7	<0.05
5/22/2014			6.48	0.228	0.526	18.9	21.4	31	365	<0.05

CCC

Table 62 Residential Roof Pollutants

Residential Roof Pollutants								
Date	**Location**	**Sample Type**	**Pollutants**					
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*
			TKN mg N/L	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*
9/10/2013	Woods Ave House #3460	Residential Roof	1.81	0.867	0.243	98.3	4.28E+05	5.21E+02
5/22/2014			1.53	0.109	0.207	62.2		
6/1/2014			1.17	0.149	0.135	112		
9/10/2013	Woods Ave House #3454		1.67	0.55	0.161	31.9	4.16E+07	4.87E+04
5/22/2014			1.52	0.203	0.193	33.6		
6/1/2014			0.873	0.401	0.182	70.9		
9/10/2013	Woods Ave House #3348		3.74	1.34	0.148	152	3.26E+06	1.52E+04
5/22/2014			6.24	0.096	0.34	48.2		
6/1/2014			3.26	0.095	0.281	65.3		
9/10/2013	Woods Ave House #3300		3.97	1.78	0.24	250	2.61E+07	9.60E+04
5/22/2014			1.95	0.136	0.144	128		
6/1/2014			1.08	0.007	0.115	79.6		
5/22/2014	SW 74th (1)		1.02	0.155	0.033	23.1		
6/1/2014			2.95	0.133	0.183	49.7		
5/22/2014	SW 74th (2)		11.1	0.17	0.553	33.6		
6/1/2014			0.599	0.519	0.027	30.5		

DDD

Table 63 Commercial Roof Pollutants

Commercial Roof Pollutants								
Date	**Location**	**Sample Type**	**Pollutants**					
			TKN	*Nitrate*	*Total P*	*Zinc*	*Total Coliforms*	*E.coli*
			TKN mg N/L	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*	*Count per 100 mL*	*Count per 100 mL*
9/10/2013	Lancaster Office Roof	Commercial Roof	6.98	1.65	0.111	396	1.73E+05	1.34E+01
4/13/2014			6.41	1.95	0.099		6.91E+02	2.00E+00
5/22/2014			1.93	0.145	0.093	256		
9/10/2013	Fireworks Restaurant Roof		5.93	0.026	0.442	77.9	3.13E+07	1.00E+00
4/13/2014			6.41	2.82	0.23		2.49E+02	1.00E+00
5/22/2014			5.52	0.259	0.2	131		

Table 64 Residential Rain Garden Pollutants

Residential Rain Garden Pollutants						
Date	**Location**	**Sample Type**	**Pollutants**			
			TKN	*Nitrate*	*Total P*	*Zinc*
			TKN mg N/L	*NO2+NO3-N (mg-N/L)*	*mgP/L*	*ug/L*
6/1/2014	House #3460 Rain Garden	Residential Rain Garden	2.82	0.135	0.558	56.7
6/3/2014			1.66	0.1	0.744	26.9
6/1/2014	House #3454 Rain Garden		2	0.189	0.451	31.2
6/3/2014			3.53	0.12	0.686	39.2
6/1/2014	House #3348 Rain Garden		4.93	0.115	0.313	36
6/3/2014			2.5	0.173	0.886	30.8
6/1/2014	House #3300 Rain Garden		3.73	0.19	0.389	71.4
6/1/2014	Twin Ridge #1 Rain Garden		0.85	0.187	0.176	29.3
6/1/2014	Twin Ridge #2 Rain Garden		8.65	0.106	0.187	40.2
6/3/2014			1.17	0.11	0.171	30.1

FFF

Appendix F Graphs

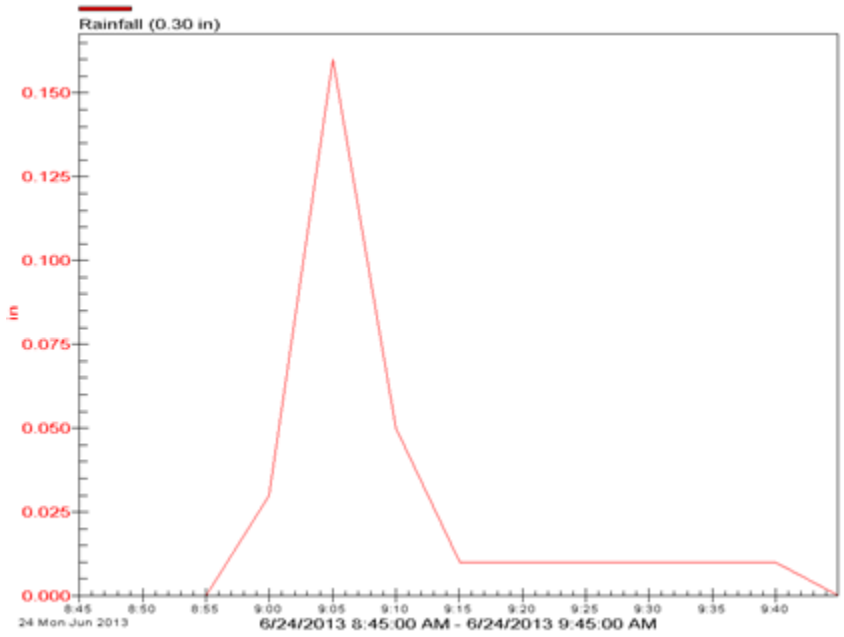

Figure 58 06/24/2013 Large Bioretention Cell Rainfall Measured

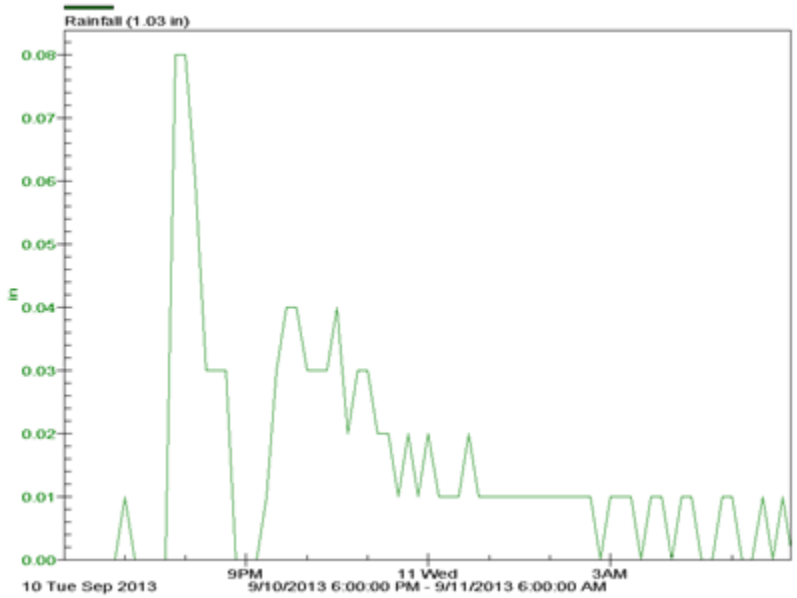

Figure 59 09/10/2013 Large Bioretention Cell Rainfall Measured

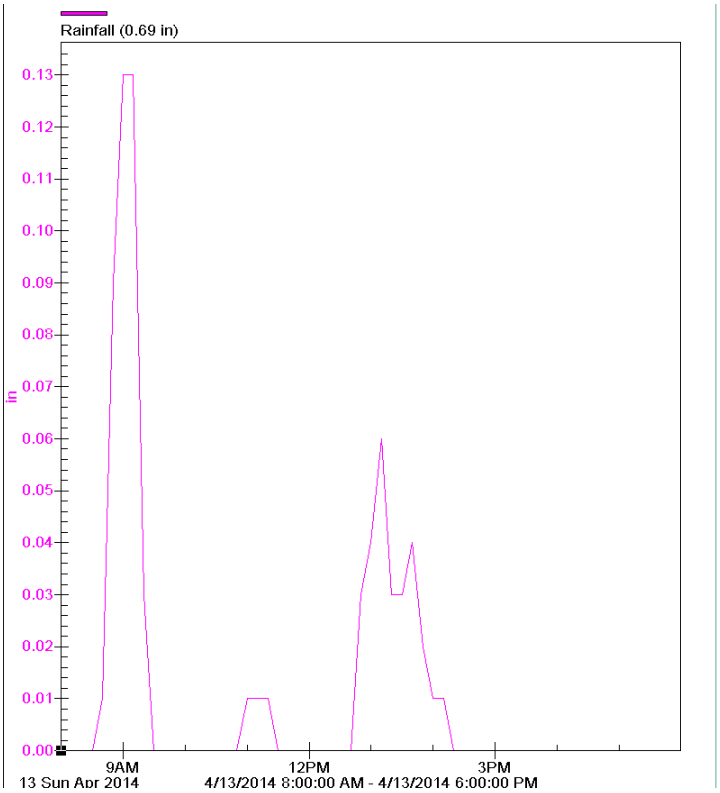

Figure 60 4/13/2014 Large Bioretention Cell Rainfall Measured

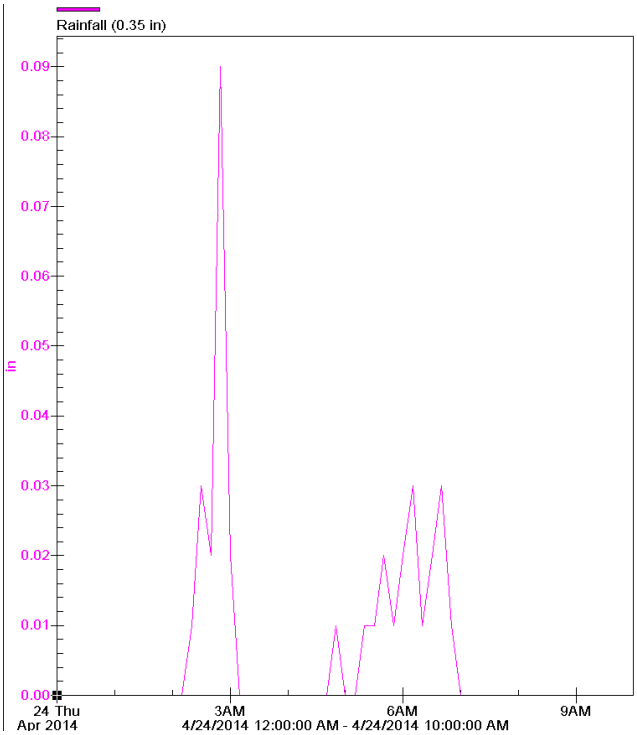

Figure 61 4/24/2014 Large Bioretention Cell Rainfall Measured

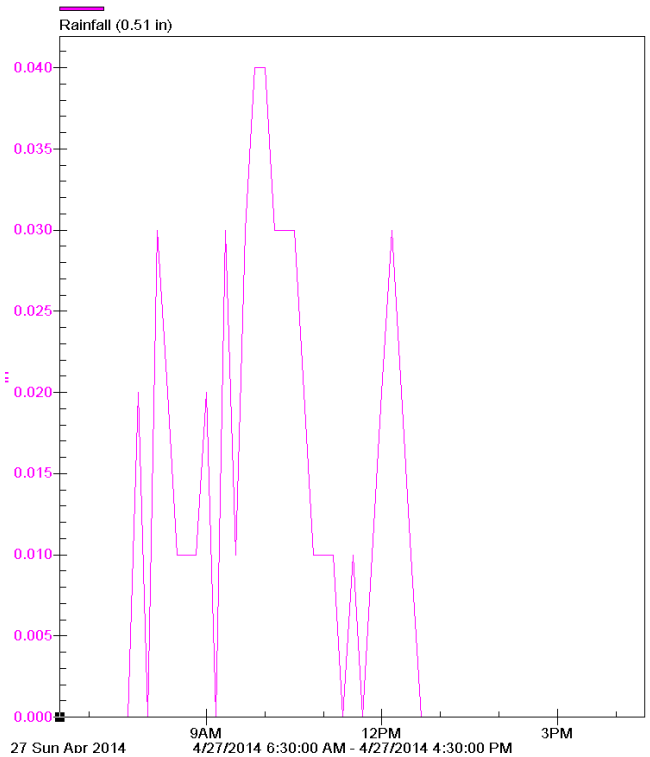

Figure 62 4/27/2014 Large Bioretention Cell Rainfall Measured

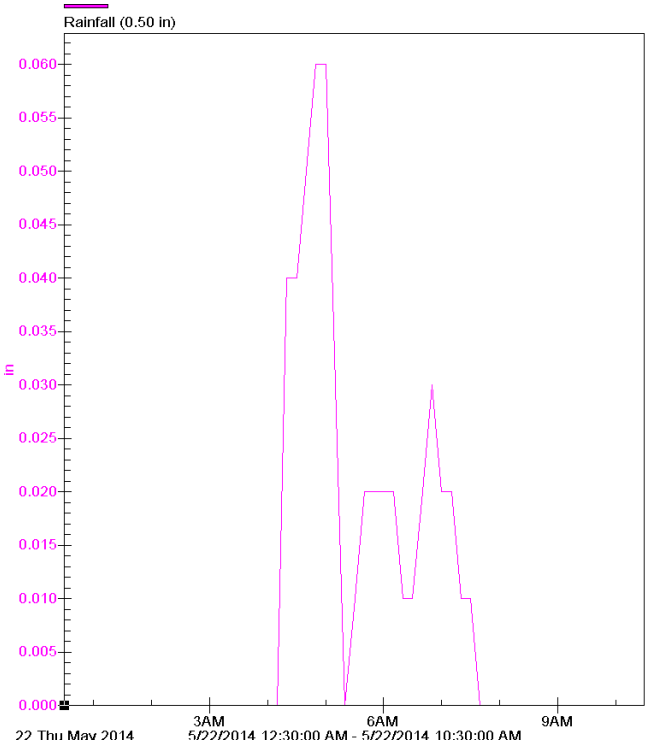

Figure 63 5/22/2014 Large Bioretention Cell Rainfall Measured

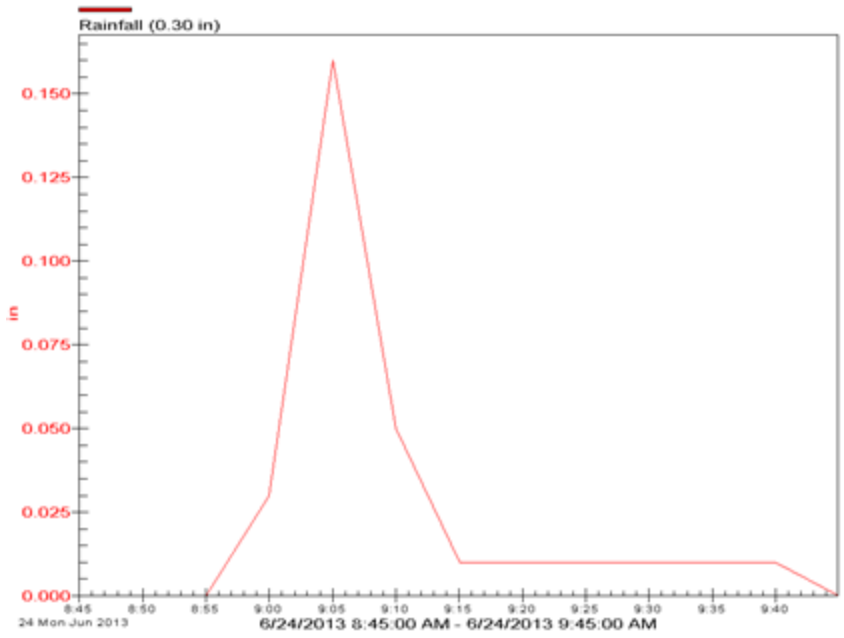

Figure 64 06/24/2013 Large Bioretention Cell Effluent Flow Riser Depth

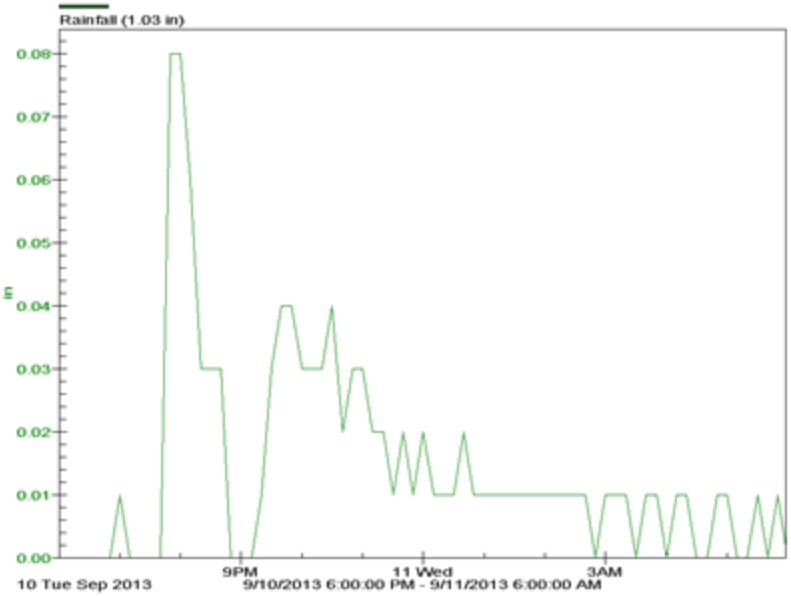

Figure 65 9/10/2014 Large Bioretention Cell Effluent Flow Riser Depth

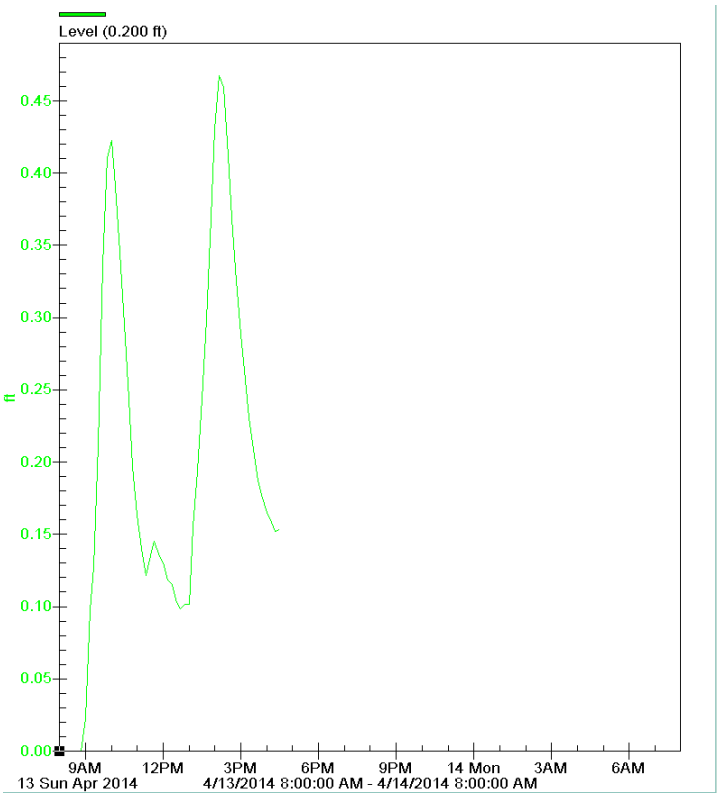

Figure 66 04/13/2014 Large Bioretention Cell Effluent Flow Riser Depth

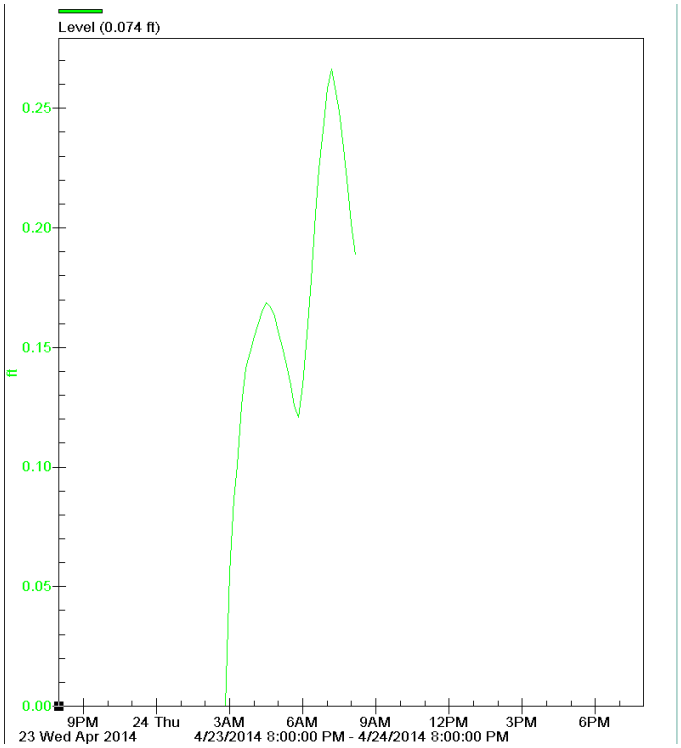

Figure 67 04/24/2014 Large Bioretention Cell Effluent Flow Riser Depth

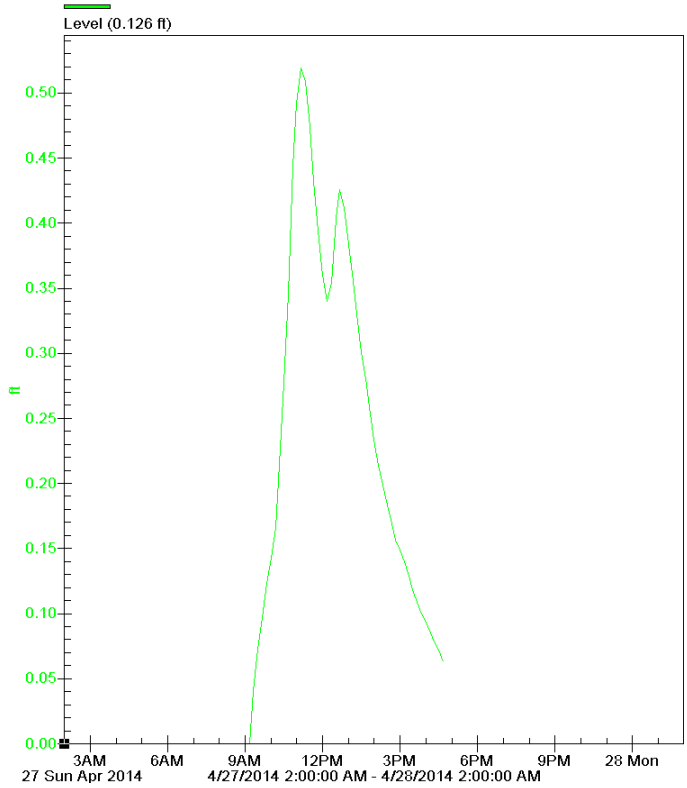

Figure 68 04/27/2014 Large Bioretention Cell Effluent Flow Riser Depth

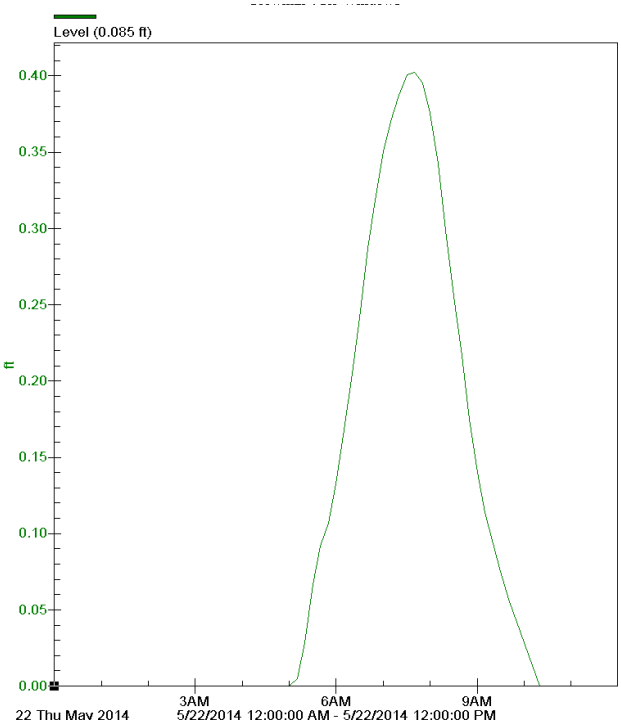

Figure 69 05/22/2014 Large Bioretention Cell Effluent Flow Riser Depth

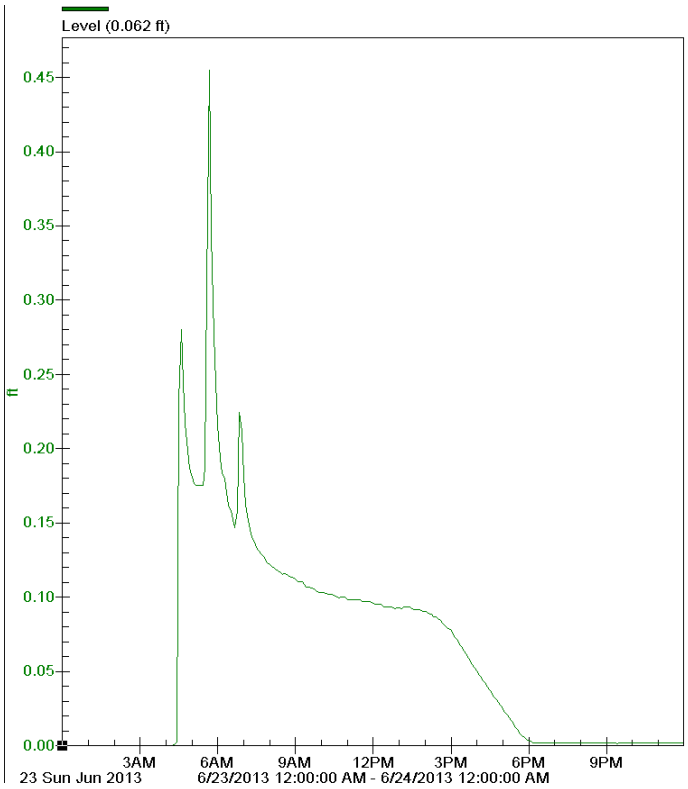

Figure 70 06/23/2013 Small Bioretention Cell Influent Water Depth

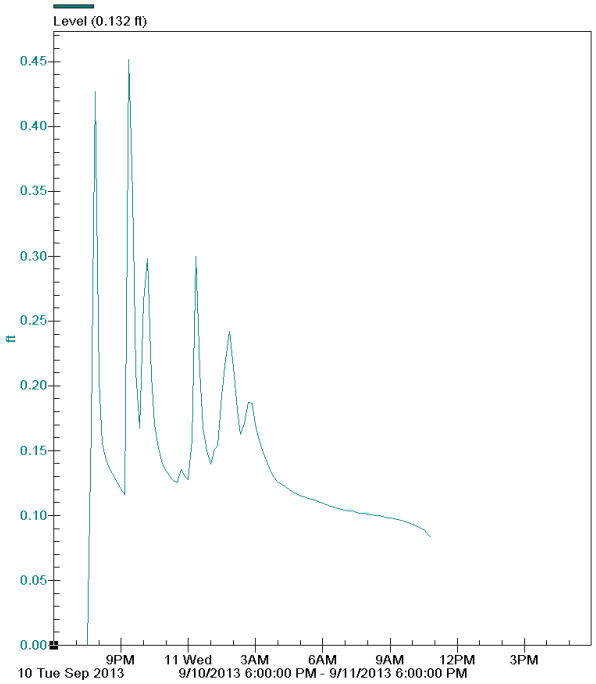

Figure 71 09/10/2013 Small Bioretention Cell Influent Water Depth

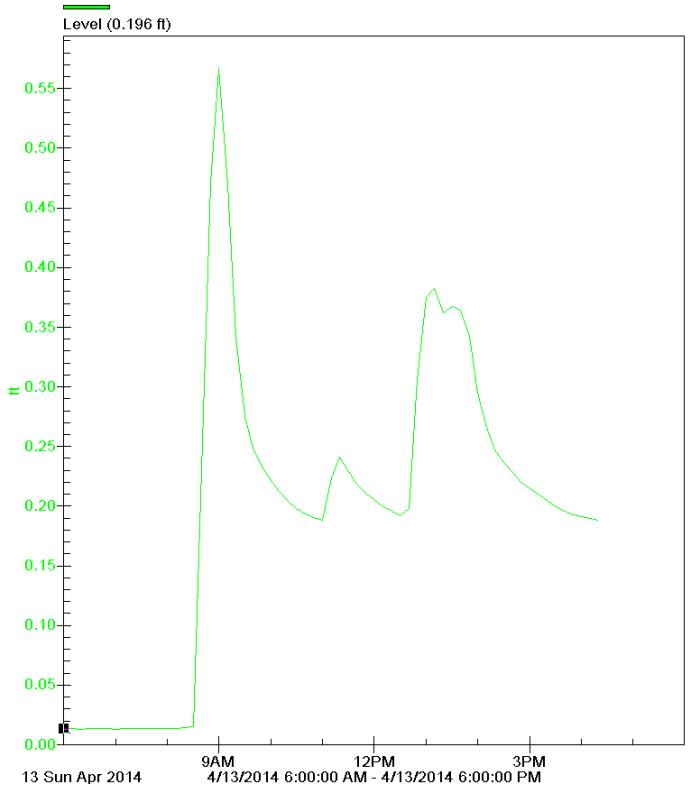

Figure 72 04/13/2014 Small Bioretention Cell Influent Water Depth

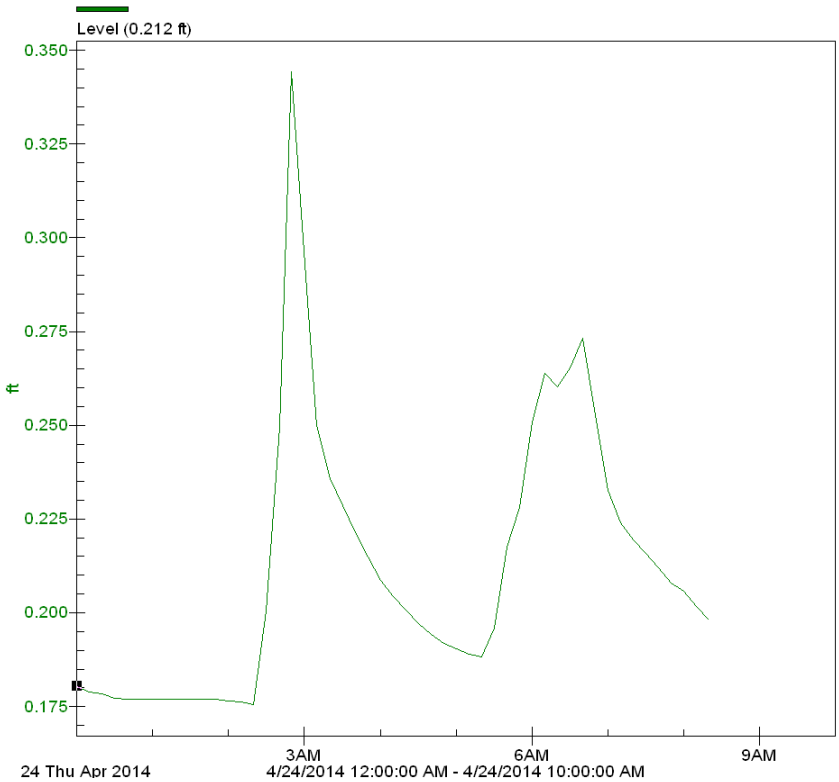

Figure 73 04/24/2014 Small Bioretention Cell Influent Water Depth

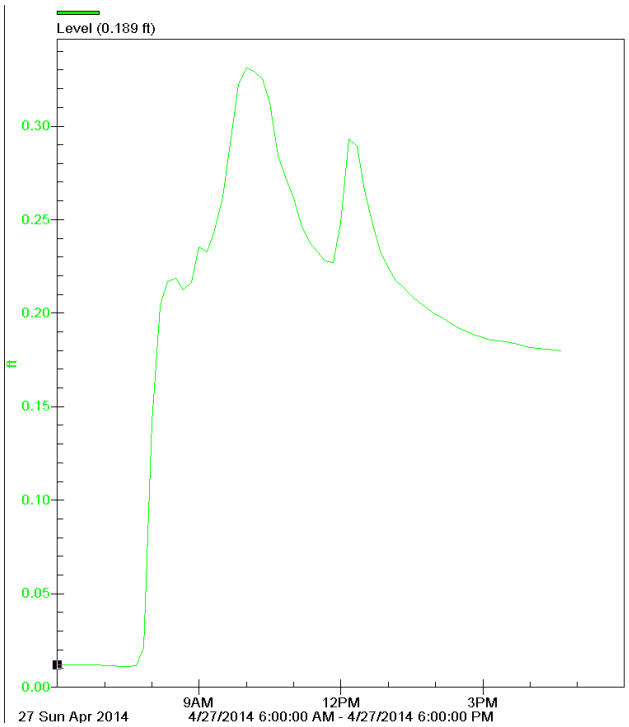

Figure 74 04/27/2014 Small Bioretention Cell Effluent Water Depth

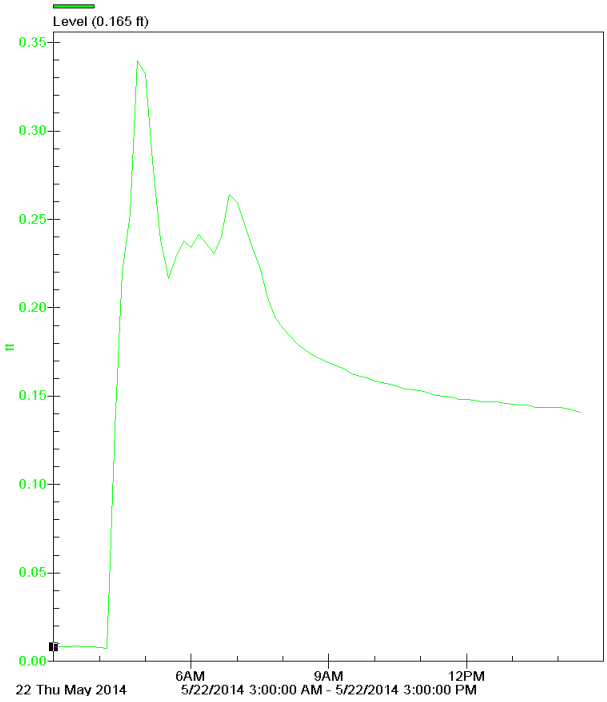

Figure 75 05/22/ 2014 Small Bioretention Cell Effluent Water Depth

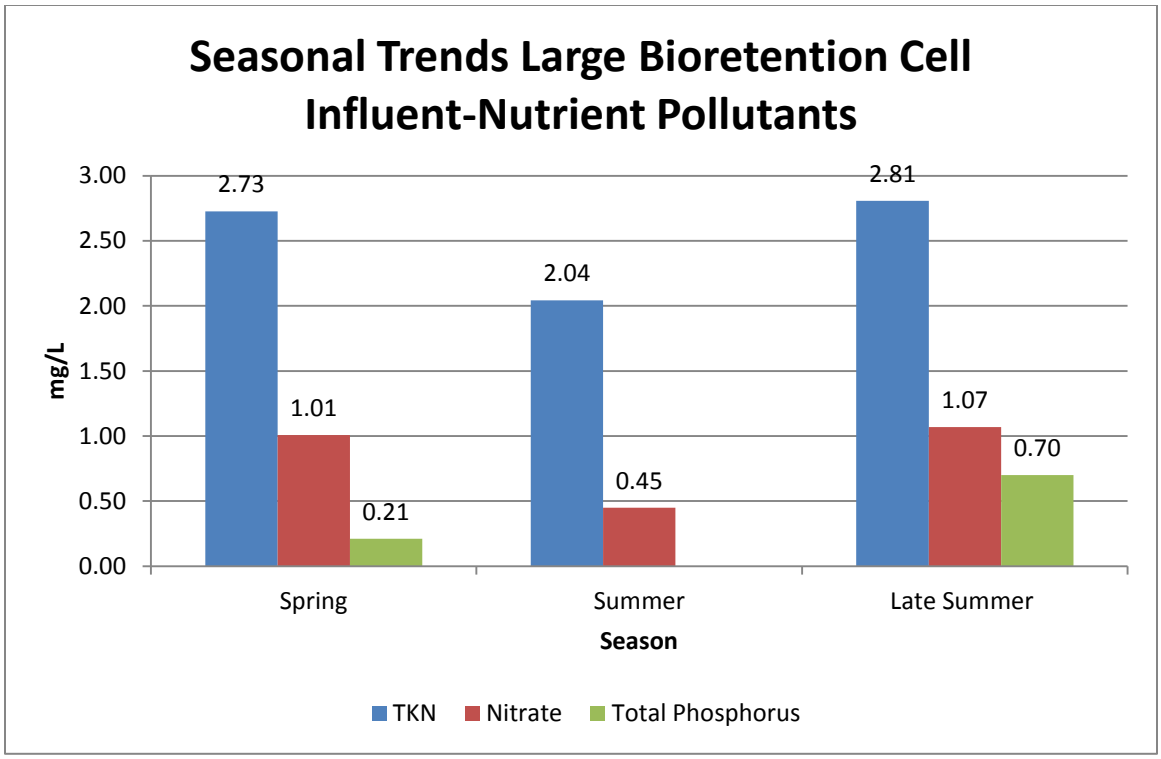

Figure 76 Large Bioretention Cell Seasonal Trends-Nutrients

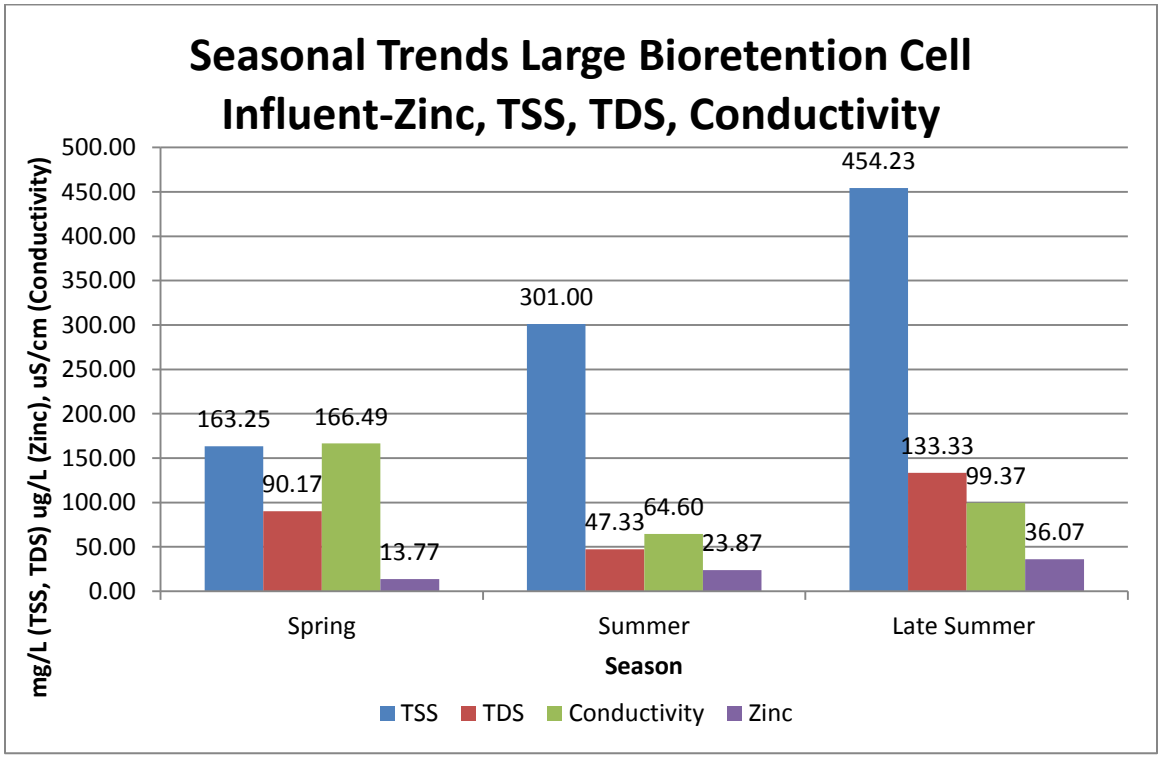

Figure 77 Large Bioretention Cell Season Trends-Non Nutrient, Non Pesticide, Non-Organic Pollutants

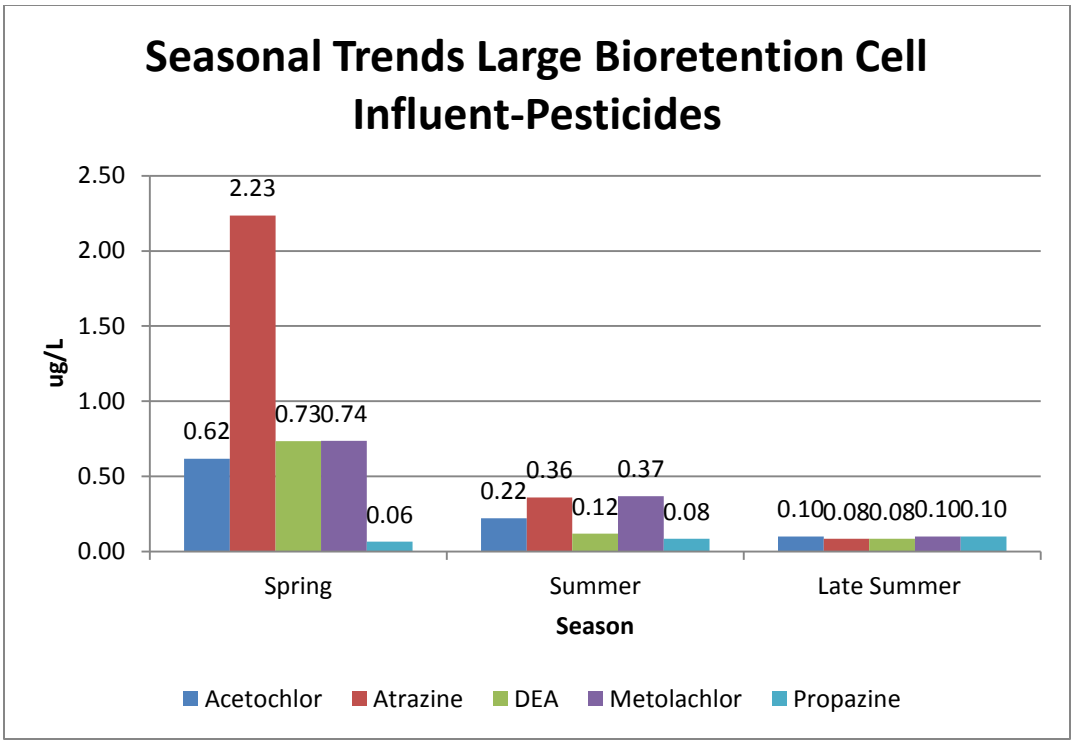

Figure 78 Large Bioretention Cell Seasonal Trends-Pesticides

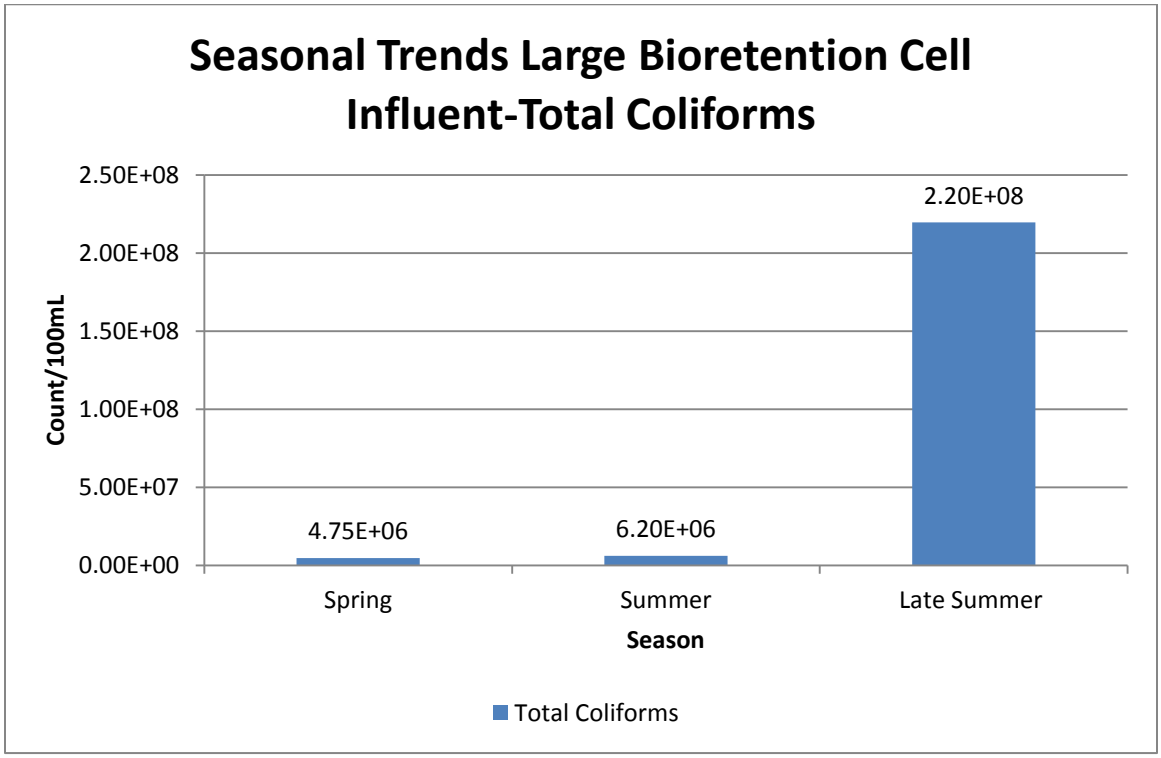

Figure 79 Large Bioretention Cell Seasonal Trends Total Fecal Coliforms

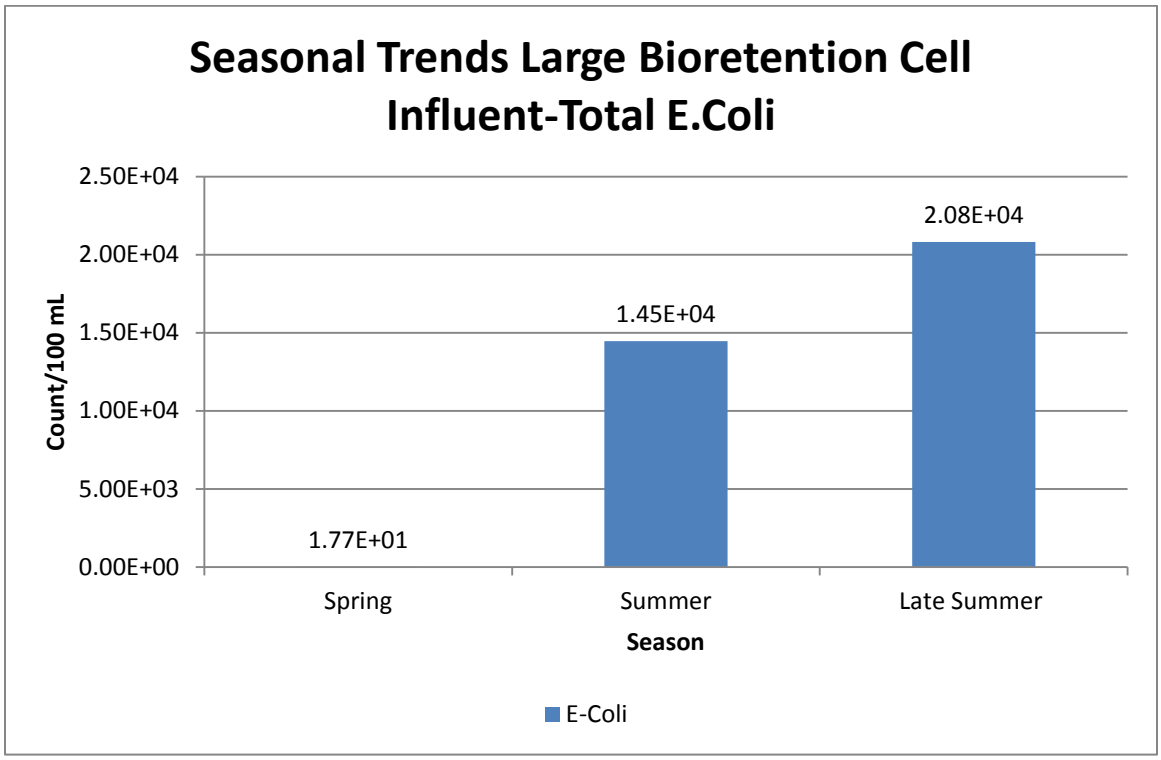

Figure 80 Large Bioretention Cell Seasonal Trends Total E.coli

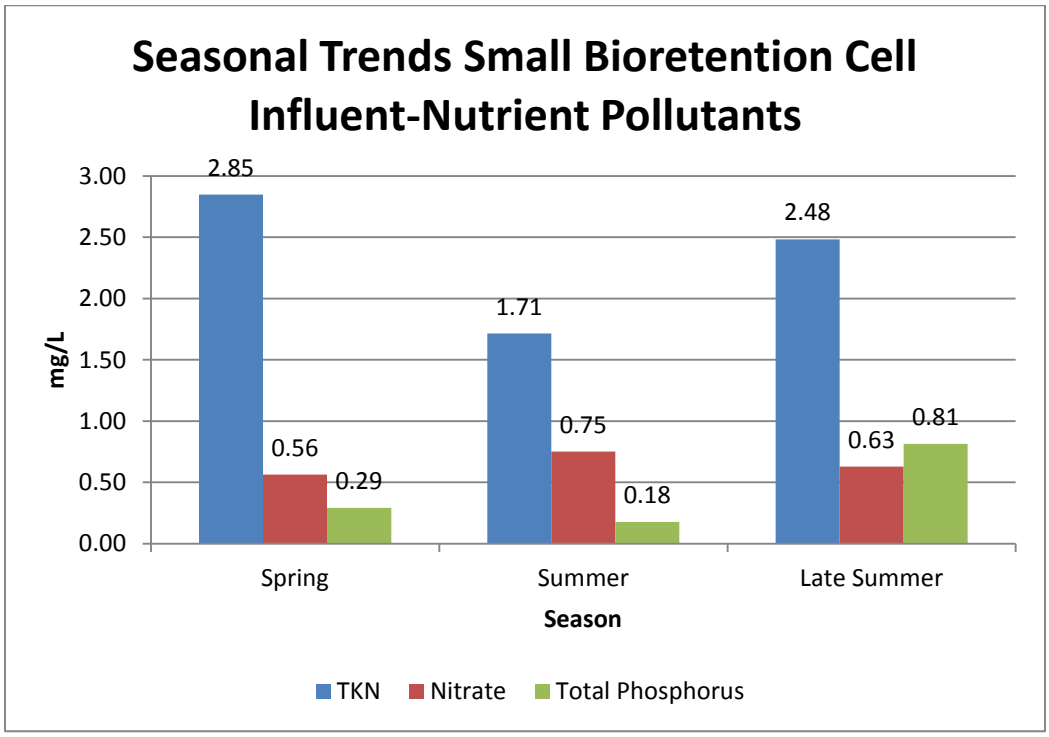

Figure 81 Small Bioretention Cell Seasonal Trends-Nutrients

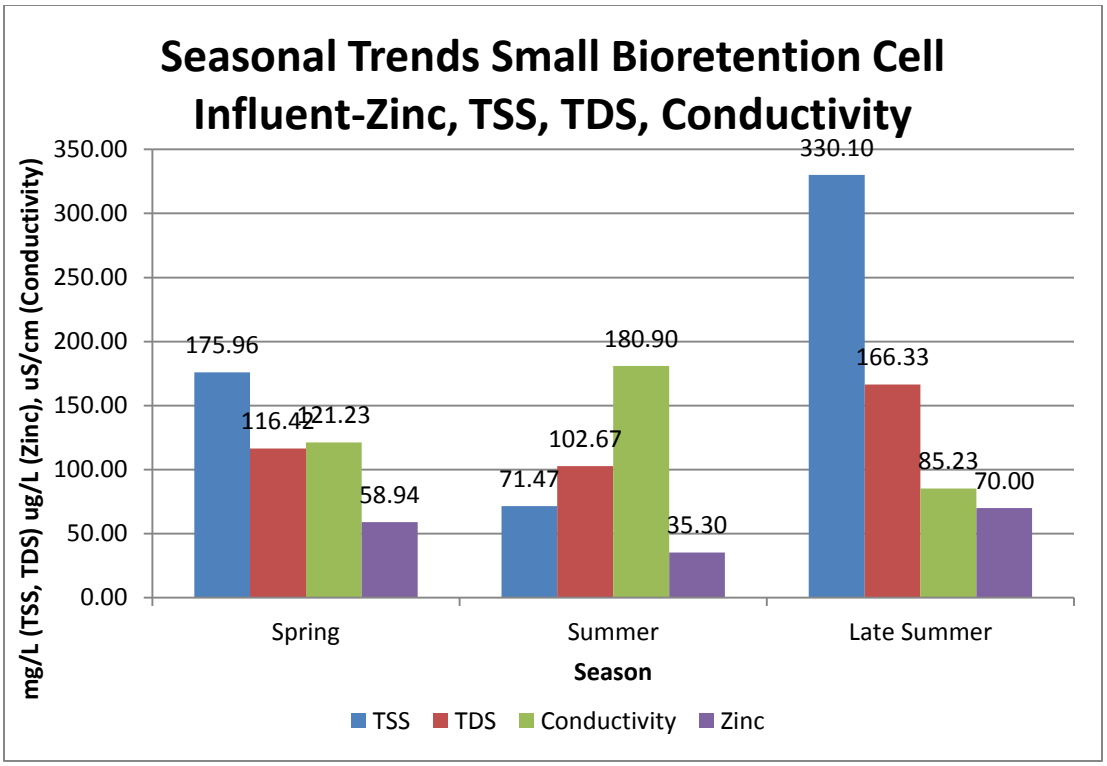

Figure 82 Small Bioretention Cell Season Trends-Non Nutrient, Non Pesticide, Non-Organic Pollutants

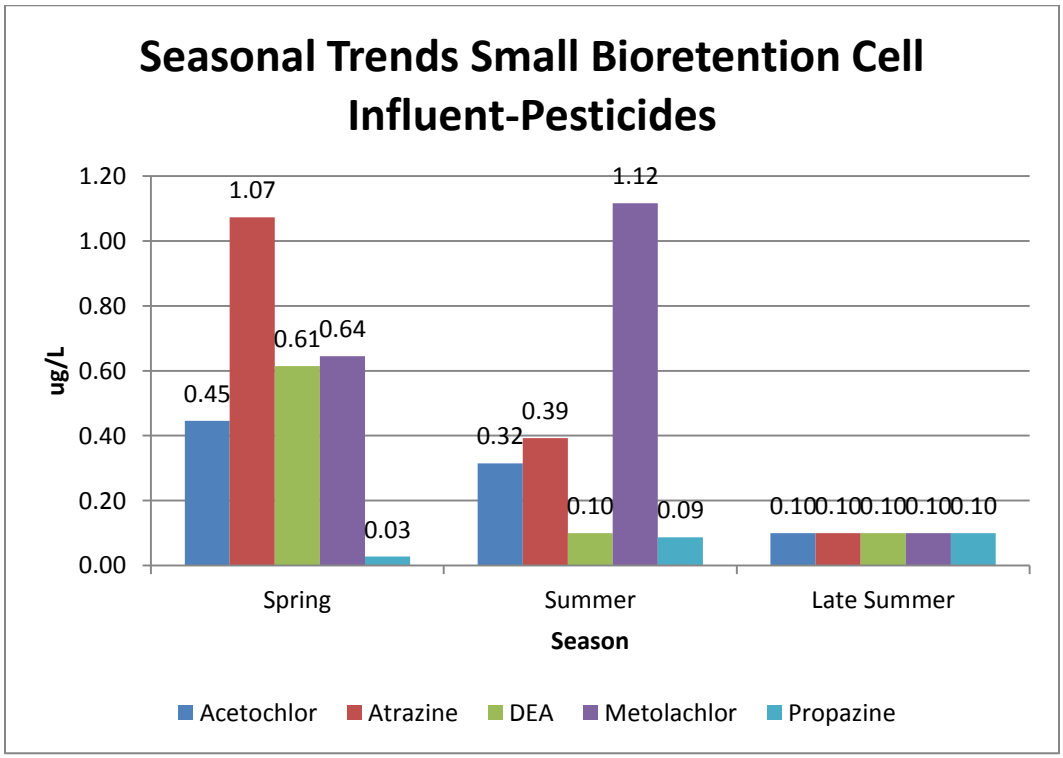

Figure 83 Small Bioretention Cell Seasonal Trends-Pesticides

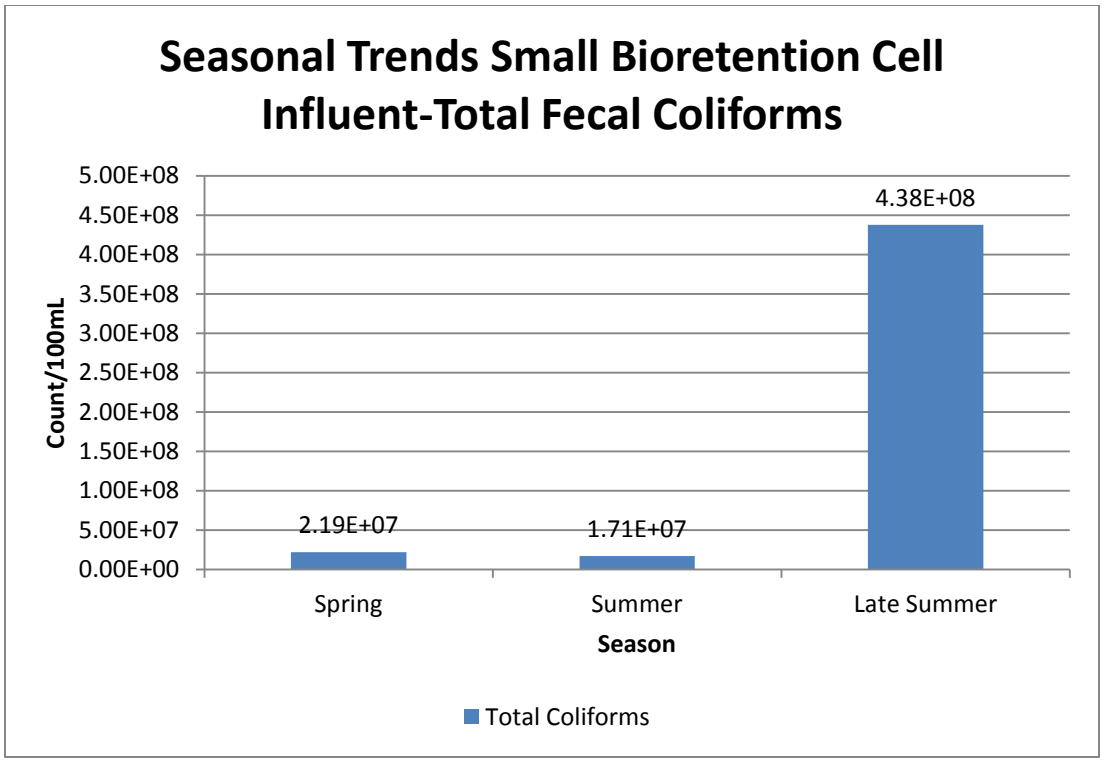

Figure 84 Small Bioretention Cell Seasonal Trends Total Coliforms

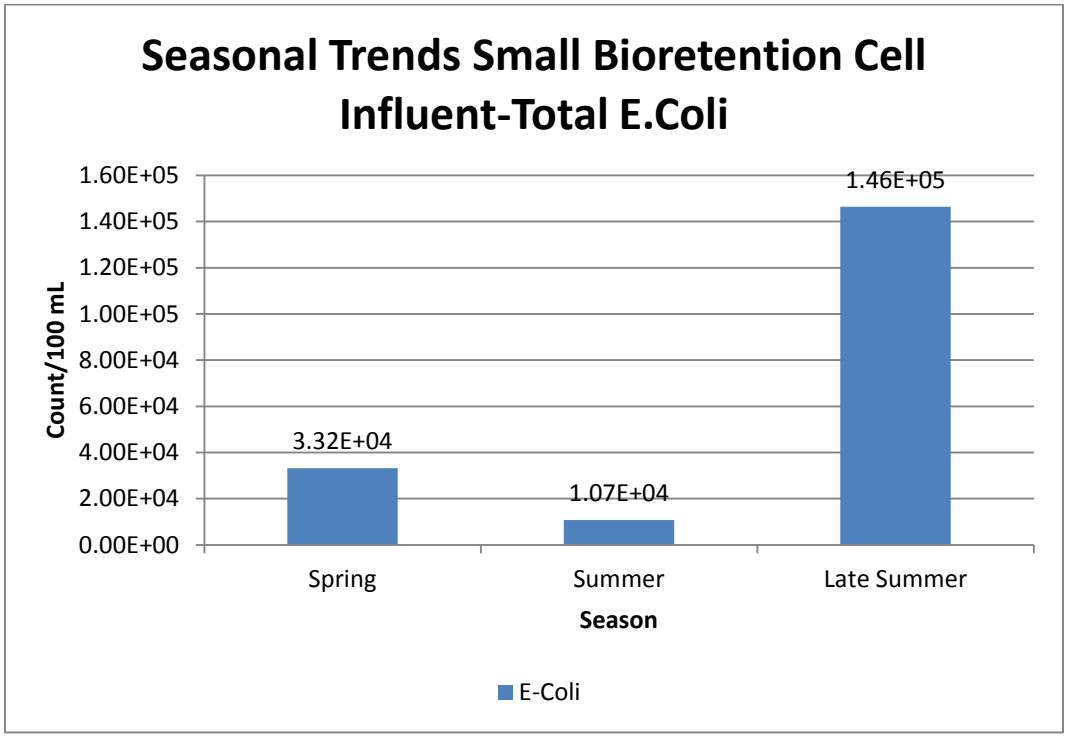

Figure 85 Small Bioretention Cell Seasonal Trends Total E.coli

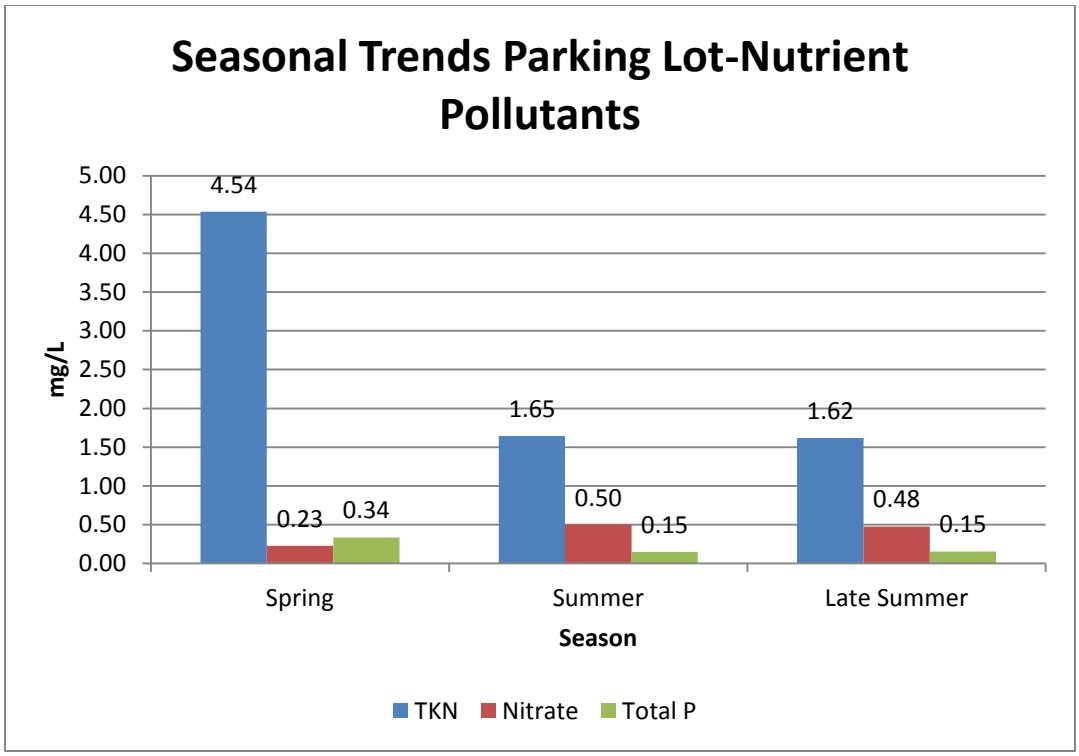

Figure 86 Parking Lot Seasonal Trends-Nutrients

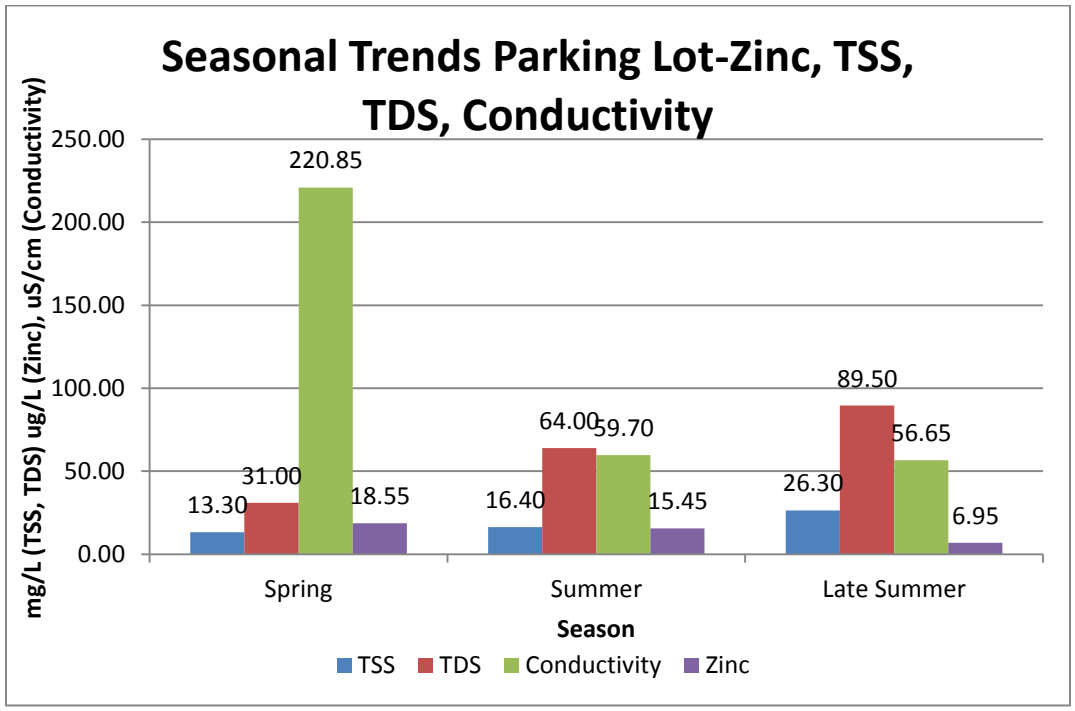

Figure 87 Parking Lot Seasonal Trends-Zinc, TSS, TDS and Conductivity

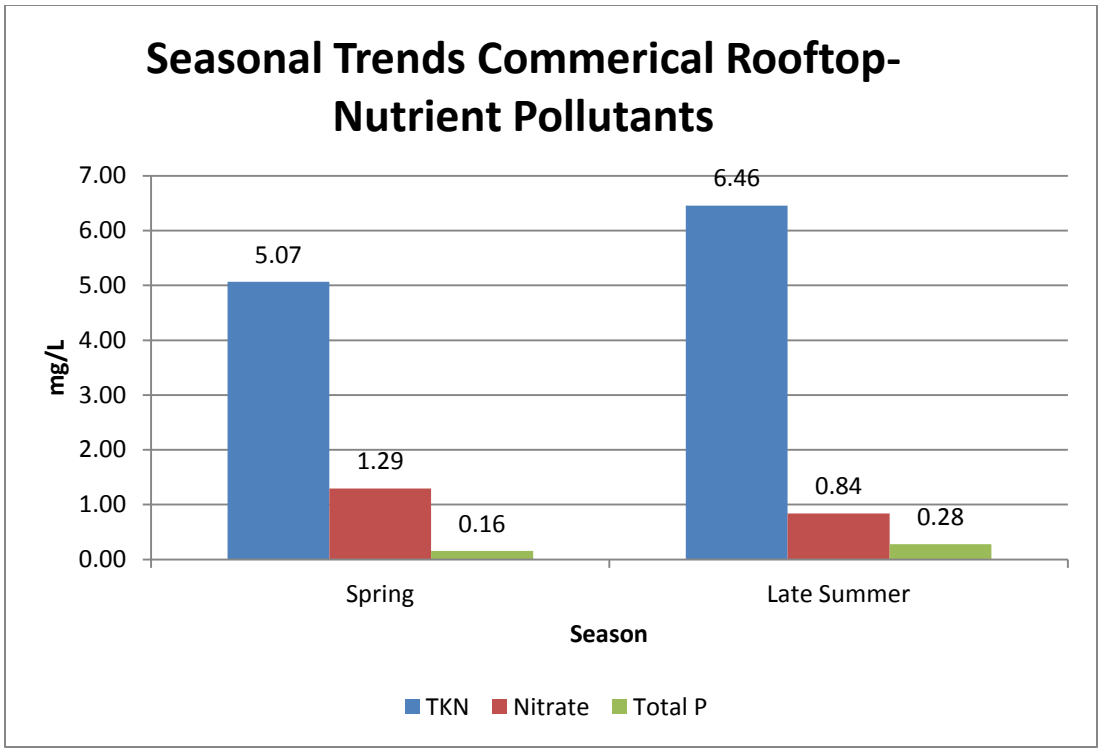

Figure 88 Commercial Rooftop Seasonal Trends-Nutrients

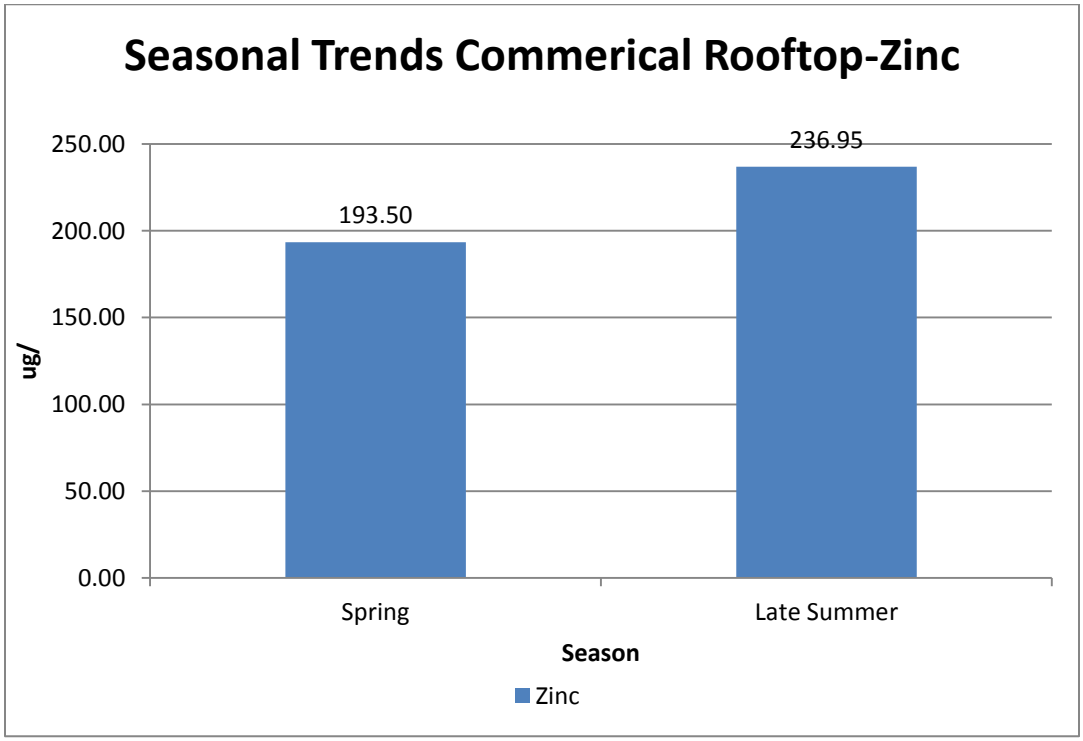

Figure 89 Commercial Rooftop Seasonal Trends-Zinc

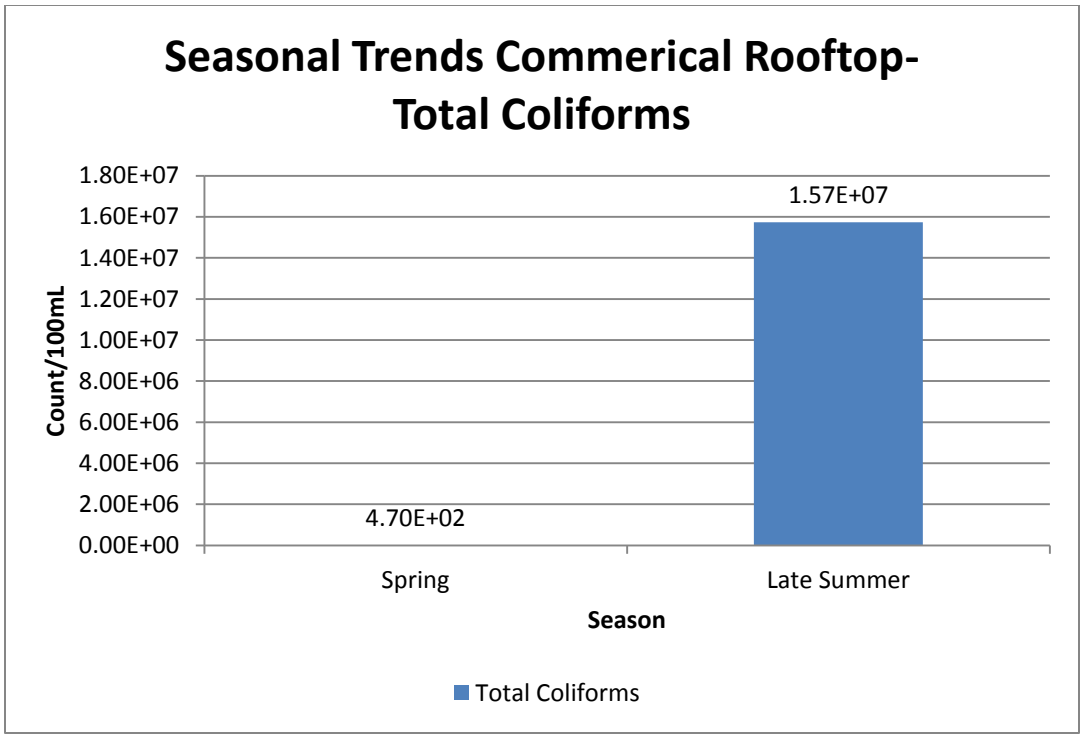

Figure 90 Commercial Rooftop Seasonal Trends Total Coliforms

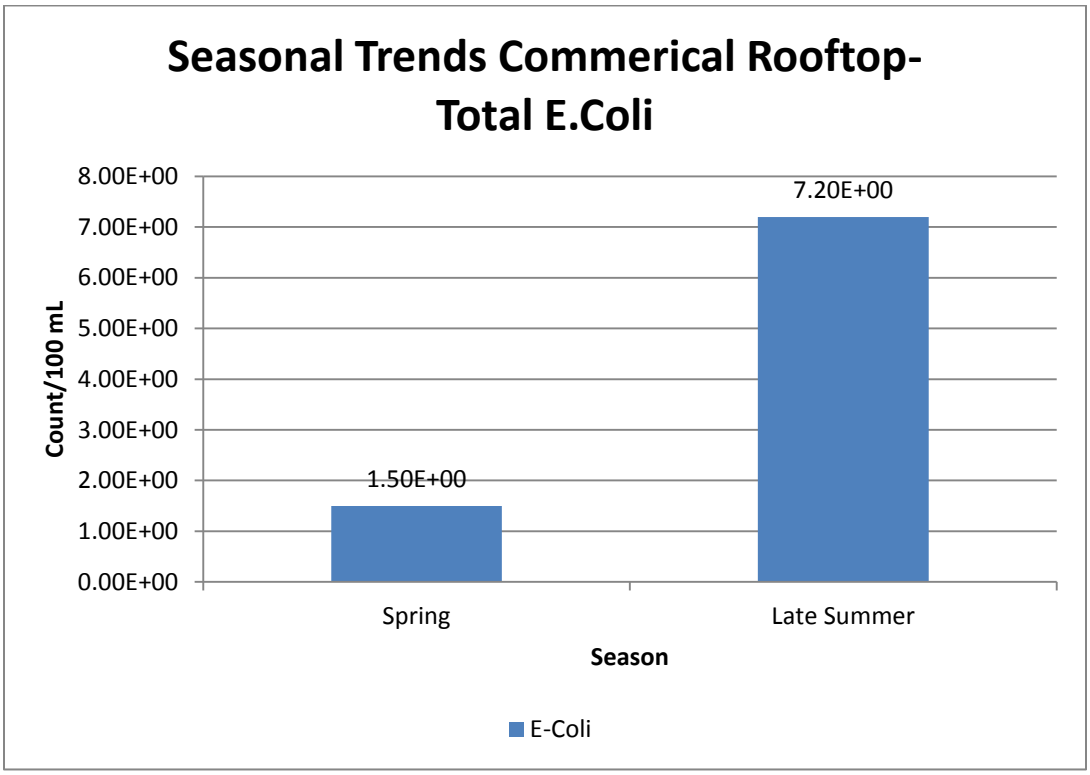

Figure 91 Commercial Rooftop Seasonal Trends Total E.coli

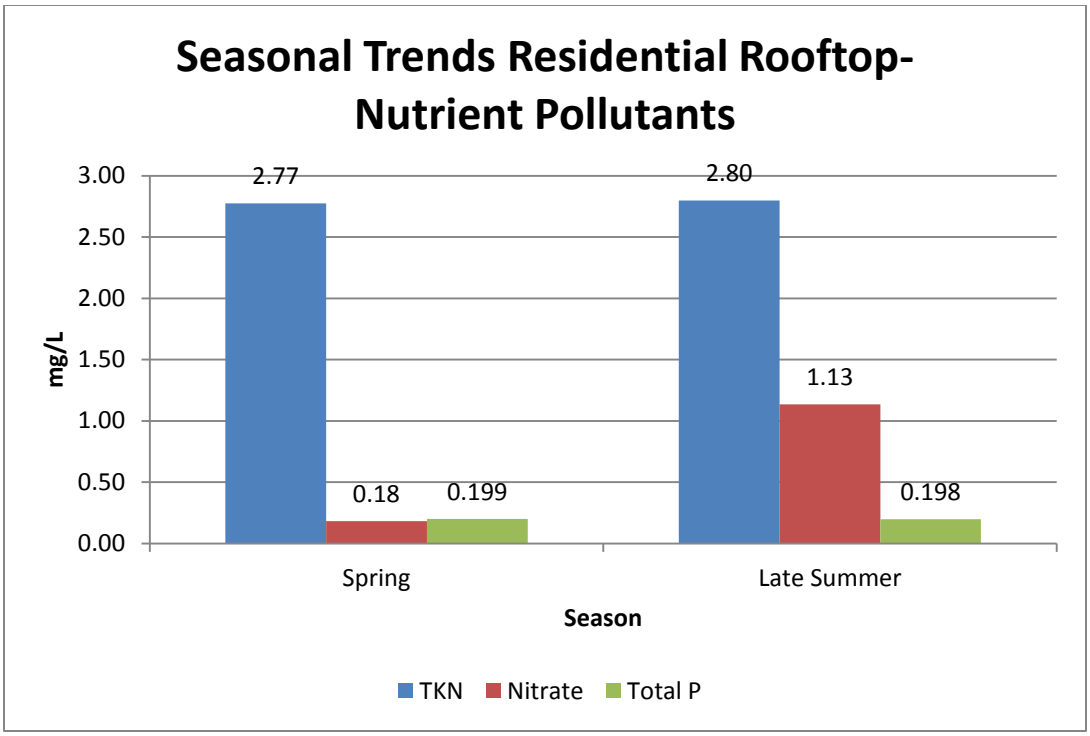

Figure 92 Residential Rooftop Seasonal Trends-Nutrients

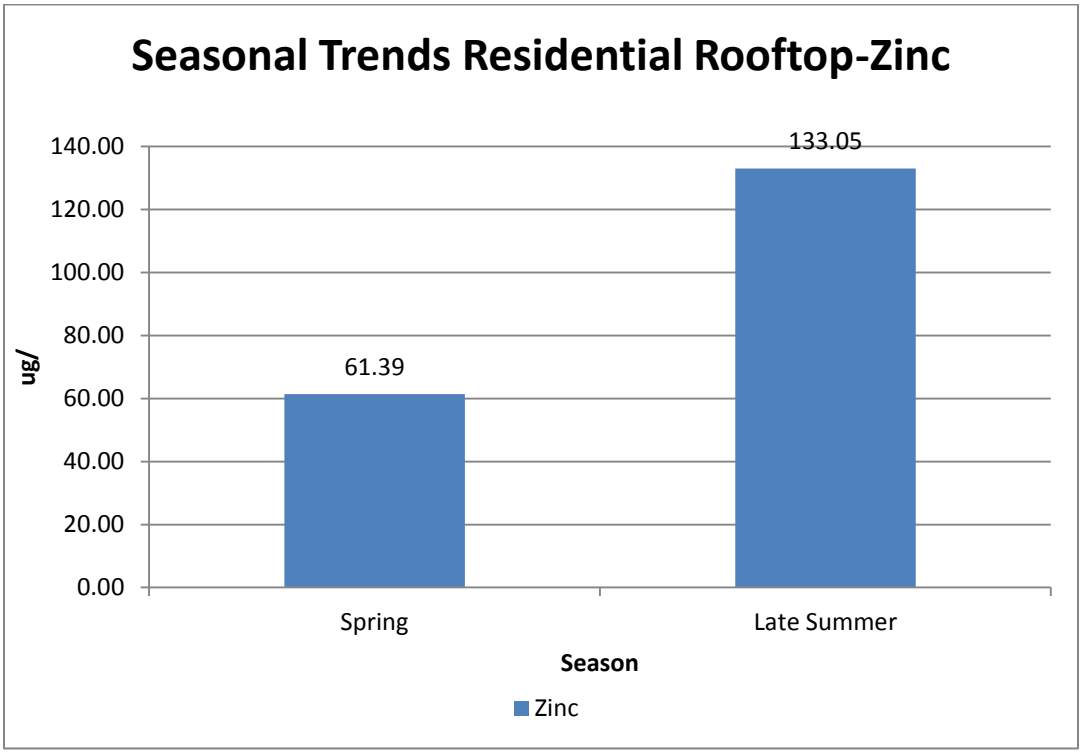

Figure 93 Residential Rooftop Seasonal Trends-Zinc

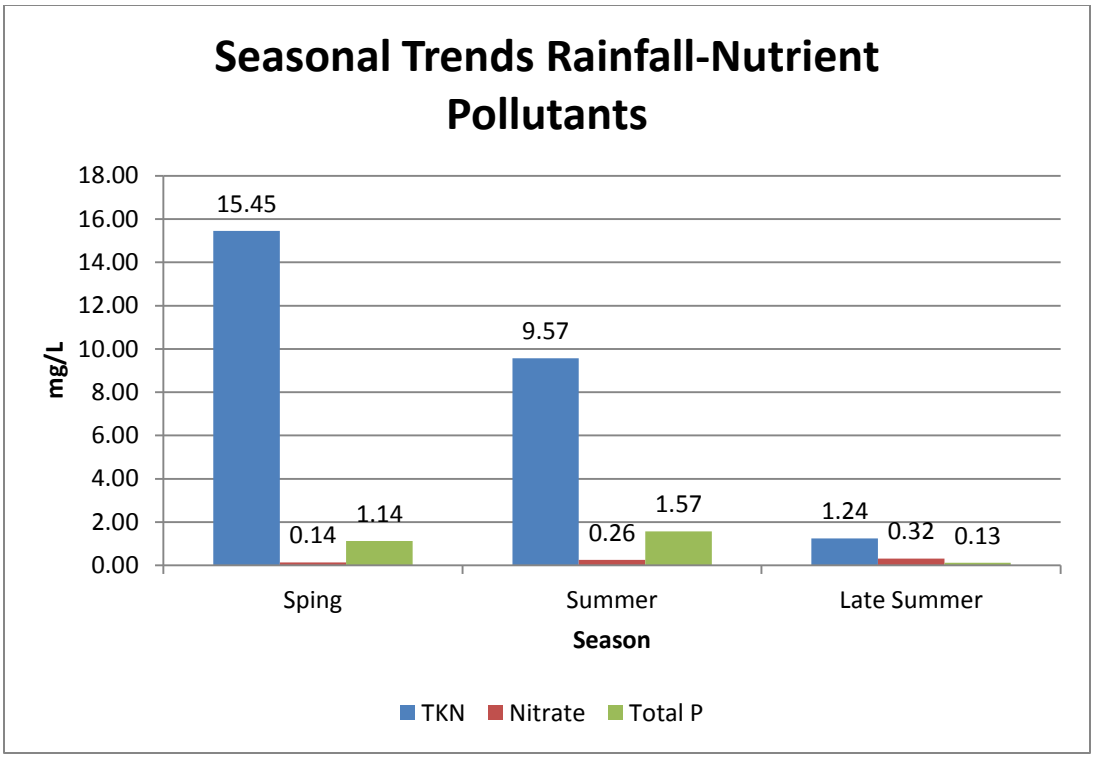

Figure 94 Rainfall Seasonal Trends-Nutrients

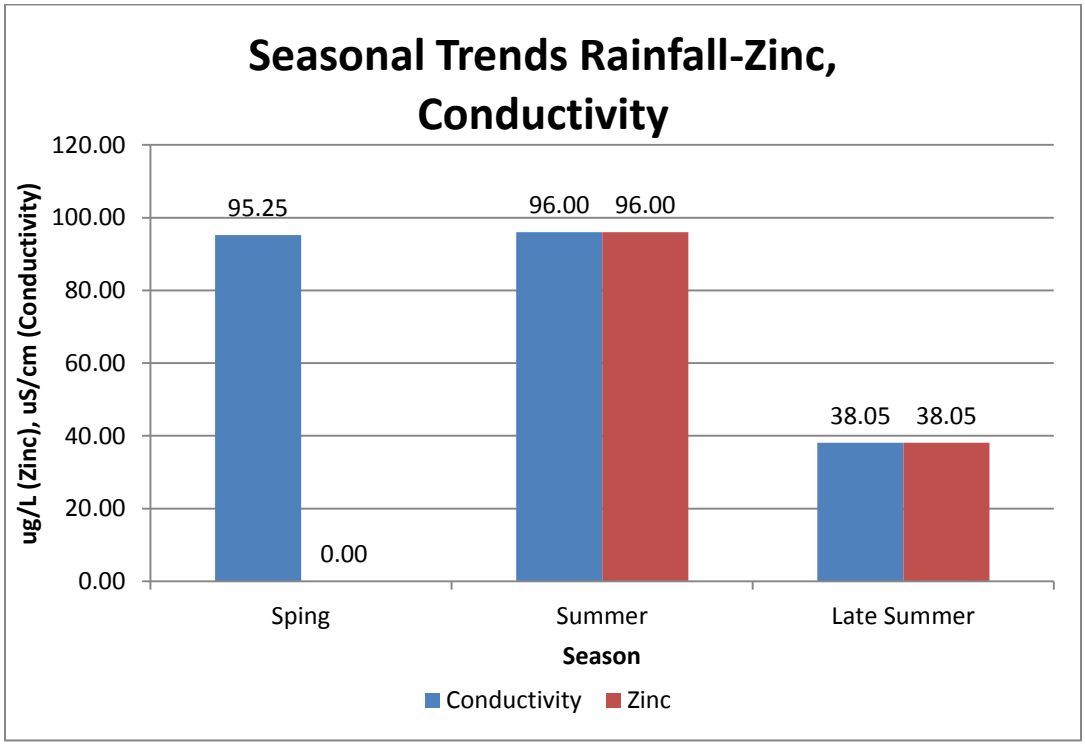

Figure 95 Rainfall Seasonal Trends-Conductivity

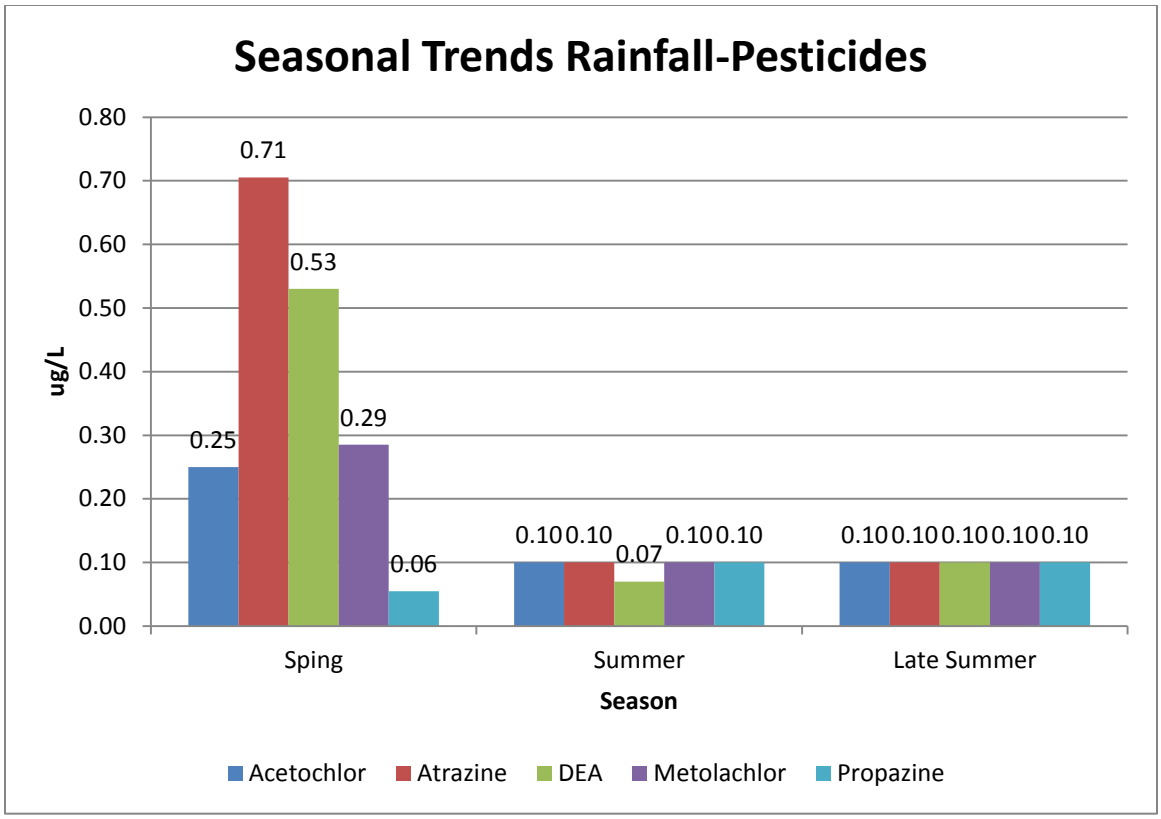

Figure 96 Rainfall Seasonal Trends-Pesticides

Appendix G SAS Programming p value Tables

Table 65 Bioretention Cell Influent and Effluent Statistical Analysis

Pollutant	Large Bioretention Cell Influent Vs Effluent Comparison P-value	Small Bioretention Cell Influent VS Effluent Comparison P-Value	Statistically Different (95% Confidence Level) p<0.05	
			Large Cell	Small Cell
TKN	0.0903	0.6048	No	No
Nitrate	0.0006	0.0562	Yes	No
Total P	0.0001	0.8194	Yes	No
Zinc	0.0032	0.0229	Yes	Yes
Total Coliforms	0.0923	-	No	No
E.coli	0.0431	0.2027	Yes	No
TSS	0.0016	0.0591	Yes	No
TDS	0.0586	0.8211	No	No
Conductivity	0.2043	0.2636	No	No
Oil/Grease	0.3803	0.5337	No	No
Acetochlor	0.0003	0.7113	Yes	No
Atrazine	0.0071	0.6222	Yes	No
DEA	0.1367	0.7178	No	No
Metolachlor	0.0016	0.334	Yes	No
Propazine	0.2458	0.213	No	No

Table 66: Large Bioretention Cell First Flush Statistical Analysis

Large Bioretention Cell First Flush Effects (Non Pesticide)											
Comparison Test		**P Values For Each Pollutant**									
Sample #1	*Sample #2*	**TKN**	**Nitrate**	**Total P**	**Zinc***	**Total Coliforms**	**E.coli**	**TSS**	**TDS**	**Conductivity**	**Oil/Grease**
LG1	LG2	0.0253	0.3248	0.7781	0.5595	N.A.	0.752	0.3009	0.6739	0.2388	0.6094
LG2	LG3	0.0022	0.2029	0.9873	0.0769	N.A.	0.329	0.0237	0.117	0.1777	0.6121
LG2	LG3	0.3178	0.9179	0.9633	0.2731	N.A.	0.441	0.1297	0.5627	0.91	0.9987
All Sites Compared		0.0024	0.2106	0.7931	0.0441	N.A.	0.195	0.0092	0.1174	0.2019	0.6366
Statistically Significant? (95% or 0.05 Confidence Level)											
LG1	LG2	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
LG2	LG3	YES	NO	NO	NO	NO	NO	YES	NO	NO	NO
LG2	LG3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		YES	NO	NO	YES	NO	NO	YES	NO	NO	NO

Table 67 Small Bioretention Cell First Flush Statistical Analysis

Small Bioretention Cell First Flush Effects (Non-Pesticide)											
Comparison Test		**P Values For Each Pollutant**									
Sample #1	*Sample #2*	**TKN**	**Nitrate**	**Total P**	**Zinc**	**Total Coliforms**	**E.coli**	**TSS**	**TDS**	**Conductivity**	**Oil/Grease**
SM1	SM2	0.9981	0.9199	0.925	0.8927	N.A.	0.847	0.602	0.4886	0.3225	0.9785
SM2	SM3	0.7847	0.705	0.7609	0.8093	N.A.	0.863	0.6362	0.2918	0.999	0.9175
SM2	SM3	0.8621	0.3599	0.8204	0.7843	N.A.	1	0.9918	0.825	0.5644	0.8666
All Sites Compared		0.7687	0.3868	0.6761	0.7068	N.A.	0.856	0.626	0.3137	0.2534	0.8434
Statistically Significant? (95% or 0.05 Confidence Level)											
SM1	SM2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SM2	SM3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
SM2	SM3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

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Table 68 Rainfall Vs Bioretention Cells

Pollutant	Bioretention Cells VS Baldwin P-value	Bioretention Cells VS Fire Station 12 P-Value	Statistically Different (95% Confidence Level) p<0.05	
			Bioretention Cells VS Baldwin	Bioretention Cells VS Fire Station 12
TKN	0.3085	0.3006	No	No
Nitrate	0.0001	0.0007	Yes	Yes
Total P	0.3853	0.3496	No	No
Zinc	0.3908	0.9462	No	No
Conductivity	0.2304	0.1295	No	No
Acetochlor	0.0197	0.0006	Yes	Yes
Atrazine	0.1574	0.1296	No	No
DEA	0.1208	0.131	No	No
Metolachlor	0.0006	0.0004	Yes	Yes
Propazine	0.8824	0.0096	No	Yes

Table 69 Seasonal Pesticide Pollutant Analysis Large Bioretention Cell

Seasonal Large Bioretention Pollutant (Pesticide)										
Comparison Test		P Values For Each Pollutant								
Season #1	*Season #2*	*Acetochlor*	*Alachlor*	*Atrazine*	*DEA*	*DIA*	*EPTC*	*Metolachlor*	*Propazine*	*Simazine*
LATESUM	SPRING	0.0001	1	0.0003	0.011	0.2419	0.5908	0.0004	0.0002	0.0002
LATESUM	SUMMER	0.0001	0.5907	0.0794	0.8286	1	1	0.2663	0.5908	0.5908
SPRING	SUMMER	0.041	0.5907	0.0012	0.0206	0.2419	0.5908	0.1977	0.5521	0.5521
All Sites Compared		0.0001	0.6186	0.0002	0.0135	0.2707	0.6186	0.0004	0.0003	0.0003
Statistically Significant? (95% or 0.05 Confidence Level)										
LATESUM	SPRING	YES	NO	YES	YES	NO	NO	YES	YES	YES
LATESUM	SUMMER	YES	NO	NO	NO	NO	NO	NO	NO	NO
SPRING	SUMMER	YES	NO	YES	YES	NO	NO	NO	NO	NO
All Sites Compared		YES	NO	YES	YES	NO	NO	YES	YES	YES

Table 70 Seasonal Non-Pesticide Pollutant Analysis Large Bioretention Cell

Seasonal Large Bioretention Pollutant (Non-Pesticide)											
Comparison Test		**P Values For Each Pollutant**									
Season #1	*Season #2*	**TKN**	**Nitrate***	**Total P**	**Zinc**	**Total Coliforms**	**E.coli**	**TSS**	**TDS**	**Conductivity**	**Oil/Grease**
LATESUM	SPRING	0.9978	0.9804	0.0014	0.3319	N.A.	0.1051	0.5035	0.4537	0.4043	N.A.
LATESUM	SUMMER	0.8623	0.0891	N.A.	0.742	N.A.	0.8745	0.8484	0.021	0.3207	N.A.
SPRING	SUMMER	0.807	0.1878	N.A.	0.3091	N.A.	0.2614	0.6246	0.1629	0.1054	N.A.
All Sites Compared		0.8059	0.068	0.0014	0.1463	N.A.	0.0505	0.3962	0.0106	0.0636	N.A.
Statistically Significant? (95% or 0.05 Confidence Level)											
LATESUM	SPRING	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO
LATESUM	SUMMER	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
SPRING	SUMMER	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	YES	NO	NO	NO	NO	YES	NO	NO

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Table 71 Seasonal Pesticide Pollutant Analysis Small Bioretention Cell

Seasonal Small Bioretention Pollutant (Pesticide)										
Comparison Test		**P Values For Each Pollutant**								
Season #1	*Season #2*	*Acetochlor*	*Alachlor*	*Atrazine*	*DEA*	*DIA*	*EPTC*	*Metolachlor*	*Propazine*	*Simazine*
LATESUM	SPRING	0.0014	1	0.0008	0.0622	0.1844	N.A.	0.0001	<.0001	0.3201
LATESUM	SUMMER	0.0347	0.3495	0.0006	1	1	N.A.	0.0023	0.5908	1
SPRING	SUMMER	0.4396	0.3495	0.0141	0.0622	0.1844	N.A.	0.1806	0.0033	0.3201
All Sites Compared		0.0005	0.3812	0.0001	0.0753	0.2101	N.A.	0.0001	0.0001	0.3513
Statistically Significant? (95% or 0.05 Confidence Level)										
LATESUM	SPRING	YES	NO	YES	NO	NO	NO	YES	NO	NO
LATESUM	SUMMER	YES	NO	YES	NO	NO	NO	YES	NO	NO
SPRING	SUMMER	NO	NO	YES	NO	NO	NO	NO	YES	NO
All Sites Compared		YES	NO	YES	NO	NO	NO	YES	YES	NO

Table 72 Seasonal Non-Pesticide Pollutant Analysis Small Bioretention Cell

Seasonal Small Bioretention Pollutant (Non-Pesticide)											
Comparison Test		**P Values For Each Pollutant**									
Season #1	*Season #2*	**TKN**	**Nitrate***	**Total P**	**Zinc**	**Total Coliforms**	**E.coli****	**TSS**	**TDS**	**Conductivity*****	**Oil/Grease**
LATESUM	SPRING	0.9108	0.9364	0.2244	0.9327	N.A.	0.5504	0.3666	0.7289	0.5426	N.A.
LATESUM	SUMMER	0.6113	0.7637	0.1181	0.2676	N.A.	0.4194	0.0057	0.5307	0.7537	N.A.
SPRING	SUMMER	0.3386	0.0241	0.0118	0.6339	N.A.	0.5375	0.4747	0.9267	0.893	N.A.
All Sites Compared		0.3405	0.0271	0.0053	0.2413	N.A.	0.274	0.0058	0.5449	0.4955	N.A.
Statistically Significant? (95% or 0.05 Confidence Level)											
LATESUM	SPRING	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
LATESUM	SUMMER	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO
SPRING	SUMMER	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	YES	YES	NO	NO	NO	YES	NO	NO	NO

Table 73 Seasonal Parking Lot Pollutant Analysis

Seasonal Parking Lot									
Comparison Test		P Values For Each Pollutant							
Season #1	*Season #2*	**TKN**	**Nitrate**	**Total P**	**Zinc**	**TSS**	**TDS**	**Conductivity**	**Oil**
LATESUM	SPRING	0.4667	0.7503	0.6938	0.1851	0.7315	0.2922	N.A.	N.A.
LATESUM	SUMMER	0.9996	0.9978	0.9986	0.3551	0.8231	0.8648	N.A.	N.A.
SPRING	SUMMER	0.4352	0.3538	0.6763	0.3278	0.9605	0.5041	N.A.	N.A.
All Sites Compared		0.4535	0.3281	0.6867	0.1316	0.7497	0.2439	N.A.	N.A.
Statistically Significant? (95% or 0.05 Confidence Level)									
LATESUM	SPRING	NO	NO	NO	NO	NO	NO	NO	NO
LATESUM	SUMMER	NO	NO	NO	NO	NO	NO	NO	NO
SPRING	SUMMER	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	NO	NO	NO	NO	NO	NO

Table 74 Seasonal Commercial Roof Pollutant Analysis

Seasonal Commercial Roof							
Comparison Test		P Values For Each Pollutant					
Season #1	*Season #2*	**TKN**	**Nitrate**	**Total P**	**Zinc**	**Total Coliforms**	**E.coli**
LATESUM	SPRING	0.308	0.6849	0.5139	0.823	0.4205	0.4562
All Sites Compared		0.308	0.6849	0.5139	0.823	0.4205	0.4562
Statistically Significant? (95% or 0.05 Confidence Level)							
LATESUM	SPRING	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	NO	NO	NO	NO

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Table 75 Seasonal Residential Roof Pollutant Analysis

Seasonal Residential Roof (Non-Pesticide)							
Comparison Test		**P Values For Each Pollutant**					
Sample #1	*Sample #2*	**TKN**	**Nitrate**	**Total P**	**Zinc**	**Total Coliforms**	**E.coli**
LATESUM	SPRING	0.9831	0.0036	0.977	0.1498	N.A.	N.A.
LATESUM	SUMMER	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
SPRING	SUMMER	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
All Sites Compared		0.9831	0.0036	0.977	0.1498	N.A.	N.A.
Statistically Significant? (95% or 0.05 Confidence Level)							
LG1	RES ROOF	NO	YES	NO	NO	NO	NO
LG1	SM1	NO	NO	NO	NO	NO	NO
RES ROOF	SM1	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	YES	NO	NO	NO	NO

Table 76 Seasonal Rainfall Pollutant (Pesticide) Analysis

Seasonal Rainfall Pollutant (Pesticide)										
Comparison Test		**P Values For Each Pollutant**								
Season #1	*Season #2*	*Acetochlor*	*Alachlor*	*Atrazine*	*DEA*	*DIA*	*EPTC*	*Metolachlor*	*Propazine*	*Simazine*
LATESUM	SPRING	0.0659	N.A.	0.0054	0.0068	N.A.	N.A.	<.0001	0.3096	0.3096
LATESUM	SUMMER	1	N.A.	1	0.1127	N.A.	N.A.	1	1	1
SPRING	SUMMER	0.0659	N.A.	0.0054	0.0059	N.A.	N.A.	<.0001	0.3096	0.3096
All Sites Compared		0.0737	N.A.	0.0061	0.0065	N.A.	N.A.	0.0001	0.3334	0.3334
Statistically Significant? (95% or 0.05 Confidence Level)										
LATESUM	SPRING	NO	NO	YES	YES	NO	NO	NO	NO	NO
LATESUM	SUMMER	NO	NO	NO	NO	NO	NO	NO	NO	NO
SPRING	SUMMER	NO	NO	YES	YES	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	YES	YES	NO	NO	YES	NO	NO

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Table 77 Seasonal Rainfall Pollutant (Non-Pesticide) Analysis

Seasonal Rainfall (Non-Pesticide)						
Comparison Test		**P Values For Each Contaminant**				
Season #1	*Season #2*	**TKN**	**Nitrate**	**Total P**	**Zinc**	**Conductivity**
LATESUM	SPRING	0.0019	0.0007	0.003	N.A.	0.1847
LATESUM	SUMMER	0.0022	0.885	0.1983	0.2204	0.3209
SPRING	SUMMER	0.0348	0.6229	0.7862	N.A.	0.9998
All Sites Compared		0.0009	0.0008	0.0033	0.2204	0.1586
Statistically Significant? (95% or 0.05 Confidence Level)						
LATESUM	SPRING	YES	YES	YES	NO	NO
LATESUM	SUMMER	YES	NO	NO	NO	NO
SPRING	SUMMER	YES	NO	NO	NO	NO
All Sites Compared		YES	YES	YES	NO	NO

Table 78 Large Bioretention Cell First Flush Analysis, Pesticides

Large Bioretention Pollutant First Flush (Pesticide)										
Comparison Test		**P Values For Each Pollutant**								
Sample #1	*Sample #2*	*Acetochlor*	*Alachlor*	*Atrazine*	*DEA*	*DIA*	*EPTC*	*Metolachlor*	*Propazine*	*Simazine*
LG1	LG2	0.7609	0.5903	0.8558	0.8977	0.7757	0.5908	1	0.9914	0.7485
LG1	LG3	0.4597	0.5903	0.6933	0.6222	0.4105	0.5908	0.9065	0.2766	0.8054
LG2	LG3	0.85	1	0.9432	0.8411	0.5908	1	0.8952	0.4237	0.9962
All Sites Compared		0.4896	0.6182	0.7135	0.6025	0.2903	0.6186	0.8804	0.2326	0.7505
Statistically Significant? (95% or 0.05 Confidence Level)										
LG1	LG2	NO	NO	NO	NO	NO	NO	NO	NO	NO
LG2	LG3	NO	NO	NO	NO	NO	NO	NO	NO	NO
LG2	LG3	NO	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	NO	NO	NO	NO	NO	NO	NO

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Table 79 Small Bioretention Cell First Flush Analysis Pesticides

Small Bioretention Pollutant First Flush (Pesticide)										
Comparison Test		**P Values For Each Pollutant**								
Sample #1	*Sample #2*	*Acetochlor*	*Alachlor*	*Atrazine*	*DEA*	*DIA*	*EPTC*	*Metolachlor*	*Propazine*	*Simazine*
LG1	LG2	0.8615	0.6396	0.8815	0.8899	0.9501	0.909	0.9835	0.9835	0.5907
LG1	LG3	0.5216	0.7087	0.6909	0.8264	0.9044	0.5042	0.9961	0.9961	1
LG2	LG3	0.846	0.8606	0.9332	0.9838	0.9882	0.6508	0.9969	0.9969	0.5907
All Sites Compared		0.5457	0.5935	0.7117	0.8404	0.9125	0.4541	0.9848	0.9848	0.3965
Statistically Significant? (95% or 0.05 Confidence Level)										
LG1	LG2	NO	NO	NO	NO	NO	NO	NO	NO	NO
LG2	LG3	NO	NO	NO	NO	NO	NO	NO	NO	NO
LG2	LG3	NO	NO	NO	NO	NO	NO	NO	NO	NO
All Sites Compared		NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 80 All Sites Seasonal Analysis Comparison

Pollutant	Comparison Test P Values			Statistically Different (95% Confidence Level) p<0.05		
	Spring Vs Late Summer	Summer Vs Late Summer	Spring Vs Summer	Spring Vs Late Summer	Summer Vs Late Summer	Spring Vs Summer
TKN	0.6056	0.9568	0.9508	No	No	No
Nitrate	0.3183	0.1057	0.7936	No	No	No
Total P	0.4908	0.9114	0.6673	No	No	No
Zinc	0.2579	0.1247	0.6679	No	No	No
Total Coliforms				-	-	-
E.coli	0.382	0.3103	0.9736	No	No	No
TSS	0.1714	0.2268	0.9986	No	No	No
TDS	0.2844	0.0469	0.5182	No	Yes	No
Conductivity	0.0517	0.7661	0.7751	No	No	No
Oil/Grease					-	-
Acetochlor	0.0001	0.0473	0.0062	Yes	Yes	Yes
Atrazine	0.0001	0.0042	0.0001	Yes	Yes	Yes
DEA	0.0002	0.9564	0.0003	Yes	No	Yes
Metolachlor	0.0001	0.0364	0.9945	Yes	Yes	No
Propazine						

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