EFFECT OF COMPACTION ON REMOVAL EFFICIENCY OF LEAD, COPPER, ZINC, NITRATE, AND PHOSPHATE IN A BIORETENTION SYSTEM: A COLUMN STUDY

By

JAMES R. MOORE

A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

graduate program in

Environmental Science

written under the direction of

Christopher Obropta Ph.D., P.E.

and approved by

New Brunswick, New Jersey

May 2008

ABSTRACT OF THE THESIS

Effect of Compaction on Removal Efficiency of Lead, Copper, Zinc, Nitrate, and Phosphate in a Bioretention System: A Column Study

by JAMES R. MOORE

Thesis Director: Christopher C. Obropta Ph.D., P.E.

Stormwater management has become an important part of the field of water resources management. The traditional method of disposing of urban stormwater was to drain it away as quickly as possible. However, in recent years, questions concerning the impacts on the receiving waters began to arise, and in response to these concerns, some communities have elected to encourage capturing and treating stormwater runoff. This is accomplished by having a portion of the stormwater infiltrate into the soil. A bioretention system is an innovative practice of pollutant control used for this purpose. These systems combine the concepts of detention ponds and biological treatment in an attempt to provide higher overall pollutant removal. However, little is known about the overall efficiency of bioretention. The purpose of this study was to see if compaction affects the pollutant removal efficiency (PRE) of a bioretention system. Fifteen columns were constructed of 8 inch diameter PVC piping. Series

ii

One through Five had bulk densities of 1.1, 1.2, 1.4, 1.5, and 1.7 g/cm³. The contaminants examined were lead, copper, zinc, nitrate, and phosphate. Soil compacted too much or too little was less efficient at removing metals from the runoff. Soil with a bulk density of 1.4 - 1.5 g/cm³ was more efficient at removing the metals than soil with bulk densities of 1.1, 1.2, and 1.7 g/cm³. However, compaction of the soil did not have a significant (p < 0.05) impact on the PREs of the metals. Also, there was no significant effect of compaction of the soil on the PREs of the nutrients. The PREs (which were usually negative) for both nitrate and phosphate improved as the compaction increased. The soil that had a bulk density of 1.7 g/cm³ had the highest PREs for both nutrients. This was an unexpected result, as most of the previous studies state that it is not a good tactic to compact the planting soil of a bioretention system as it tends to decrease the infiltration rate.

Acknowledgements

I most want to thank my wife, Patty, for her unconditional support throughout my college experience, without which, this endeavor would not have been possible. Thank you to my mother, Peggy; my brothers, John and Jerry; my sister, Janet; and my in-laws, Kathy, Kate, and Jim; for continually asking me how and what I was doing in college. I also want to thank my graduate advisor, Christopher C. Obropta, Ph.D., P.E., for his continued support through the years. Thank you to all the members of my committee, Christopher Obropta Ph.D., P.E., Doctor Peter Strom, and Doctor John Reinfelder for their important technical assistance on this project. A special thank you goes to Doctor John R. Reinfelder, my undergraduate advisor, for steering me in the right directions and also for letting me use his Perkin-Elmer atomic absorption spectrophotometer to analyze all of the samples for lead, copper, and zinc. Thank you to Dave Specca for his continued support and also for letting me set up a laboratory at the Rutgers Eco-Complex. I would like to thank Michael Mak for the construction of the columns, as well as the benches to hold the columns, and also for his help in the collection of the samples. I also want to thank Greg Rusciano for the design of the columns, since the columns I used were closely modeled after the columns in his experiment. Thank you to Derek Wright and Lora Smith for all of their advice and for serving as my sounding board. Thank you to Robert Miskewitz and Lisa Evrard for their guidance. I also appreciate the support and assistance

iv

of Lorraine Magee, Magda Comeau, Cheryl Burdick, Melissa Arnesen, Rita Lehman, Neermala Gezzi, Jeanie Nicewicz, Barbara Pasture, Dawn Skoube, Veronica Tompkins, and Priscilla Walsh. A special thank you goes to Martha Rajaei for her procedural guidance and support. Thank you to all of those undergraduates who helped with the cleaning of the sample collection vials.

Table of Contents

Titlei
Abstractii
Acknowledgementsiv
Table of Contentsvi
List of Tablesix
List of Figuresxv
Introduction1
The Laws
Clean Water Act 3
Coastal Zone Management Act5
The Watershed Approach6
Stormwater Management – Basic Concepts 10
The Problem 12
Literature Review
A Little about Soils
Best Management Practices
Detention/Retention Ponds 20
Wet Retention Ponds 21
Dry Detention Ponds 22
Disconting Systems 22

	The Basics	27
	Parameters	28
	Lead	28
	Copper	29
	Zinc	30
	Phosphate	31
	Nitrate	33
Metho	dology	38
	Columns	38
	Supporting Benches	39
	Design Storm	40
	Rational Method	40
	Synthetic Stormwater	41
	Sample Collection Technique	42
	Sample Preservation	43
	Running the Experiment	43
	Analyzing the Samples	44
Result	S	47
	The Eighth Sampling Event	48
	Statistics	48
Discus	ssion	51
Conclu	usions	54

References	55
Acronyms	66
Appendix	68

List of Tables

TABLE 1: Concentrations of lead, copper, and zinc found in California highway
runoff for the years 2000-2003. Adapted from Kayhanian et al. 2003
and 200771
TABLE 2: Metals found in building sidings. Adapted from Davis <i>et al.</i> 200172
TABLE 3: The varying amounts of soil contained in each column in each series
and the bulk density of each series
TABLE 4: General runoff coefficients for the rational method. Adapted from
Thompson 200673
TABLE 5: Synthetic stormwater recipe modeled after the recipe used by Davis <i>et</i>
al. 2001 which was based on data obtained by Prince George's
County
TABLE 6: Metals data for bioretention column 1. 74
TABLE 7: Metals data for bioretention column 2. 75
TABLE 8: Metals data for bioretention column 3. 76
TABLE 9: Metals data for bioretention column 4. 77
TABLE 10: Metals data for bioretention column 5
TABLE 11: Metals data for bioretention column 6
IABLE 12: Metals data for bioretention column /
TABLE 12: Metals data for bioretention column /

TABLE 15:	Metals data for bioretention column 10 83
TABLE 16:	Metals data for bioretention column 11 84
TABLE 17:	Metals data for bioretention column 12 85
TABLE 18:	Metals data for bioretention column 13 86
TABLE 19:	Metals data for bioretention column 14
TABLE 20:	Metals data for bioretention column 15 88
TABLE 21:	Nutrient data for bioretention column 1
TABLE 22:	Nutrient data for bioretention column 2
TABLE 23:	Nutrient data for bioretention column 3 91
TABLE 24:	Nutrient data for bioretention column 4 92
TABLE 25:	Nutrient data for bioretention column 5
TABLE 26:	Nutrient data for bioretention column 6 94
TABLE 27:	Nutrient data for bioretention column 795
TABLE 28:	Nutrient data for bioretention column 8
TABLE 29:	Nutrient data for bioretention column 9 97
TABLE 30:	Nutrient data for bioretention column 10
TABLE 31:	Nutrient data for bioretention column 11
TABLE 32:	Nutrient data for bioretention column 12
TABLE 33:	Nutrient data for bioretention column 13101
TABLE 34:	Nutrient data for bioretention column 14102
TABLE 35:	Nutrient data for bioretention column 15

TABLE 36: Table showing the averages for the three columns in each of the five series for lead......104 TABLE 37: Table showing the averages for the three columns in each of the five TABLE 38: Table showing the averages for the three columns in each of the five TABLE 39: Table showing the averages for the three columns in each of the five TABLE 40: Table showing the averages for the three columns in each of the five series for phosphate.....107 TABLE 41: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the five series for TABLE 42: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the five series for TABLE 43: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the five series for zinc......109 TABLE 44: Analysis of variance (ANOVA) test to see whether or not the three sample results from each column could be combined into one sample

result for lead,	for each	of the	fifteen	columns,	for each	of the eig	ht
sampling event	ts						110

- TABLE 49: Analysis of variance (ANOVA) test to see whether or not the sample

 results from the three columns could be combined into one result for

 zinc, for each of the five series, for each of the eight sampling

 events.
 112

- TABLE 53: Statistics summary table for lead......116
- TABLE 54:
 Statistics summary table for copper.
 116

 TABLE 55: Statistics summary table for zinc.
 116

- TABLE 56: Statistics summary table for nitrate.
 117

- TABLE 62: ANOVA table for all five series for phosphate.
 118

 TABLE 61: ANOVA table for all five series for nitrate.
 118

TABLE 63:	Pollutant removal efficiencies (PREs) for lead1	18
TABLE 64:	Pollutant removal efficiencies (PREs) for copper1	19
TABLE 65:	Pollutant removal efficiencies (PREs) for zinc1	19
TABLE 66:	Pollutant removal efficiencies (PREs) for nitrate1	19
TABLE 67:	Pollutant removal efficiencies (PREs) for phosphate1	20
TABLE 68:	Typical Levels of Metals Found in Stormwater Runoff (μ g/L)1	20

List of Figures

FIGURE 1: Map of New Jersey's WMAs and Water Regions121
FIGURE 2: A hydrograph showing the effects development has on both the
discharge and the timeframe of that discharge and also what a
detention basin does to both122
FIGURE 3: Schematic of bench containing six experimental bioretention
columns
FIGURE 4: Graph showing the average lead influent and the average lead
effluent, for each of the three samples, of the three columns making
up Series One, for each sample event123
FIGURE 5: Graph showing the average lead influent and the average lead
effluent, for each of the three samples, of the three columns making
up Series Two, for each sample event123
FIGURE 6: Graph showing the average lead influent and the average lead
effluent, for each of the three samples, of the three columns making
up Series Three, for each sample event
FIGURE 7: Graph showing the average lead influent and the average lead
effluent, for each of the three samples, of the three columns making
up Series Four, for each sample event

- FIGURE 37: Picture of an actual Bioretention system147

FIGURE 39:	Schematic of a cross-sectional view of a typical bioretention system
	(Source: NJDEP 2004)148
FIGURE 40:	Bioretention system that serves as a rain garden149
FIGURE 41:	Functioning Bioretention system149
FIGURE 42:	Bioretention system in ultra-urban setting. Note curb cut, gravel
	energy dissipater, and clean out/observation wells (Source:
	VDCR 1999)150
FIGURE 43:	Bioretention system located in required parking lot green space
	(Source: VDCR 1999)150
FIGURE 44:	Bioretention system in multi-family residential setting (Source:
	VDCR 1999)151
FIGURE 45:	Bioretention systems in office setting parking lot (Source: VDCR
	1999)151

Introduction

Water is of fundamental importance for life, since the mechanisms of metabolism and synthesis are in close relation with the specific characteristics of water. Transport of nutrients inside cells and interactions with the environment without water are impossible. Furthermore, water resources are limited, and only 2.66% of the total global water resources, comprising groundwater, lakes, rivers, polar ice, and glaciers, is fresh water. Additionally, only a small fraction of the fresh water, about 0.6%, is usable as drinking water. For this reason, water resources necessarily must be treated properly, and wastewater treatment must be done efficiently. The fast movement of humans towards urbanization, industrialization, and agricultural activities has introduced various contaminants into the environment (Ghafari *et al.* 2007).

Millions of miles of sewers and thousands of treatment plants were built throughout this country and the world, and in many places the receiving waters have improved. However, within the last several decades it has been realized that more than half of all pollution originates from sources that are diffuse and difficult to control. Stormwater is one such source of pollution (Novotny 1995).

Stormwater management has become an important part of the general field of water resources management and engineering. In the 1960s, serious interest in stormwater management began to take place due to the adverse consequences of the urbanization following World War II. The traditional method of disposing of urban stormwater was to drain it away as quickly as possible using a swale, a gutter, or a storm sewer to convey the runoff to the nearest stream, river, wetland, pond, or lake. However, in recent years, questions concerning the impacts on the receiving waters have begun to arise, and in response to these concerns, some communities have elected to encourage local disposal of stormwater. This is done by having a portion of the stormwater infiltrate or percolate into the soil (Stahre and Urbonas 1990).

Stormwater runoff is a major constituent of what has been termed nonpoint source pollution (NSP) (Hunt et al. 2006). Individuals have a more direct role in the generation of nonpoint source contaminants than industrial or municipal waste discharges. NSP closely links the activities of individual humans to such variables as soil types, climate, drainage basin topography, types and quantities of materials used in the basin, land use patterns, land management practices, and drainage basin demography. Individual actions may seem insignificant; however, cumulatively they can have substantial negative impacts on the quality of the environment. Thus, everyone has a potential role to play in addressing nonpoint source contamination problems; they are not problems just to be addressed by politicians, administrators, and managers (Thornton *et al.* 1999). Yet, the control of nonpoint sources is usually more complex and difficult than point sources, in that nonpoint sources often involve complex transport and transformation through several media. Furthermore, one cannot directly regulate nonpoint source emissions but only the activities that may cause such emissions (Novotny 1995).

The Laws

Most of the requirements for stormwater management have arisen from federal statutes. The two federal statutes that are most important with respect to stormwater management are the Clean Water Act (CWA) and the Coastal Zone Management Act (CZMA).

Clean Water Act

The Federal Water Pollution Control Act (FWPCA) is located in 33 United States Code (U.S.C.) Chapter 26 §§ 1251-1387. It is the federal statute regulating the discharge of pollutants into the nation's waterways. The FWPCA was enacted in 1948, and amended in 1965 with the Water Quality Act of 1965. This act provided for the adoption of water quality standards for interstate waters, and it was later amended in 1966, 1970, 1972, 1977, and 1987. The FWPCA Amendments passed in 1972 [Public Law (P.L.) 92-500] came about due to growing awareness of environmental degradation in general, but with water pollution in particular. The goals of these amendments were that "the discharge of pollution into navigable waters be eliminated by 1985," "the discharge of toxic pollutants in toxic amounts be prohibited," and an "interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and ... recreation in and on the water ... by July 1, 1983" [CWA § 101(a), 33] U.S.C. § 1251(a)]. Furthermore, in 1972, section 402 established the National Pollutant Discharge Elimination System (NPDES) to authorize issuance of

discharge permits (33 U.S.C. § 1342) by the United States Environmental Protection Agency (USEPA).

The Act became known as the Clean Water Act (CWA) with the amendments of 1977 (P.L. 95-217), which amended the FWPCA extensively. Among the components of particular significance were: the development of "Best Management Practices" (BMPs) as part of the state areawide planning program (33 U.S.C. § 1288); and the authority for the United States Army Corps of Engineers (USACE) to issue general permits on a state, regional, or national level for any category of activities that are similar in nature, will cause only minimal environmental effects when performed separately, and will have only minimal cumulative adverse impact on the environment [33 U.S.C. § 1344(e)].

The 1987 amendment to the CWA required implementation of a two phase comprehensive national program for addressing storm water discharges. The first phase of the CWA stormwater management program (Phase I) was set forth on November 16, 1990 [55 Federal Register (FR) 47990], and required NPDES permits for stormwater discharges from medium to large municipal separate storm sewer systems (MS4s) for populations of 100,000 or more, and several industrial activity categories, including construction activity that disturbs five acres or more of land. The second phase of the CWA stormwater management program (Phase II) required permits for stormwater discharges from certain small MS4s, construction activities disturbing one to five acres of land, and certain industrial activities.

4

Coastal Zone Management Act

The CZMA of 1972 (16 U.S.C. §§ 1451-1464, Chapter 33; P.L. 92-583) was passed to encourage coastal states to develop and implement coastal zone management plans (CZMPs). The Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 required development of Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (USEPA 1993). States with coastal zone management programs are required to develop coastal nonpoint pollution control programs consistent with the Management Measures. The Existing Development Management Measures of Chapter Four (Urban Areas) (USEPA 1993) require development and implementation of programs to reduce pollution from existing improvement activities. The management measures for urban areas address runoff from: roads, highways and bridges, developing areas, construction sites, existing development, on-site disposal systems, and general sources (households, commercial activities, and landscaping activities) (USEPA 1993 and USEPA 2005).

The 1972 Clean Water Act and the 1974 Safe Drinking Water Act were paramount in the progress toward attaining the USEPA's ultimate goal of, "protecting and restoring the physical, chemical, and biological integrity of our waters" (USEPA 1995b). Significant advances have been made in water pollution control with the management and monitoring of point sources of pollution required by the two acts. However, more than 30 years after the passage of these acts, over 40% of our nation's rivers and streams still remain too polluted for fishing, swimming, and other recreational uses (USEPA 1991b). The primary causative agents are nonpoint sources of pollution, such as: silts, fertilizers, and runoff events. There are other recognized sources of impairment including sewage from combined sewer overflow (CSOs), disease-causing bacteria, toxic metals, and oil and grease (USEPA 1995b). To address these pollutants, the USEPA has promoted a new integrated program called the watershed protection approach.

The Watershed Approach

The watershed protection approach is a comprehensive methodology of water resource management strategies that address multiple water quality problems, such as nonpoint source pollution, point source pollution, and habitat degradation. The USEPA suggests that integrating point and nonpoint source pollution control and management on a watershed scale can best protect water quality resources. Watershed approaches are likely to result in significant restoration and maintenance of water quality because of their broad range and focus. Many states, including Washington, South Carolina, North Carolina, and Oklahoma, are already managing environmental problems on a watershed scale. The watershed protection approach and water resource management can be integrated into a comprehensive environmental program (USEPA 1995a).

The New Jersey Department of Environmental Protection (NJDEP) adopted a watershed-based approach to water resources protection in 1997 when it published the Draft Statewide Watershed Management Framework Document for the State of New Jersey in January of that year. However, the term "watershed approach" is mentioned in the NJDEP's 1994 Best Management Practices Manual. The statewide framework was based in part on the lessons learned from New Jersey's watershed pilot project, the Whippany River Watershed Management Project, which was initiated in October 1993, and incorporated many of the elements from USEPA's 1991 publication on the watershed-based approach (NJDEP 1994).

In November of 1998, the Division of Watershed Management was created within the NJDEP. The Statewide Watershed Management Program is administered by NJDEP's Division of Watershed Management as a coordinating framework for comprehensive watershed planning and management. The New Jersey Statewide Watershed Management Program emphasizes that the primary objective of water quality and watershed management planning is, wherever attainable, to restore, maintain, and enhance water quality, water quantity, and ecosystem health. It serves as a coordinating framework for integrating surface and groundwater quality standards and assessments, antidegradation, total maximum daily loads (TMDLs), and water quality maintenance in wastewater and watershed management planning (NJDEP 1994). The Statewide Watershed Management Program (SWMP) conducts regional water resource planning at the watershed management area scale and integrates water resource protection measures and land use development scenarios on a watershed basis in order to achieve water resource objectives. The Watershed Management Program promotes a collaborative planning process where the watershed community participates in the development of effective strategies to address water quality, water quantity, and ecosystem health issues to achieve the desired results for a specific watershed management area. Through the SWMP, watershed management area plans are being developed as dynamic and flexible planning tools, consisting of certain minimum elements and also incorporating watershedspecific components. Watershed management supports the integration and coordination of planning efforts across all planning levels (state, regional, county, and municipal) and across Departmental programs (wastewater, water supply, and land use) (NJDEP 1994).

The state's watershed boundaries are delineated into a nested layer of watersheds, watershed management areas (WMAs), and water regions (Figure 1). The State's efforts focus mainly on the 20 WMAs which are nested within 5 water regional offices or bureaus. The water regions correlate roughly with United States Geological Survey's (USGS) 8-digit hydrologic unit codes (HUCs). Each region consists of between three and five WMAs. Each WMA consists of between one and four HUC-11 watersheds. Population densities were also factored into the watershed delineations (NJDEP 1994).

The states initial plan was to complete a comprehensive characterization report, identify problem areas, and then begin to address the problem areas in each WMA. However, the approach was recently reoriented, and rather than

8

focusing on documents or penalties collected, instead it focuses on a resultsbased management concept that evaluates progress based on environmental measures and results.

Water quality, resource protection, and restoration efforts are implemented within each of the 20 WMAs according to a sequence of watershed management steps. These are: (1) initial planning and stakeholder involvement; (2) visioning and goal-setting; (3) identification and funding of projects to address known problems with known solutions; (4) targeted monitoring and data collection to fill in data gaps and identify root causes [as needed for TMDL development]; (5) strategy development, including: TMDLs, open space acquisition, zoning changes, land use ordinances, nonpoint source BMPs, and "track down and clean up"; (6) watershed management plan and proposal development; (7) watershed management plan adoption and implementation; and (8) evaluation [including monitoring] and refinement (NJDEP 1994).

The state is managing the development of WMA plans under contracts with lead entities in each of the WMAs. These lead entities serve as agents of the Department while the Division of Watershed Management oversees the planning process through the SWMP. Each lead entity has a team of contractors and staff that are responsible for the WMA. One person from the team is assigned as the education and outreach coordinator for the WMA. It is his or her responsibility, along with the contract entity, to encourage the formation of citizen committees so that work is coordinated with the public. In 2001, NJDEP executed grant agreements with 16 lead entities to administer the watershed planning process and develop watershed management area plans for all 20 of New Jersey's WMAs. The contract deadlines required WMA plans to be developed for all 20 WMAs by 2005 (NJDEP 1994). New Jersey is currently in what it is calling the "continuing planning process" (CPP).

<u>Stormwater Management – Basic Concepts</u>

In the last decade, one of the major changes to stormwater management principles was the emergence of the improvement of stormwater quality as a key function of stormwater management techniques. Traditionally, stormwater management structures were designed mainly as quantity-control or flow-control structures. Stormwater controls were designed to reduce the peak rate of runoff, as is illustrated in Figure 2.

Early water pollution control laws and regulations focused their efforts on removal of pollutants from point sources. As the nation's waterways became less polluted, it became clear that nonpoint sources of pollution were now the major threat to water quality. Therefore, attention was focused on the removal of pollutants from the main sources of nonpoint pollution, including stormwater runoff.

A large portion of contaminant load to surface and ground waters originates from the land around these waters rather than from specific point sources. This is due to the fact that NSP is intimately linked to the hydrologic cycle and particularly drainage from storm events. Indeed, aquatic ecosystems are the ultimate sinks for virtually all natural and anthropogenic materials from the land surfaces, as well as those transported in the atmosphere (Thornton *et al.* 1999).

For many years, there has been little disagreement that NSP is a major cause of water quality degradation on a global scale. For instance, the very first comprehensive study directed primarily at NSP, the International Joint Commission (1969), reported that the conditions of Lake Erie, Lake Ontario, and the International Section of the Saint Lawrence River could not be related entirely to pollutant loadings from readily-identifiable point sources. Furthermore, it was found that approximately 30-40% of the total phosphorus loads to Lake Erie and Lake Ontario were from nonpoint sources within the drainage basin. In addition, another study, the Commission's International Reference Group on Pollution of the Great Lakes (PLUARG 1978), reported the Great Lakes were being polluted from land drainage (nonpoint) sources by phosphorus, sediments, some industrial organic compounds, some previouslyused pesticides, and some metals (Thornton *et al.* 1999).

The Problem

Probably the greatest detrimental change to water guality is due to urbanization. Urbanization is the change of land use from natural or agricultural, and it occurs in several steps. Urbanization changes the atmospheric composition, hydrology of the watershed, receiving streams and other water bodies, and soil. Waste emissions increase dramatically (Novotny 1995). The impacts of urbanization on water quality have been well documented. Regional case studies demonstrate that urban streams exhibit increased levels of phosphorus (Novotny 1991, Soranno et al. 1996, and May et al. 1997), nitrogen (Novotny 1991, Lenat and Crawford 1994, McMahon and Harned 1998, and Basnyat et al. 2000), total suspended solids (Novotny 1991, May et al. 1997, and McMahon and Harned 1998), biochemical oxygen demand (BOD) (Fitzpatrick 1995), metals (Lenat and Crawford 1994, Mumley 1995, Fitzpatrick 1995, May et al. 1997, and Bhaduri et al. 2000), oil and grease (Fitzpatrick 1995), and fecal coliform bacteria (Schueler 1994 and Duda et al. 1998) relative to reference streams. The sources of these emissions include industries, transportation, household heating, sewage conveyance and disposal, garbage collection and disposal, litter deposition, fallen leaves on impervious surfaces, and street salting (Novotny 1995).

Soil loss from construction sites can reach magnitudes of over 100 tons per hectare per year. A few percent of the watershed under construction can contribute a major portion of the sediment being carried by the stream, thus affecting the streams themselves, sometimes irreversibly. Straightening and lining destroys the natural habitat, and the streams can no longer support fish and other biota. Increased imperviousness increases the volume of surface runoff, while at the same time diminishes groundwater recharge (USEPA 2005).

Furthermore, unsewered communities are typically served by on-site disposal systems such as septic tanks that discharge the wastewater into the soil. Septic tanks provide only minimal treatment by sedimentation and anaerobic decomposition. There are approximately fifty million households in the United States with septic systems, representing the highest total volume of wastewater discharged to the groundwater and the most recorded source of groundwater contamination. When the absorption capacity of the soil is exhausted, contamination of surface waters by organics and pathogenic microorganisms may occur and be severe (Novotny 1995).

The use of lawn care chemicals and fertilizers in the American suburbs is also a concern. The typical suburban dweller with a lawn uses more chemicals per area than a farmer. Therefore, losses of these chemicals into surface and groundwater can be considerable. A steady increase of nitrate contamination of groundwater as well as detection of the chemicals in suburban surface runoff is often exhibited (Novotny 1995).

Therefore, the USEPA has required the states to implement ways of improving, or decontaminating the runoff before entering the receiving waters. The implementation of Best Management Practices is one way that the states are

13

accomplishing this. The installation of bioretention systems has become a popular BMP, especially in the state of New Jersey. However, little research has been done on the effectiveness of these systems, particularly during the construction phase.

The purpose of this study is to investigate if compaction of the soil has any effect on the pollutant removal efficiency of metals (lead, copper, and zinc) and nutrients (nitrate and phosphate). Furthermore, since nothing was planted in the columns, this study just examines the effectiveness of the soil layer at removing pollutants.

Literature Review

According to the National Water Quality Inventory Report (2000), NPS pollution is responsible for the pollution of 51% of the estuaries, 45% of the lakes, and 39% of the rivers in assessed water bodies in the United States. Urban stormwater runoff is one of the main sources of NPS pollution, and it is the second largest pollution source for estuaries and the third largest for lakes (USEPA 2002).

Urbanization increases the area of impervious surfaces such as parking lots, rooftops, and road pavement. Rain falling on these impervious surfaces runs off, mobilizes deposited pollutants along the flow path, and transports a wide range of pollutants into receiving water bodies. The Nationwide Urban Runoff Program (NURP) study conducted by the USEPA revealed that metals such as lead, copper, and zinc are prevalent pollutants in runoff (USEPA 1983). A number of local studies have found a range of metals in runoff (Drapper *et al.* 2000, Sansalone and Buchberger 1997, Wu *et al.* 1998, Zhang *et al.* 2003, and Zobrist *et al.* 2000). Runoff from heavily traveled roads frequently has metal concentrations exceeding water quality standards. For example, in urban highway runoff in Cincinnati, Ohio, the event mean concentration of total zinc ranged from $459 - 15,244 \mu g/L$, total copper from $43 - 325 \mu g/L$, and total lead from $31 - 97 \mu g/L$ (Sansalone and Buchberger 1997).

Vehicular activity, roadway abrasion and degradation, building material weathering, and atmospheric deposition (Davis and Burns 1999, Davis *et al.*

2001, Mason *et al.* 1999, Turer *et al.* 2001, and Zobrist *et al.* 2000) are some of the major sources of metals in runoff. Painted structures contribute a significant load of lead to runoff (Davis and Burns 1999). Engine exhaust was a major lead source until leaded gasoline was banned in the United States, and is still the case where leaded gasoline is not prohibited (Turer *et al.* 2001). Building sidings are an important source for lead, copper, and zinc; vehicle brake emissions for copper; and tire abrasion and oil leakage for zinc (Davis *et al.* 2001).

Retention of metals in soils is often associated with the content of iron, aluminum, and manganese oxides and hydroxides, clay, organic matter, and pH (Barbosa and Hvitved-Jacobsen 1999, Davis 1984, Farrah and Pickering 1976, Gadde and Laitinen 1974, Gong and Donahoe 1997, McKenzie 1980, and Norrström and Jacks 1998). Research has been undertaken to find more effective filter media for metal removal (Liu *et al.* 2005). Also, a cost-effective filter medium is needed to reduce the expense of stormwater BMPs.

A Little about Soils

Soil is formed from the decomposition of rocks over time. Several physical, chemical, and biological processes combine to produce different soils, even from similar parent rocks. These processes include formation of secondary materials, such as clay, and the development of an organic matter fraction. Soil is constituted of mineral and organic matter, and pores that may be occupied either by water or air, in a dynamic exchange. The relative proportions of these
three phases depend on factors like weather, vegetation, and anthropogenic action. Several phenomena, such as: absorption of water and chemicals, ion exchange, adhesion, swelling and shrinking, dispersion and flocculation, and capillary action can take place in soil systems (Hillel 1998).

When using soil for very special purposes, such as metal retention, it is important to bear in mind that the soil is a very heterogeneous material, with variations in space and depth. Local differences may result from natural causes such as vegetation and from man's own activity.

The sorption of metal cations to soil is mainly due to three processes: cation exchange, specific absorption, and surface precipitation. The cation exchange process is an exchange between the counter-ions balancing the surface charge on the colloids, clay particles or organic matter, and the ions in the soil solution. Specific absorption is related to the metal ions ability to form hydroxy complexes and their ionic size. It involves covalent and ionic bonding permitting higher interaction strengths than cation exchange. Surface precipitation occurs when the solid surface is covered with inner-spherecomplexes and the metal cation forms a precipitate with an anion that may be derived from the mineral dissolution (co-precipitation). Another not so common sorption process is the diffusion of metals into the crystal layers. It is extremely slow and may be irreversible. Clay minerals that have a restricted and tortuous interlayer space allow this type of process to take place. Generally speaking, sorption reaction on soils can occur on time scales of microseconds to months (Alloway *et al.* 1988, Alloway 1990, and Sparks 1995).

Best Management Practices

Much of the literature suggests that significant portions of total stormwater pollution loads are produced during the first stages of a storm event. This is typically called the first flush phenomenon, which is usually considered to be the first half inch of runoff from a drainage area. Stormwater treatment facilities typically focus on treating the first flush of pollutants (Young *et al.* 1996).

Stormwater Best Management Practice (BMP) includes the concept of source control, i.e., a passive system that intercepts pollutants at the source and disposes of the stormwater close to the point of the rainfall (Ashley *et al.* 1997). Since BMPs dispose of stormwater as much as possible near the source, the cost of transporting it in sewer systems to wastewater treatment plants or to receiving waters is reduced.

Best Management Practices are measures used to control nonpoint sources of pollution. BMPs can be defined as any practice, structural or nonstructural, designed to act as a practical means of minimizing the impact of nonpoint source pollution on water quality (Bell and Nguyen 1994). Structural BMPs function by trapping runoff for an extended period of time while physical, chemical, or biological processes remove pollutants. Non-structural BMPs can be

18

defined as means or measures designed to reduce pollutant accumulation and initial pollutant concentrations in runoff (Dennison 1996).

The Federal Highway Administration (FHWA) has performed extensive research on highway stormwater quality and control (Young *et al.* 1996). In fact, the majority of stormwater and BMP research has been presented in government documents with little representation in technical journals (Loos 1996). The most comprehensive stormwater sources from the FHWA to date include: Constituents of Highway Runoff (Gupta *et al.* 1981), Effects of Highway Runoff Pollution on Receiving Water Bodies (Dupuis *et al.* 1985), Pollutant Loadings and Impacts from Highway Stormwater Runoff (Driscoll *et al.* 1990), and Evaluation and Management of Highway Runoff Water Quality (FHWA 1996). Considerable research on stormwater control structures and BMPs has also been conducted at the state and local level. Many state departments of transportation have guidelines and manuals for the construction, selection, and evaluation of structural BMP stormwater controls (Young *et al.* 1996).

Recently, a new trend in BMP development has occurred in the private sector with the development of new space-limited BMPs (FHWA 1998). Prominent companies in BMP and stormwater management include GKY and Associates, Stormceptor, Stormwater Management, Vortechnics, StormTreat Systems, and Fox Environmental Systems (Zhang 2003).

Metals are of particular interest in stormwater due to their toxicity, ubiquitousness, and the fact that they cannot be chemically destroyed. 19

Generally, the levels follow this order: zinc $(20 - 5000 \,\mu g/L) > copper (5 - 200 \,\mu g/L)$ $\mu q/L$) = lead (5 – 200 $\mu q/L$) > cadmium (12 $\mu q/L$) (Davis *et al.* 2001). Hvitved-Jacobsen *et al.* (1994) found that lead ranges anywhere from $50 - 150 \mu g/L$, that copper ranges from 5 – 40 μ g/L, and that zinc can range anywhere from 300 – 500 μ g/L in urban runoff. Kayhanian *et al.* 2003 and Kayhanian *et al.* 2007 found that lead ranges from 12.7 – 2300 mg/L, that copper ranges from 21.1 – 270 mg/L, and that zinc can range anywhere from 111.2 – 1680 mg/L in a study of California highway conducted during 2002 – 2003. Kayhanian *et al.* 2003 and Kayhanian *et al.* 2007 results are listed in Table 1. Davis *et al.* (2001) performed tests to examine the concentrations of release in runoff of various different materials. Their findings of the release in runoff of different building siding materials are in Table 2 (Davis *et al.* 2001). The sources of lead can be brakes, fuels and oils, and de-icing salts. The sources for copper can be tires and brakes, and the sources for zinc can be tires, brakes, and the frame and body (Hvitved-Jacobsen et al. 1994).

Detention/Retention Ponds

Wet retention ponds and dry detention ponds are perhaps some of the most widely used structural BMPs for hydrologic and water quality control of runoff (Loos 1996). The primary purpose of extended detention ponds and wet retention ponds is to remove particulates and reduce runoff peak flow and volume levels. Wet retention ponds, are designed to retain a permanent pool of water in addition to detaining runoff temporarily (Osmond *et al.* 1995). Ponds are typically used on sites with large drainage areas, and a well designed wet retention pond or a dry detention pond can function for approximately 20 years (Yousef *et al.* 1991). It is generally recognized that preliminary planning and design of ponds should be based on long-term assessment of pond performance (Yu and Field 1992).

Wet Retention Ponds

When properly sized and maintained, wet retention ponds can achieve a high removal efficiency for total suspended solids (TSS), biological oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), and metals, such as lead (Pb), zinc (Zn), copper (Cu), iron (Fe), nickel (Ni), chromium (Cr), and cadmium (Cd) (Yousef *et al.* 1991). Wet retention ponds, when well designed, have a greater potential for pollutant removal than extended dry detention ponds (NVPDC 1987). A large pond size and low soil infiltration rates are required. Maintenance requirements include inspection of the integrity of embankments, erosion control, periodic sediment removal, and algae control. Pond pollutant removal efficiencies can be enhanced by maximizing the distance between pond inlets and outlets.

Average pollutant removal efficiencies (PREs) for wet detention ponds vary greatly depending upon maintenance and design. Average PREs for welldesigned wet ponds have been reported to be 74% for TSS, 49% for TP, 34% for TN, and 65% for metals (Young *et al.* 1996).

Dry Detention Ponds

Dry detention basins are ponds that dry out between storm events and do not maintain a permanent pool of water after storm events. Overall, they are comparatively less effective for pollutant removal than wet retention ponds, but they still are extremely effective at controlling downstream peak discharges. A designed control outlet regulates flows through dry detention ponds. Disadvantages of dry detention basins include aesthetic problems, sediment resuspension, moderate area requirements, and the need for regular maintenance. Advantages include the lack of a need for maintenance of a permanent pool of water and smaller area requirements than wet detention pond systems (Dorman *et al.* 1988).

Pollutant removal efficiencies of dry detention ponds vary greatly depending on design considerations and maintenance. Average PREs of 68% for TSS, 42% for TP, 40% to 60% for metals, and 42% for COD have been reported in the literature for a well designed dry detention basin (Stahre and Urbonas 1990).

Bioretention Systems

Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention system (sometimes referred to as "rain gardens") is designed to perform a specific function. The grass filter strip (or grass channel) reduces incoming runoff velocity and filters particulates from the runoff. The ponding area provides temporary storage for runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity. The organic or mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The planting soil in the bioretention system acts as a filtration system, and clay in the soil provides absorption sites for hydrocarbons, metals, nutrients, and other pollutants. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants and also serve to stabilize the surrounding soils. Finally, a sand bed provides for positive drainage and aerobic conditions in the planting soil and provides a final polishing treatment medium.

Bioretention is a terrestrial-based (up-land 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 runoff. Some of the processes that may take place in a bioretention system include sedimentation, absorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage capacity (ETA and Biohabitats 1993). The design, operation, and maintenance of bioretention systems are described in Section 3.11 of the Virginia Stormwater Management Handbook (VDRC 1999) as well as Chapter 9.1 of the New Jersey Stormwater Best Management Practices Manual (NJDEP 2004). The Virginia Stormwater Management Handbook describes two types of bioretention systems: 1) rain garden-type areas called "Bioretention Filters" in the Virginia Stormwater Management Handbook to emphasize the primary pollutant reduction mechanism related to phosphorus and metals, and 2) "Green Alleys," which are networks of bioretention basins, infiltration trenches, or bioretention filters that provide both water quality management and stormwater conveyance to other stormwater management facilities (VDCR 1999).

Bioretention systems are presumed to be able to remove 80% (VDCR 1999) – 90% (NJDEP 2004) of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed bioretention systems can reduce TSS removal performance. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment; TSS – 80%, TP – 60%, TN – 50% (VDCR 1999), fecal coliform – 92% (Rusciano and Obropta 2007), and metals – 80%. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach (VDCR 1999).

A well-designed bioretention system consists of: (1) a grass filter strip (or grass channel) between the contributing drainage area and the ponding area, (2) a ponding area containing vegetation with a planting soil bed, (3) an organic/mulch layer, and (4) a gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers, or bioretention systems can optionally be designed to infiltrate into the soil.

Bioretention system design will also include some of the following: (1) optional sand filter layer to spread flow, filter runoff, and aid in aeration and drainage of the planting soil, (2) a stone diaphragm at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter, and (3) an inflow diversion or an overflow structure consisting of one of five main methods: (a) a flow diversion structure, (b) an inlet deflector, (c) a slotted curb with the parking lot graded to divert the runoff into the area, (d) a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow into the bioretention system, and (e) an in-system overflow consisting of an overflow catch basin inlet and/or a pea gravel curtain drain overflow (VDCR 1999 and NJDEP 2004).

A bioretention system is an innovative practice for pollutant control. It combines the concepts of detention ponds and bioretention in an attempt to provide higher overall pollutant removal. However, little is known about the overall efficiency of bioretention. Typical bioretention systems consist of a vegetated strip of land that allows stormwater percolation for biological and physical treatment. Bioretention is typically used in an area of one acre or less and consists of an excavated bed filled with sand and covered with a layer of permeable soil. Terrestrial vegetation with a high moisture tolerance is suggested for planting in bioretention systems (VDCR 1999 and NJDEP 2004).

Bioretention is a fairly new best management practices (BMP), developed in 1987 by Prince George's County, Maryland, to be employed by the United States Environmental Protection Agency (USEPA 1999 and Hunt 2006). It can be conceptualized as a modified infiltration trench (Young *et al.* 1996; USEPA 1999). Originally modeled after the hydrologic and physical characteristics of an upland terrestrial forest or a meadow, (Coffman and Winogradoff 1999), the bioretention system treats stormwater by absorption, filtration, volatilization, ion exchange, and microbial decomposition (VDCR 1999 and NJDEP 2004). The typical bioretention system consists of five basic features: pretreatment, treatment, conveyance, maintenance reduction, and landscaping (UVI 2002).

In areas with high infiltration rates, the surrounding soil can be used for infiltration. In low percolation areas, runoff is collected through an underdrain system that leads to a conventional stormwater conveyance (ETA and Biohabitats 1993). Minimum design criteria for the construction and maintenance of bioretention systems can be found in the Design Manual for Use of Bioretention in Stormwater, which was updated in 1998, by the Prince George's County Maryland Department of Environmental Resources, as well as Chapter 9.1 of NJDEP Stormwater BMP Manual (2004). Potential benefits of bioretention include low-maintenance costs, water quality control potential, small size, and aesthetic enhancement (Coffman *et al.* 1997). It is important to note that the bioretention cell can be used to maintain ground water recharge (Clar *et al.* 2006). Potential problems with bioretention systems include groundwater contamination in high percolation areas and mosquitoes and pest breeding in areas where ponding levels are high (Coffman *et al.* 1997), or where the system clogs or is in poor draining soil.

The Basics

Pretreatment can be performed by surrounding the bioretention system with a grass buffer strip in order to capture and remove the coarse sediment from the stormwater runoff, thereby reducing the maintenance costs and the chances of the bioretention system getting clogged. Treatment consists of the infiltration area and the ponding area. The infiltration area is made up of the planting soil on top of a bed of sand into which could be placed a perforated piece of pipe. The infiltration area should be between 5% and 10% of the impervious area draining into it (USEPA 1999, Coffman *et al.* 1999, VDCR 1999, NJDEP and NJDA 1994, Urbonas and Stahre 1993, and NJDEP 2004).

Although the conceptual benefits seem to be ascertainable, few studies have examined the PRE of this technology. Design considerations and maintenance for bioretention systems will certainly change as more monitoring data become available. Studies of bioretention systems are being performed at the University of Virginia (Yu *et al.* 1999) and have been performed by the University of Maryland in 1997. Preliminary results from the University of Maryland study suggest potential high PREs for bioretention systems, but further studies are needed for a complete assessment. PREs for biodetention facilities have been reported as 80% for TSS, 72% for TP, 47% for TN, and 40% to 80% for metals (Yu *et al.* 1999).

Parameters

Lead

The most common sources of lead (Pb) are corrosion of plumbing, leaded fuel, and erosion of natural deposits (USEPA 1999). Possible sources of Pb from highway runoff are leaded gasoline exhaust (although this has substantially dropped in the US in the recent past due to the elimination of leaded gasoline), tire wear, lubricating oil, and bearing wear (Loos 1996). Average concentrations of Pb in the literature range from 73 – 1780 μ g/L (Barrett *et al.* 1998). The MCL for Pb for drinking water in public water systems (PWS) is 15 μ g/L (USEPA 2003). Lead can cause severe health effects in children and adults including delayed physical and mental development and kidney damage (USEPA 1999).

Lead is a well-known pollutant that is toxic to many organisms and is acutely toxic to humans in concentrations as low as 1 mg/L (Horne and Goldman 1994). It is mostly particulate bound in highway runoff and exhibits a poor first flush. Sources of lead in the runoff are primarily from brakes, tires, fuels/oils, and to a smaller extent, de-icing salts (Sansalone and Buchberger 1997). Lead has the same trends as copper in that the highest concentrations were found in runoff during winter months and snowmelt runoff events. Progressively lower concentrations were found in mixed events and rainfall events, and in spring, summer, and fall months (Moxness 1986). Mean concentrations in runoff events ranged from 30 – 450 μ g/L.

Copper

The copper (Cu) test provides a measure of all forms of copper including free ions and organic and inorganic ligands. Copper in the environment is primarily sediment bound and is typically associated with TSS loads. Common sources of Cu for receiving water bodies are corrosion of plumbing, erosion of natural deposits, and leaching from wood preservatives. Values for Cu in highway runoff in the literature range from 22 – 7033 μ g/L. The current drinking water quality standard for Cu is 1.3 mg/L (USEPA 2003). Short-term exposure and long-term health effects from copper exposure include gastrointestinal distress and liver or kidney damage (USEPA 1999).

Copper is a trace nutrient that functions mainly as a metalloprotein component and is required by enzymes concerned with nitrate transformation. When Cu reaches toxic concentrations, it interferes with the activity of enzymes situated on cell membranes of algae. This interference prevents cell division and causes photosynthesis to stop (Levine 1975). Copper is especially toxic to smaller organisms such as phytoplankton and zooplankton. As little as 0.1 μ g/L of ionic copper can kill some algae in waters with low concentrations of chelating agents. In lakes with normal concentrations of chelating agents, 5 – 10 μ g Cu/L affects blue-green algae while most fish are almost unaffected by copper until the concentration reaches 100 – 500 μ g/L (Horne and Goldman 1994). In highway runoff, Cu is present in both particulate and dissolved forms and also exhibits a strong first flush (Sansalone and Buchberger 1997). Copper has the same patterns as cadmium with respect to the season and the type of runoff event.

Zinc

Primary increases in zinc (Zn) concentrations have been attributed to mining operations, agricultural use of sewage sludge, and fertilizer application (Loos 1996). Common highway sources of Zn are from tire wear, motor oil, grease deposits (Barrett *et al.* 1993), brakes, frame, and body (Sansalone and Buchberger 1997). Zinc is also a constituent of the coating used on galvanized nails. Zinc concentrations in highway runoff typically range from 56 – 929 μ g/L (Barrett *et al.* 1993). The current nationally recommended maximum concentration for Zn is 5 mg/L. This is only a secondary drinking water standard, and the USEPA does not enforce it. The primary concerns related to Zn are taste, odor, and aesthetic problems (USEPA 2003). Zinc is a trace nutrient for both flora and fauna and has been found to occasionally be a limiting nutrient for phytoplankton growth (Goldman 1965). It serves as an activator in some enzymatic reactions and is a cofactor for the enzyme carbonic anhydrase. This enzyme catalyzes a critical rate-limiting step for carbon use in photosynthesis (Levine 1975). However, the addition of Zn into natural waters from urban runoff, mine drainage, and zinc plating of pipes, gutters, and culverts can increase zinc concentrations to toxic levels (Sansalone and Buchberger 1997). Zinc is primarily present in dissolved form in highway runoff and exhibits a strong first flush (Lundberg *et al.* 1999; Sansalone and Buchberger 1997). The highest concentrations of zinc were measured in snowmelt runoff events, followed by mixed events and rainfall events; runoff concentrations were highest in the winter, followed by spring, summer, and fall (Moxness 1986). Mean concentrations in runoff ranged from 23 – 4280 μ g/L.

Phosphate

Phosphorus is an essential nutrient required by all living organisms. In freshwater aquatic environments, phosphorus is frequently limited and therefore is a limiting factor on the growth of primary organisms, such as algae. When phosphorus rich water enters lakes and streams, it can upset the natural limitation on the growth of aquatic plants and cause them to grow in abundance. Such uncontrolled growth can lead to water quality degradation through eutrophication that results in such problems as foul taste and odors, depletion of dissolved oxygen, and aesthetic and recreational impairment (Comings *et al.* 2000).

In the past decade, phosphorus has been considered the main contributor to eutrophication in rivers and lakes (Abou Nohra *et al.* 2006, Jordan *et al.* 2008, and Jalali 2007). Eutrophication of lakes can be initiated by concentrations of phosphorus as low as 0.01 mg/L. Therefore, the loss of small amounts of phosphorus from soil to surface waters and by subsurface drainage waters can lead to a deterioration of water quality (Jalali 2007). Elevated concentrations of phosphorus in surface water (> 0.03 mg/L) are attributed to non-point source pollution from agricultural watersheds as a result of continuous application of manure as fertilizer. Moreover, it has been shown that a considerable percentage of phosphorus loads in these watersheds come from subsurface discharge.

Phosphorus is being transported from the field into rivers and lakes through surface and subsurface runoff. Phosphorus interacts with soil particles in its exchangeable form known as orthophosphate; in soils it can be found as dissolved species or bound to the soil. The different forms of orthophosphoric acid that can exist in the soil solution are H_3PO_4 , $H_2PO_4^{1-}$, HPO_4^{2-} , and PO_4^{3-} . The relative concentration of the different forms is controlled by pH; however, PO_4^{3-} has the strongest binding capacity to the soil (Abou Nohra *et al.* 2006).

In lakes and streams, only a small percentage of total phosphorus is in soluble form with the vast majority being held in biologically less available forms

32

in particulate matter (Horne and Goldman 1994). Phosphorus sorption capacity of the soil is influenced by the aluminum and iron content of the soil, and by the buffering capacity of the soil (Abou Nohra *et al.* 2006).

More than 90% of the phosphorus carried by rivers to estuaries and coastal waters is associated with suspended solids. Particulate phosphorus may be bound to iron, manganese, aluminum, calcium, or organic carbon. Often particulate phosphorus fractions are analyzed by sequential extractions and digestions. Such analyses have rarely been applied to suspended particles in streams and rivers. Moreover, riverine fluxes of total particulate phosphorus are poorly quantified because a large proportion of the flux of particulate matter generally occurs during brief, unpredictable episodes of high water flow that often go unobserved (Jordan *et al.* 2008).

Phosphorus was measured in highest concentrations in runoff from snowmelt events. Runoff from mixed events had the next highest concentrations, and the lowest concentrations were measured in rainfall runoff events (Moxness 1986). Mean concentrations of phosphorus in runoff events ranged from 0.19 – 0.57 mg/L.

Nitrate

Nitrogen-containing compounds are examples of contaminants that can create serious problems when released into the environment, such as eutrophication of rivers, deterioration of water quality, and potential hazard to human or animal health. Nitrate is one of these compounds, though it does not pose a human or animal health threat by itself. It is potentially converted to nitrite in the gastrointestinal tract or to nitrous nitrogen compounds through reduction.

In addition, nitrate exposes infants and pregnant women to danger due to the potential reduction of nitrate to nitrite inside the stomach of the infant after digesting nitrate by the mother. Perhaps in pregnant women it passes the placenta into the fetus's bloodstream. Once inside the bloodstream, the nitrite reacts with the hemoglobin in blood and converts the hemoglobin into methemoglobin, which does not carry oxygen to cell tissues. This phenomenon results in a bluish color of the infant's skin the so called methemoglobinemia, or the blue baby syndrome (Ghafari *et al.* 2007). Another important concern is that vegetables are an important part of most babies' diets. Young babies with low stomach acidity may suffer from infantile methemoglobinemia due to excessive nitrates in their diet, where nitrite is substituted for oxygen in hemoglobin and death may occur (Prasad and Chetty 2008).

Water resources (ground and surface water) are contaminated by nitrate in several ways. Most of the contamination of groundwater by nitrate is primarily attributed to nonpoint sources. Nitrate from agricultural sources is growing all over the world due to the extreme use of fertilizers. Nitrate salts reach the groundwater as they percolate through the soil. Some other sources of nitrate in ground and surface water are from uncontrolled land discharges of treated or raw wastewater from domestic and industrial wastes, landfills, and animal wastes, particularly from animal farms. Nitrate in groundwater is increasingly an important problem, which prohibited the direct use of the groundwater resources for human consumption in some parts of the world including India, Japan, China, Saudi Arabia, USA, UK, and several parts of Europe. With the aim to protect consumers from adverse effects of high nitrate intake, the United States, Canada, and the World Health Organization (WHO) have set standards to regulate the nitrate concentration in drinking water to 50 mg NO₃⁻/NO₂⁻-N/L. Also, the United States Environmental Protection Agency (USEPA) and WHO have set the maximum contaminant level (MCL) of 10 mg NO₃⁻-N/L in drinking water. The same concern in Europe put the MCL of 12 mg NO₃⁻-N/L in drinking water (Ghafari *et al.* 2007).

Nitrates form part of the essential chemistry of soils and plants. Thus plant roots are able to absorb nitrate directly from the soil. Since nitrogen plays a key role in plant growth, most agricultural fertilizers contain nitrate. A main concern for public health is the link between nitrates and stomach cancer. It is due to the fact that nitrates help in the formation of carcinogenic nitrosamines. The elevation of gastric pH > 5.5 leads to bacterial growth followed by rapid conversion of nitrate to nitrite. Nitrite is a precursor in the formation of nitrosamines.

Nitrates are not intrinsically carcinogenic, but can be endogenously transformed into nitrites by the digestive bacterial microbiota, while nitrites can be further transformed into N-nitroso compounds (NOCs), i.e. into alkylnitrosamines and nitrosamides through nitrosation. Alkyl-nitrosamines and nitrosamides are highly mutagenic molecules. Secondary or tertiary amines and amides are found as common dietary contaminants. Since NOCs are powerful transplacental neurocarcinogens, they may be involved in the recent increase of childhood brain tumors. Moreover, an increased risk of colon cancer has been put forward in association with drinking water with nitrate concentrations over the regulatory level. However, because the pollution by nitrates impacts the overall population and because the transformation of nitrates into mutagenic NOCs depends on many factors, including diet and microbiota modifications, their carcinogenic role is difficult to clearly assess through epidemiological studies. Before changes to the regulatory level for nitrates in drinking water can be considered, further comparative studies analyzing the precise role of nitrates in selected populations must be performed (Belpomme *et al.* 2007).

Different industrial wastewaters are reported to contain more than 200 mg NO₃⁻-N/L, and some contain higher nitrate concentrations. For instance, effluent from some industries producing explosives, fertilizer, pectin, and cellophane contain greater than 1000 mg NO₃⁻-N/L. Furthermore, the nuclear industry produces nitrate loaded wastes in extremely high concentration at many points during the nuclear fuel cycle. The processing of radioactive metal products at nuclear weapons production plants and research labs reported production of wastewater containing nitrate in excess of 50,000 mg NO_3^--N/L primarily derived from nitric acid used for metal cleaning (Ghafari *et al.* 2007).

Methodology

<u>Columns</u>

Fifteen columns were constructed using 30" (76.2 cm) segments by 8" (23.3 cm) diameter schedule 40 PVC (poly vinyl chloride) piping (AASHTO M-278). Three of these columns were clear; the rest were the standard white. Each of these columns had an 8" (23.3 cm) to 6" (15.2 cm) reducing coupling and a 6" (15.2 cm) end cap on one end with the other end open to the atmosphere of the laboratory. Into the end cap of each column, a quarter inch hole was drilled, using a new titanium drill bit, to allow the synthetic runoff water to flow through. The end that was open to the atmosphere was covered by placing an autoclave bag over the entire pipe. Between the pipe and the reducer coupling was a single layer of non-woven filter fabric (geotextile), while the reducer coupling below was filled with pea gravel (AASHTO M-43).

All of the columns were designed to hold 18" (45.7 cm) of soil, rather than the minimum of three to four feet (91.4 – 121.9 cm) required by the NJDEP, and two" (5.1 cm) of mulch with six to eight inches (15.2 – 23.3 cm) of head space, for the ponding of the synthetic runoff water. The soil used was consistent with that of the NJDEP recommended planting soil for a bioretention system: onethird compost, one-third topsoil, and one-third sand (AASHTO M-6/ASTM C-33) (NJDEP 2004). The one foot sand filter at the bottom of the planting soil was not used. These columns were separated into five groups of three, with each group of three holding a different amount of the bioretention system planting soil mix. The first group, which was called Series One, held 35 pounds (15.9 kg) of soil mix and had a bulk density of 1.1 g/cm³; Series Two held 40 lbs. (18.1 kg) of soil mix and had a bulk density of 1.2 g/cm³; Series Three held 45 lbs. (20.4 kg) and had a bulk density of 1.4 g/cm³, Series Four held 50 lbs. (22.7 kg) and had a bulk density of 1.5 g/cm³, and Series Five held 55 pounds (24.9 kg) of soil mix and had a bulk density of 1.7 g/cm³ (Table 3). The soil was compacted using a circular piece of plywood, a two-foot (61.0 cm) long section of a 2" by 4", and a small sledgehammer.

Supporting Benches

Three benches were constructed using heavy-duty plywood, 2" by 4"s, metal brackets, and screws. Each bench was designed to hold six columns, and to hold each column high enough in order to slide a five gallon bucket under the column to facilitate the collection of the synthetic runoff water that flowed through the column, and to collect the samples. The last bench held only three columns, even though it was designed to hold six. These benches were approximately eight feet (244.0 cm) long, two feet (61.0 cm) wide, and four feet (122.0 cm) high. They had two shelves with holes cut in them, for the columns. The 8" to 6" reducer coupling rested on the lower shelf with the six" side of the reducer coupling able to protrude, but not the eight" side, (Figure 3).

Design Storm

According to the NJDEP's New Jersey Stormwater Best Management Practices Manual (2004), a stormwater quality design storm has a total depth of 1.25 inches (3.2 cm) and a total duration of 2 hours, or 0.625 in/hr (0.265 mm/min). This is based on rainfall data collected between 1913 and 1975 in Trenton, New Jersey.

According to the Bioretention Manual (2002), developed by Prince George's County, Maryland, the minimum size for a bioretention system is 7.2% of the drainage area. For this experiment, each experimental bioretention system column was set at 5% of the total drainage area. Then, each column was potentially draining an area of $\pi r^2/0.05 = 1005.3$ square inches (about 7 square feet = 0.65 m²). Using a stormwater quality design storm and the rational method (see below) with a coefficient of 0.8, each bioretention system column would be filtering approximately 8.4 cubic inches per minute (137.2 mL/min).

Rational Method

The rational method, first developed in 1889 by Kuichling, is a simple technique for estimating a design discharge from a small watershed. In fact, it was developed for small drainage basins in urban areas. The rational method (Q = CIA) is the basis for the design of many small structures. The A in the equation stands for the area of the drainage basin. The I stands for the average

rainfall intensity, and the C stands for the runoff coefficient, representing a ratio of runoff to rainfall. The runoff coefficient is the variable of the rational method least susceptible to precise determination and requires judgment and understanding on the part of the designer. Table 4 lists the recommended ranges for the runoff coefficient value with respect to the general land use.

Synthetic Stormwater

The 137.2 mL/min for each of the 15 columns turns out to be a total of 2.5 X 10⁵ mL or 65 gallons for the two hour design storm. To transport all of this synthetic runoff water, two 20 gallon (75.7 L) white plastic drums and two 50 liter (13.2 gallons) carboys were used. To deliver the 137.2 mL/min to each column required the use of pumps (Masterflex model # EW-07553-70 L/S variable speed), pump heads (Masterflex model # EW-07016-20 standard pump head for L/S 16 tubing), and tubing (Masterflex 06404-16 norprene). To cut down on costs, only three pumps and nine pump heads were purchased for this experiment. Each pump held three pump heads, so only three sets of three columns could be run at a time, rather than running all fifteen columns at the same time. The synthetic runoff water was modeled after Davis et al. (2001), which was based on runoff sampling data obtained by Prince George's County (ETA and Biohabitats 1993). Table 5 specifies the target recipe for the synthetic runoff water. However, not all targeted concentrations were meet 100% of the time due to the fact that more than one person was preparing the concentrated

stock solutions. Concentrated stock solutions were prepared in a 500 mL containers and added to two 20 gallon (75.7 L) and two 50 (13.2 gallons) liter containers filled with Type I water with a resistance of $17.5 \times 10^5 - 17.7 \times 10^5$ ohm meters. This had to be done for seven out of the eight different sampling events. The eighth sampling event, which took place on February 13, 2007 (six weeks after the seventh sampling event), did not contain any of the parameters, e.g., it was just Type I water.

Sample Collection Technique

Samples for metals were collected in 500 mL Nalgene polypropylene containers (02-893C Fisher Scientific, www.fishersci.com) directly from the stream of water flowing out of the columns and into a five gallon bucket. A Target all-plastic 20 mL syringe (03-377-24 Fisher Scientific, www.fishersci.com) was used to remove the sample from the 500 mL container. The next step was to attach an Acrodisc ion chromatography syringe filter (28143-292 VWR International, www.vwr.com) to the syringe and push 10 mL of the sample through the filter into a Corning Brand 15 mL centrifuge tube (05-538-53F Fisher Scientific, www. fishersci.com). Anything that was to come into contact with the sample was first washed with ten-fold dilution of concentrated hydrochloric acid (HCI). This was done by filling the items with diluted HCl and then letting them sit in an oven (Fisher Scientific 13-247-637G, www.fishersci.com) at 60° C overnight. Upon taking the items out in the morning to cool, they were inverted. Once they had cooled, each item was rinsed 5 times with Type I water.

Sample Preservation

Sample containers and preservation techniques were selected based on the constituents to be analyzed. A volume of acid sufficient to lower the sample pH to \leq 2 was placed in sample containers after sample collection. Two plastic bottles were used to split samples for different analyses: one with Optima nitric acid (HNO₃) (Fisher Scientific, A467-250, www.fishersci.com) for metals and one with no preservative for NO₃⁻ and PO₄³⁻. Then, the samples were transferred to the freezer until the analyses could be performed. The holding time for the samples was six months for metals and 28 days for NO₃⁻, but only 48 hours for PO₄³⁻.

Running the Experiment

A pre-run was done mainly to wet down the planting soil mix, but it was also used to see whether or not the column would change the pH of the synthetic runoff water. For this sampling event, thirty gallons of distilled water were purchased from local grocery stores, and two gallons were poured slowly into each column. The pH was taken prior to the pouring, using a calibrated Accumet Basic pH meter (Fisher Scientific, 13-636-AB15P, www.fishersci.com), by adding a pinch (0.1 g) of salt (NaCl) to 200 mL of the distilled water. The pH was taken after the distilled water had flowed through the column by collecting a sample in a Corning Brand 15 mL centrifuge tube from each column and measuring the pH of each sample. Very little change (5.8 - 6.1) in pH had occurred.

The first sampling event was conducted two weeks later and was the first of the eight sampling events using Type I water spiked with nutrients (PO_4^{3-} and NO_3^{-}) and metals (Pb, Cu, and Zn). This sampling event was used to collect enough of the sample in order to develop the methods for analyses, i.e., after collecting the sample in the 500 mL container one 10 mL sample was collected for each metal. This was done for each sampling time, or a total of three times. Each sample was then preserved using Optima nitric acid (Fisher Scientific, A467-250, www.fishersci.com). Enough nitric acid was added to lower the pH of the sample to ≤ 2 , which made each sample about a 0.2% solution of nitric acid.

For the 2nd through the 8th sampling events, only one 10 mL sample was collected per column per sampling time. Since the design storm was a 2 hour event, a sample was collected when the synthetic runoff water first started coming out of the column, another sample was collected 1 hour later, and the final sample was collected from the last of the synthetic runoff water to flow through the columns. For the eighth sampling event, only the first and last samples were collected.

Analyzing the Samples

In addition to analyzing for lead, copper, and zinc, nitrate and phosphate were also analyzed. One 125 mL Nalgene polypropylene container (Fisher Scientific, www.fishersci.com) was filled from the synthetic stormwater effluent flowing through each column for each sampling event (1-8) for this purpose. One 125 mL sample of the synthetic stormwater runoff from each of the four feed reservoirs (two 20 gallon and two 50 liter) was collected as well. Lead, copper, and zinc were analyzed by graphite furnace atomic absorption spectrophotometry (Perkin Elmer, 4100ZL, www.las.perkinelmer.com). Lead was analyzed using USEPA's method #239.2 with a concentration range of 5 – 100 μ g/L and a detection limit of 1 μ g/L. Copper was analyzed using USEPA's method #220.2. The concentration range was 5 – 100 μ g/L, and the detection limit was 1 μ g/L. Zinc was analyzed using USEPA's method #289.2 with a concentration range of 0.2-4 μ g/L. The method detection limit was 0.05 μ g/L. No matrix modifiers were used in any of these methods; however, all three methods required optimization. Only the zinc method required the dilution of the sample.

Nitrate and phosphate were analyzed by flow injection analysis spectrophotometry (Lachat, QuikChem 8500, www.lachatinstruments.com). Nitrate was analyzed using Lachat's method #10-107-04-1-A. The concentration range is $0.2 - 20 \text{ mg NO}_3^-$ -N/L, and the detection limit is 0.01 mg NO $_3^-$ -N/L. Phosphate was analyzed using Lachat's method #10-115-01-1-A with a concentration range of $0.01 - 2 \text{ mg PO}_4^{3-}$ -P/L, and a detection limit of 0.002 mg PO₄³⁻-P/L. All results were statistically analyzed using Microsoft Excel, 2003 Edition, Version 11 and a trial version of Statgraphics Centurion.

Results

The results for this study are enhanced when they are seen in graphical format or in a table. Rather than going through and listing the results, this paper will describe the charts and tables.

Figures 4 through 18 show the average concentrations of the influent and the effluent for the first, second, and third samples for the metals (lead, copper, and zinc) for each sampling event for Series 1 - 5. Figure 19 shows the percent removal of lead verses the bulk density for seven of the sampling events. Figure 20 shows the percent removal of copper verses the bulk density for seven of the sampling events. Figure 21 shows the percent removal of zinc verses the bulk density for seven of the sampling events.

The lead, copper, and zinc data are included in Tables 6 through 20, and the nitrate and phosphate data can be found in Tables 21 through 35. Both sets of tables are located within this document in the Appendix. The compiled data are also listed for lead (Tables 36 and 41), copper (Tables 37 and 42), zinc (Tables 38 and 43), nitrate (Table 39), and phosphate (Table 40). However, it is better presented in graphical format in Figures 22 and 25 for lead, Figures 23 and 26 for copper, Figures 24 and 27 for zinc, Figures 28 and 30 for nitrate, and Figures 29 and 31 for phosphate.

Figures 32 – 36 show the correlations between the effluent concentrations and the influent concentrations for all parameters for five of the eight sampling events. The eighth sampling event was not included because the influent was just Type I water. The first sampling event also was not included because it was the first event.

The Eighth Sampling Event

The eighth sampling event was conducted six weeks after the seventh sampling event on February 13th, 2007. The synthetic runoff used for this sampling event was Type I water, without any constituents added. The concentration was less than 5 μ g/L for lead, copper, and zinc, and less than 0.1 mg/L for nitrate and phosphate.

Statistics

All samples were analyzed in triplicate. From these results, a mean and a standard deviation were calculated. The results were divided up according to metal, date of sampling, series, and column. A one way analysis of variance (ANOVA) with a significance level of $\alpha = 0.05$ was conducted first to see whether or not the three samples taken from each column could be pooled into one result for each column for each event for each metal. The outcomes can be found in Tables 44, 45, and 46 for lead, copper, and zinc, respectively. To summarize the results of the ANOVA: lead – two out of 40 ANOVAs disagree that the results could be pooled; copper – three out of 40 ANOVAs disagree that the results could be pooled; and zinc – 15 out of 40 ANOVAs disagree that the results could be pooled.

Second, a one way ANOVA was performed to see whether or not the three columns in each series could be pooled into one final result for each series for each date of each sampling event for each metal. These results can be found in Tables 47, 48, and 49 for lead, copper, and zinc, respectively. This left one result for each of the five series for each event for each of the three metals. To summarize the results of these ANOVAs: lead – two out of 40 ANOVAs disagree that the results could be pooled; copper – 16 out of 40 ANOVAs disagree that the results could be pooled; and zinc – one out of 40 ANOVAs disagree that the results could be pooled.

As a double check, a two way ANOVA was performed to see whether or not the three results from each column and the three columns from each series could be combined into one result for each series for each of the different events for each metal. The outcomes can be found in Tables 50, 51, and 52 for lead, copper, and zinc, respectively. To summarize the results of these ANOVAs: lead – three of the 40 results from each individual column and two of 40 results from the three columns, or five out of 80 disagree that the results could be pooled; copper – seven of the 40 results from each individual column and 16 of 40 results from the three columns, or 23 out of 80 disagree that the results could be pooled; and zinc – 13 of the 40 results from each individual column and four of 40 results from the three columns, or 17 out of 80 disagree that the results could be pooled. Then using a trial version of a statistic program (Statgraphics Centurion), a summary of statistics table was created for all three metals (Tables 53 – 55) and the nutrients (Tables 56 and 57). They include measures of central tendency, measures of variability, and measures of shape. Of particular interest here are the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of -2 to +2 indicate significant departures from normality, which would tend to invalidate many of the statistical procedures normally applied to this data.

Finally, an ANOVA was performed on all five series for the metals (Tables 58 - 60) as well as the nutrients (Tables 61 and 62). An ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-statistic is a ratio of the between-group estimate to the within-group estimate. If the P-value of the F-test is greater than or equal to 0.05, there is not a statistically significant difference between the means of the variables at the 95.0% confidence level. The P-values for this study were all over 0.05, and they are: lead – 0.8397, copper – 0.2013, zinc – 0.2016, nitrate – 0.2976, and phosphate – 0.0600. Tables 63 - 67 list the pollutant removal efficiencies for the five parameters looked at in this study.

Discussion

Column studies were conducted to investigate the effect compaction of the soil in a bioretention system had on the pollutant removal efficiency (PRE) for the metals lead, copper, and zinc, as well as for the nutrients phosphate and nitrate. One clear trend from Tables 6 - 35 is that most of the effluent concentrations for the nutrients are larger than the influent concentrations, thereby, giving negative PREs. Hunt *et al.* (2006) had similar results. This might be due to the fact that there was nothing growing in any of the columns, i.e. no plants, or because the soil mix (soil was mixed according to NJDEP's specifications) was probably high in both nitrate and phosphate. It appears that the phosphorus content of the soil used in the bioretention media is critical to phosphorus removal performance (Clar *et al.* 2006)

One other expected result, was that all of the columns worked very well at removing the metals, with most of the PREs in the high 90% range, as was reported by Davis *et al.* (2001 and 2003). Table 68 lists the concentrations of lead, copper, and zinc normally found in runoff.

There is one other effect that needs to be mentioned. When the input was reduced, as in the sampling event conducted on November 3rd 2006, the output is also expected to be reduced. However, the opposite happened, especially for copper. This observation suggests something about the mechanisms, but what is unclear because this study did not include testing of leachate prior to the addition of the synthetic stormwater. It might have

something to do with the solute concentration not being great enough to displace the ions already adsorbed by the soil, or it just might be due to the leaching of the built up contamination.

The columns performed better at removing lead and zinc than at removing copper, with lead having the greatest PREs. This is illustrated in the PRE tables (Table 63 – 65), as well as Figures 22 and 25. As can be seen in the charts for copper, Figures 23 and 26, as the experiment progressed, the concentration in the effluent decreased in all five series, but so too did the influent concentrations. However, with zinc, as the experiment advanced, the concentration in the effluent increased while the concentration in the influent decreased for all five series. This is illustrated in Figures 24 and 27. Nevertheless, none of the above mentioned appeared related to the compaction of the soil.

According to the ANOVAs performed on the results for all five series, for all five parameters (Tables 58 to 62), the P-values of the F-tests are greater than or equal to 0.05. This means that there is not a statistically significant difference between the means of the 5 variables at the 95.0% confidence level. Even though Series Three and Series Four had the highest average PREs for lead, copper, and zinc (Tables 63 – 65).

On the other hand, the nutrients were a different story. Since there were not any plants growing in any of the columns, this study could represent a bioretention system during its construction phase, up to the point when the

52
plants are planted. According to this study, during this time frame the bioretention system serves as a source for nitrate and phosphate. Further investigation needs to be done to see whether or not this is actually the case or whether this was just a result of not using the full four feet of planting medium. Regardless, the compaction of the soil seemed to help in the retention of the nutrients, with Series 5 (bulk density of 1.7 g/cm³) having the least negative PREs and even a some positive PREs for nitrate, as can be seen in Table 66 for nitrate and Table 67 for phosphate, as well as Figures 28 and 30 for nitrate and Figures 29 and 31 for phosphate.

Another important effect pointed out by this study was what happens to the effluent concentration when the source concentration (influent) is either lowered or eliminated. The influent concentration does not seem to affect the effluent concentration (Figures 32 - 36). Quite the opposite of what was expected to happen happened. When the source was eliminated, the effluent concentrations rose.

Figures 37 and 40 through 45 are pictures of the various different forms of bioretention systems. Figures 38 and 39 are schematic drawings of a bioretention system, with Figure 38 being a mostly top view and Figure 39 being a side view.

Conclusions

Compaction of the soil in a bioretention system does not have a significant (p < 0.05) impact on the pollutant removal efficiency (PRE) of soil. This study has determined that the compaction level of the soil has no effect on the removal of lead, copper, zinc nitrate, and phosphate in a bioretention system.

There was also no significant effect of compaction of soil on the PREs (which were mostly negative) of the nutrients: nitrate and phosphate. However, as the compaction increased, so too did the PREs for both nitrate and phosphate. This was an unexpected result of this study, as most of the previous studies (ETA and Biohabitats 1993, Bell and Nguyen 1994, USEPA 2000, NJDEP and NJDA 1994, NJDEP 2004, NVPDC 1987, Yu *et al.* 1999, Urbonas and Stahre 1993, and Novotny 1995) state that it is not a good tactic to compact the planting soil of the bioretention system. In fact, they say to use uncompacted soil to improve infiltration and plant growth.

Further study needs to be performed in order to confirm the enhanced PREs on compacted soils for the removal of nitrate and phosphate. In addition, further study should be done with the purpose of validating the necessity of using the full four feet of planting soil mix.

54

References

- Abou Nohra J. S., C. A. Madramootoo , and W. H. Hendershot. (2007). Modeling phosphate absorption to the soil: application of the non-ideal competitive absorption model. *Environ. Pollut.*, 149: 1-9.
- Alloway, B. J. (1990). <u>Heavy Metals in Soils</u>. Chapman and Hall: London.
- Alloway, B. J., I. Thornton, G. A. Smart, J. C. Sherlock, and M. J. Quinn. (1988). Metal availability. *Sci. Total Environ.*, 75: 41-69.
- American Association of State Highway and Transportation Officials (AASHTO). (2002). AASHTO M-278, Standard Specification for Class PS46 Poly Vinyl Chloride (PVC) Pipe. Washington, DC. www.transportation.org.
- American Association of State Highway and Transportation Officials (AASHTO). (2003). AASHTO M-006, Standard Specification for Fine Aggregate for Portland Cement Concrete. Washington, DC. www.transportation.org.
- American Association of State Highway and Transportation Officials (AASHTO). (2005). AASHTO M-043, Standard Specification for Sizes of Aggregate for Road and Bridge Construction. Washington, DC. www.transportation.org.
- American Society for Testing and Materials (ASTM). (2003) ASTM Standard C 33, Specification for Concrete Aggregates. ASTM International, West Conshohocken, PA. www.astm.org.
- Ashley, K., L. C. Thompson, D. C. Lasenby, L. McEachern, K. E. Smokorowski, and D. Sebastian. (1997). Restoration of an interior lake ecosystem: the Kootenay Lake fertilization experiment. *Water Quality Research J. of Canada*, 32: 295-323.
- Barbosa, A. E., T. Hvitved-Jacobsen. (1999). Highway runoff and potential for removal of heavy metals in an infiltration pond in Portugal. *Sci. Total Environ.*, 235: 151-159.
- Barrett, M., L. B. Irish, J. F. Malina, and R. J. Charbeneau. (1998). Characterization of highway runoff in Austin, Texas. *J. of Environ. Eng.*, 124: 131-137.
- Basnyat, P., L. D. Teeter, B. G. Lockaby, and K. M Flynn (2000). The use of remote sensing and GIS in watershed level analysis of nonpoint source pollution problems. *Forest Ecol. and Managem.*, 128: 65-73.

- Bell, W. E., and T. Nguyen. (1994). Applying BMP technologies in urban and ultra-urban settings. Alexandria, VA.
- Belpomme, D., P. Irigaray, L. Hardell, R. Clapp, L. Montagnier, S. Epstein, and A. J. Sasco. (2007). The multitude and diversity of environmental carcinogens. *Environ. Research*, 105: 414–429.
- Bhaduri, B., J. Harbor, B. Engel, and M. Grove. (2000). Assessing watershedscale, long-term hydrologic impacts of land-use change using a GIS-NPS model. *Environ. Managem.*, 28: 643-658.
- Chapra, S. C. (1997). <u>Surface Water Quality Modeling</u>. McGraw-Hill: New York.
- Clar, M., A. Davis, W. Hunt, and R. G. Traver. (2006). Bioretention technology: an overview of current practice and future needs. The Low Impact Development (LID) Technical Committee of the Urban Water Resources Research Council (UWRRC), the Bioretention Design and Construction Task Committee. Omaha, Nebraska.
- Clesceri, L. S., A. E. Greenburg, and R. R. Trussell, eds. (1989). <u>Standard</u> <u>Methods for the Examination of Water and Wastewater</u>, 17th ed. American Public Health Association, American Water Works Association, Water Pollution Control Federation: Washington, DC.
- Coffman, L. S., J. Smith, and M. Lahlou. (1997). Environmentally Sensitive Low-Impact Development. (http://www.epa.gov/owow/watershed/Proceed/coffman.html).
- Coffman, L. S. and D. A. Winogradoff. (1999) Bioretention: an efficient, cost effective stormwater management practice. In national conference on retrofit opportunities for water resource protection in urban environments. United States Environmental Protection Agency. EPA 625-R-99-002. Office of Research and Development. Washington, DC.
- Comings, K. J., D. B. Booth, and R. R. Horner. (2000). Stormwater pollutant removal by two wet ponds in Bellevue, Washington. *J. Environ. Eng.*, 126: 321-330.
- Davis, A. P. and M. Burns. (1999). Evaluation of lead concentration in runoff from painted structures. *Water Research*, 33: 2949-2958.

- Davis, A. P., M. Shokouhian, S. Ni. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere*, 44: 997-1009.
- Davis, A. P., M. Shokouhian, H. Sharma, and C. Minami. (2001). Laboratory study of biological retention for urban stormwater management. *Water Environ. Research*, 73.
- Davis, A. P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. (2003). Water quality improvement through bioretention: lead, copper, and zinc removal. *Water Environ. Research*, 75.
- Davis, J. A. (1984). Complexation of trace metals by adsorbed natural organic matter. *Geochim. Cosmochim. Acta*, 48: 679-691.
- Dennison, M. S. (1996). <u>Storm Water Discharges: Regulatory Compliance and</u> <u>Best Management Practices</u>. CRC Press: Boca Raton, Florida.
- Dorman, M. E., J. Hartigan, and B. Maestri. (1988). Retention, detention, and overland flow for pollutant removal from highway runoff: interim guidelines for management measures. FHWA RD-870-056. Federal Highway Administration, Versar: Springfield, VA.
- Drapper, D., R. Tomlinson, and P. Williams. (2000). Pollutant concentrations in road runoff: southeast Queensland case study. *J. Environ. Eng.*, 126: 313-320.
- Driscoll, E. D., P. E. Shelly, and E. W. Strecker. (1990). Pollutant loadings and impacts from highway stormwater runoff. Federal Highway Administration. Report FHWA RD-88-007. Washington, DC.
- Duda, A. M., D. R. Lenat, and D. L. Penrose. (1998). Water quality in urban streams what we can expect. *J. of Water Pollut*. Control Federation, 54: 1139-1147.
- Dupuis, T. V., P. Bertram, J. Meyer, M. Smith, N. Kobringer, and J. Kaster. (1985). Effects of highway runoff on receiving waters, Volume I: Executive Summary. FHWA RD-84-062. Federal Highway Administration. Rexnord, Inc., EnviroEnergy Technology Center. Milwaukee, WI.
- Earles, T. E. (1996). Wetlands: stormwater monitoring quality assurance/quality control plan. Department of Civil Engineering, University of Virginia, Charlottesville.

- Engineering Technology Associates, Inc. and Biohabitats, Inc. (1993). Design manual for use of bioretention in stormwater management. Prince George's County Department of Environmental Resources, Division of Environmental Management, Watershed Protection Branch, Landover, MD.
- Environmental Protection Handbook (EPH). Stormwater Runoff Control Practices. Bioretention. Chapter 4, 4-16 – 4-18.
- Farrah, H. and W. F. Pickering. (1977). Influence of clay-solute interactions on aqueous heavy metal ion levels. *Water, Air, Soil Pollut.*, 8: 189-197.
- Federal Highway Administration (FHWA). (1996). Evaluation and management of highway runoff water quality. FHWA PD-96-032. Washington, DC.
- Federal Highway Administration (FHWA). (1998). Draft: best management practices in an ultra-urban setting. Tetra Tech, Inc.
- Fitzpatrick, W. P. (1995). Wisconsin smart program: Starkweather Creek. In: United States Center for Environmental Research Information, National Conference on Urban Runoff Management: Enhancing urban watershed management at the local, county, and state levels. U.S. Environmental Protection Agency. EPA 625-R-95-003. Cincinnati, Ohio.
- Gadde, R. R. and H. A. Laitinen. (1974). Studies of heavy metal absorption by hydrous iron and manganese oxides. *Anal. Chem.*, 46: 2022-2026.
- Ghafari, S., M. Hasan, and M. K. Aroua. (2007). Bio-electrochemical removal of nitrate from water and wastewater a review. *Bioresource Technol*, accepted May, 2007. In Press.
- Goldman, C. R. (1965). Micronutrient limiting factors and their detection in natural phytoplankton populations. In: <u>Primary Productivity in Aquatic</u> <u>Environments</u>. C. R. Goldman (Ed.) pg. 121-135.
- Gong, C. and R. J. Donahoe. (1997). An experimental study of heavy metal attenuation and mobility in sandy loam soils. *Appl. Geochem.*, 12: 243-254.
- Gupta, M. K., R. W. Agnew, and N. P. Kobringer. (1981). Constituents of highway runoff. Volumes I-IV. FHWA RD-81-042-046. Federal Highway Administration. Envirex, Inc., Environmental Sciences Division. Milwaukee, WI.

- Hillel, D. (2004). <u>Introduction to Environmental Soil Physics</u>. Elsevier Academic Press: Amsterdam.
- Horne, A. J. and C. R. Goldman. (1994). Limnology. McGraw-Hill: New, York.
- Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. (2006). Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *J. of Irrigation and Drainage Eng.*, 132.
- Hvitved-Jacobsen, T., N. B. Johansen, and Y. A. Yousef. (1994). Treatment systems for urban and highway runoff in Denmark. *Sci. Tot. Environ.*, 146.
- International Joint Commission Canada And United States. (1969). Pollution of Lake Erie, Lake Ontario and the international section of the Saint Lawrence River. E95-1970. Ontario, Canada.
- Jalali, M. (2007). Phosphorus status and sorption characteristics of some calcareous soils of Hamadan, western Iran. *Environ Geol.*, 53: 365-374.
- Jordan, T. E., J. C. Cornwell, W. R. Boynton, and J. T. Anderson. (2008). Changes in phosphorus biogeochemistry along an estuarine salinity gradient: The iron conveyer belt. *Limnol. Oceanogr.*, 53: 172–184.
- Kayhanian, M., A. Singh, C. Suverkropp, and S. Borroum. (2003). Impact of annual average daily traffic on highway runoff pollutant concentrations. *J. Environ. Eng.*, 129: 975–990.
- Kayhanian, M., C. Suverkropp, A. Ruby, and K. Tsay (2007). Characterization and prediction of highway runoff constituent event mean concentration. *J. Environ. Managem.*, 85: 279–295.
- Lenat, D. R. and J. K. Crawford. (1994). Effects of land use on water quality and aquatic biota of three North Carolina piedmont streams. *Hydrobiologia*, 294: 185-199.
- Levine, P. E. (1975). Sorption of zinc, lead, and cadmium on glacial outwash soil. MS Thesis, University of Washington.
- Little, L. M., R. R. Horner, and B. W. Mar. (1983). Assessment of pollutant loadings and concentrations in highway stormwater runoff. Federal Highway Administration. FHWA-WA-RD-39. McLean, VA
- Liu, D., J. J. Sansalone, and F. K. Cartledge. (2005). Comparison of sorptive filter media for treatment of metals in runoff. *J. Environ. Eng.*, 131: 1178-1186.

- Loos, C. G. (1996). Water quality impact due to highway runoff: a study of the Rte. 17 bypass and Warrenton Reservoir. Masters Thesis, Department of Civil Engineering, University of Virginia, Charlottesville.
- Lundberg, K., M. Carling, and P. Lindmark. (1999). Treatment of highway runoff: a study of three detention ponds. *Sci. Tot. Environ.*, 235: 363-365.
- Mason, Y., A. A. Ammann, A. Ulrich, and L. Sigg. (1999). Behavior of heavy metals, nutrients, and major components during roof runoff infiltration. *Environ. Sci. Techonol.*, 33: 1588-1597.
- May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, and E. B. Welch. (1997). Effects of urbanization on small streams in the Puget Sound lowland ecoregion. *Watershed Protect. Techniq.*, 2: 483-494.
- McKenzie, R. M. (1980). The absorption of lead and other heavy metals on oxides of manganese and iron. *Aust. J. Soil Research*, 18: 61-73.
- McMahon, G. and D. A. Harned. (1998). Effect of environmental setting on sediment, nitrogen, and phosphorus concentrations in Albemarle-Pamlico drainage basin, NC and VA, USA. *Environ. Managem*, 22: 887-903.
- Moxness, K. L. (1986). Characteristics of urban freeway runoff, Phase I. Water Quality Unit, Environmental Services Section. Office of Technical Support. Minnesota Department of Transportation.
- Mumley, T. E. (1995). Urban runoff pollution prevention and control planning: San Francisco Bay experiences. In: United States Center for Environmental Research Information, National Conference on Urban Runoff Management: Enhancing urban watershed management at the local, county, and state levels. U.S. Environmental Protection Agency. EPA 625-R-95-003. Cincinnati, Ohio.
- New Jersey Department of Environmental Protection (NJDEP) and New Jersey Department of Agriculture (NJDA). (1994). Stormwater and nonpoint source pollution control best management practices. Trenton.
- New Jersey Department of Environmental Protection (NJDEP). (2004) New Jersey stormwater best management practices manual. Division of Watersheds. Trenton.

- Norrström, A. C. and G. Jacks. (1998). Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts. *Sci. Total Environ.*, 218: 161-174.
- Northern Virginia Planning District Commission (NVPDC). (1987). BMP handbook for the Occoquan Watershed. Annandale, VA.
- Novotny, V. (1991). Urban diffuse pollution: sources and abatement. *Water Environ and Technol.*, 3: 60-65.
- Novotny, V. (1995). <u>Nonpoint Pollution and Urban Stormwater Management</u>. Water Quality Management Library, Volume 9. Technomic: Lancaster, PA.
- Osmond, D. L., D. E. Line, J. A. Gale, R. W. Gannon, C. B. Knott, K. A. Bartenhagen, M. H. Turner, S. W. Coffey, J. Spooner, J. Wells, J. C. Walker, L. L. Hargrove, M. A. Foster, P. D. Robillard, and D. W. Lehning. (1995). WATERSHEDS: water, soil and hydro-environmental decision support system. NCSU Water Quality Group, North Carolina State University, Biological and Agricultural Engineering. Raleigh, NC. (http://h2osparc.wq.ncsu.edu/estuary/rec/urbstorm.html).
- Pitt, R., A. Maestre, and R. Morquecho. (2004). The national stormwater quality database (NSQD) Version 1.1 Report. University of Alabama, Department of Civil and Environmental Engineering. Tuscaloosa, AL.
- Pollution from Land Use Activities Reference Group (PLUARG). (1978). Environmental Management Strategy for the Great Lakes System. Final report to the International Joint Commission. Windsor, Ontario.
- Prasad, S. and A. A. Chetty. (2008). Nitrate-N determination in leafy vegetables: study of the effects of cooking and freezing. *Food Chem.*, 106: 772–780.
- Prince George's County Department of Environmental Resources (PGDER). (1997). Low-impact development design manual. Prince George's County, Md.
- Prince George's County Department of Environmental Resources (PGDER). (2001). The bioretention manual. Programs and Planning Division. Prince George's County, Md.
- Rusciano, G. M. and C. C. Obropta. (2007). Bioretention column study: fecal coliform and total suspended solids reductions. *Transactions of the ASABE*, 50: 1261-1269.

- Sansalone, J. J. and S. G. Buchberger. (1997). Partitioning and first flush of metals in urban roadway storm water. *J. Environ. Eng.*, 123: 134-143.
- Schueler, T. R. (1994). The importance of imperviousness. *Watershed Protect. Techniq.*, 1: 100-111.
- Schueler, T. R. (1998). Stormwater pond and wetland options for stormwater quality control. Metropolitan Washington Council of Governments. Washington, DC.
- Soranno, P. A., S. L. Hubler, S. R. Carpenter, and R. C. Lathrop. (1996). Phosphorus loads to surface waters: a simple model to account for spatial pattern of land use. *Ecolog. Applic.*, 6: 865-878.
- Sparks, D. L. (1995). Sorption phenomena on soils. In <u>Environmental Soil</u> <u>Chemistry</u>. Academic Press: San Diego, CA, pg. 99-139.
- Stahre, P. and B. Urbonas. (1990). <u>Stormwater Detention for Drainage, Water</u> <u>Quality, and CSO Management</u>. Prentice Hall: Englewood Cliffs, NJ.

Stat

- Thompson, D. B. (2006). The rational method, regional regression equations, and site-specific flood frequency relations. Texas Tech University, Report 0–4405–1, 92 pg.
- Thornton, J. A., W. Rast, M. M. Holland, G. Jolankai, and S. O. Ryding. (1999). <u>Assessment and Control of Nonpoint Source Pollution of Aquatic</u> <u>Ecosystems A Practical Approach</u>. Man and the Biosphere Series, Volume 23. UNESCO: Paris.
- Turer, D., J. B. Maynard, and J. J. Sansalone. (2001). Heavy metal contamination in soils of urban highways: comparison between runoff and soil concentrations at Cincinnati, Ohio. *Water, Air, Soil Pollut.*, 132: 293-314.
- Urbonas, B. and P. Stahre. (1993). <u>Stormwater: Best Management Practices and</u> <u>Detention for Water Quality, Drainage, and CSO Management</u>. Prentice Hall: Englewood Cliffs, N.J.
- U.S. Environmental Protection Agency (USEPA). (1983). Results of the nationwide urban runoff program: Volume 1. Final Rep. NTIS Publication No. 83-18552. Water Planning Division. Washington, DC.

- U.S. Environmental Protection Agency (USEPA). (1990). National pollution discharge elimination system permit application regulations for stormwater discharges. Final Rule. Federal Register.
- U.S. Environmental Protection Agency (USEPA). (1991a). Guidance manual for the preparation of part 1 of the NPDES permit applications for discharges from municipal separate storm sewer systems. Office of Water Enforcement and Permits. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1991b). The watershed protection approach: an overview. EPA 503-9-92-001. Office of Water Enforcement and Permits. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1993). Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA 840-B-92-002. Office of Water. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1995). Controlling nonpoint source runoff pollution from roads, highways and bridges. EPA 841-F-95-008a. Office of Water. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1995a). Watershed protection: a statewide approach. EPA 841-R-95-004. Office of Water Enforcement and Permits. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1995b). Watershed protection: a project focus. EPA 841-R-95-003. Office of Water Enforcement and Permits. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (1999). Stormwater technology fact sheet, bioretention. EPA 832-F-99-012. Office of Water. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (2000). Low impact development: a literature review. EPA 841-B-00-005. Office of Water. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (2002). National water quality inventory: 2000 Report. EPA 841-R-02-001. Office of Water. Washington, DC.

- U.S. Environmental Protection Agency (USEPA). (2003). National primary drinking water standards. EPA 816-F-03-016. Office of Water. Washington, DC.
- U.S. Environmental Protection Agency (USEPA). (2005). National management measures to control nonpoint source pollution from urban areas. EPA 841-B-05-004. Office of Water. Washington, DC.
- University of Virgin Islands (UVI) Cooperative Extension Service. (2002). Virgin Islands environmental protection handbook. 3rd Revision. Virgin Islands.
- Virginia Department of Conservation and Recreation (VDCR). (1999). Virginia stormwater management handbook. Volumes 1 and 2. Division of Soil and Water Conservation.
- Wu, J. S., C. J. Allan, W. L. Saunders, and J. B. Evett. (1998). Characterization and pollutant loading estimation for highway runoff. *J. Environ. Eng.*, 124: 584-592.
- Young, G. K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. (1996). Evaluation and management of highway runoff water quality. FHWA-PD-96-032. GKY and Associates Inc., Springfield, VA.
- Yousef, Y. A., L. Lin, J. V. Sloat, and K. Y. Kaye. (1991). Maintenance guidelines for accumulated sediments in retention/detention ponds receiving highway runoff. FLDOT RMC-0381-3286. Florida Department of Transportation, University of Florida, Orlando.
- Yu, S. L. and R. Field. (1992). Derived distribution approach to detention pond design. In proceedings of the sixth annual IAHR international symposium on stochastic hydraulics. Taipei, Taiwan.
- Yu, S. L. and R. L. Stanford. (2004). Manual of practice for stormwater management. FHWA VTRC 05-CR5. Virginia Department of Transportation.
- Yu, S. L., X. Zhang, T. E. Earles, and M. Sievers. (1999). Field testing of ultraurban BMPs.
- Zhang, M., Z. He, D. V. Calvert, P. J. Stoffella, and X. Yang. (2003). Surface runoff losses of copper and zinc in sandy soils. *J. Environ. Qual.*, 32: 909-915.

Zobrist, J., S. R. Müller, M. A. Ammann, T. D. Bucheli, V. Mottier, M. Ochs, R. Schoenenberger, J. Eugster, and M. Boller. (2000). Quality of roof runoff for groundwater infiltration. *Water Research.*, 34: 1455-1462.

Acronyms

	American Association of State Highway and
AASHTU	Transportation Officials
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
BMPs	Best Management Practices
BOD	biochemical oxygen demand
COD	carbonaceous oxygen demand
CSO	combined sewer overflow
CWA	Clean Water Act
CZARA	Coastal Zone Act Reauthorization Amendment
CZMA	Coastal Zone Management Act
CZMP	coastal zone management plan
ETA	Engineering Technology Associates
Fe, Ni, Cr, Cd	iron, nickel, chromium, cadmium
FHWA	Federal Highway Administration
FR	Federal Register
FWPCA	Federal Water Pollution Control Act
HCI	hydrochloric acid
HNO ₃	nitric acid
HUC	hydrologic unit code
MCL	maximum contaminant level
MS4s	municipal separate sewer systems
NaCl	sodium chloride salt
NJDA	New Jersey Department of Agriculture
NJDEP or DEP	New Jersey Department of Environmental Protection
NO ₃ , PO ₄	nitrate, phosphate
NOC	n-nitroso compounds
NPDES	National Pollutant Discharge Elimination System
NSP	nonpoint source pollution
NURP	Nationwide Urban Runoff Program
NVPDC	Northern Virginia Planning District Commission
P.L.	Public Law
Pb, Cu, Zn	lead, copper, zinc
PLUARG	Pollution from Land Use Activities Reference Group
PREs	pollutant removal efficiencies
PVC	poly vinyl chloride
PWS	public water systems
SWMP	Statewide Watershed Management Program
TMDL	total maximum daily load
TN, TP	total nitrogen, total phosphorus

TSS	total suspended solids
U.S.C.	United States Code
UK	United Kingdom
USA	United States of America
USACE	United States Army Corps of Engineers
USEPA or EPA	United States Environmental Protection Agency
USGS	United States Geological Society
UVI	University of the Virgin Islands
VDCR	Virginia Department of Conservation and Recreation
WHO	World Health Organization
WMA	watershed management area

Appendix

<u>Tables</u>

- Table 1 lists the concentrations found in California highway runoff.
- Table 2 lists the concentrations found in building sidings.
- Table 3 lists the amount of soil contained in each series of columns.
- Table 4 lists the runoff coefficients for the rational method.
- Table 5 lists the stormwater recipe used as a model in this experiment.
- The metal (lead, copper, and zinc) data are listed in Table 6 20.
- Tables 21 35 contain the nutrient (nitrate and phosphate) data.
- Tables 36, 37, and 38 list the average series data for the metals.
- Tables 39 and 40 contain the average nutrient data for each series.
- Tables 41 43 list the average of the three samples for each series for the metals.
- Tables 44 52 contain the statistical information for the metals.
- Table 53 57 contain the statistical data for the metals and the nutrients.
- Tables 58 62 are the ANOVA tables for all five series for all five parameters
- Tables 63 67 lists the PREs for each series for both the nutrients and the metals.
- Table 68 has typical levels of metals found in runoff listed.

Figures

- Figure 1 is a map of New Jersey's WMAs and Water Regions
- Figure 2 is a hydrograph
- Figure 3 is a schematic of the benches and the columns
- Figures 4 8 show the three samples from each event for each series for lead.
- Figures 9 13 show the three samples from each event for each series for copper.
- Figures 14 18 show the three samples from each event for each series for zinc.
- Figure 19 shows the PREs verses the bulk density for lead.
- Figure 20 shows the PREs verses the bulk density for copper.
- Figure 21 shows the PREs verses the bulk density for zinc.
- Figure 22 shows the lead inputs and outputs for all sampling events for each series.
- Figure 23 shows the copper inputs and outputs for all sampling events for each series.
- Figure 24 shows the zinc inputs and outputs for all sampling events for each series.
- Figure 25 shows the lead inputs and outputs for each sampling event for all series and include the bulk density for each series.

- Figure 26 shows the copper inputs and outputs for each sampling event for all series and include the bulk density for each series.
- Figure 27 shows the zinc inputs and outputs for each sampling event for all series and include the bulk density for each series.
- Figure 28 shows the nitrate inputs and outputs for all sampling events for each series.
- Figure 29 shows the phosphate inputs and outputs for all sampling events for each series.
- Figure 30 shows the nitrate inputs and outputs for each sampling event for all series and include the bulk density for each series.
- Figure 31 shows the phosphate inputs and outputs for each sampling event for all series and include the bulk density for each series.
- Figures 32 36 are correlations between effluent and influent.
- Figure 37 is a picture of a bioretention system.
- Figures 38 and 39 are schematics of a bioretention system.
- Figures 40 -45 are more pictures of bioretention systems.

	Median	Mean	Maximum
Metals (dissolved)	μ g/L	μ g/L	m g/L
Lead	1.2	7.6	480
Copper	10.2	14.9	130
Zinc	40.4	68.8	1017
Metals (total)	μg/L	μ g/L	m g/L
Lead	12.7	47.8	2600
Copper	21.1	33.5	270
Zinc	111.2	187.1	1680

Table 1: Concentrations of lead, copper, and zinc found in California highway runoff for the years 2000-2003. Adapted from Kayhanian *et al.* (2003 and 2007).

	Metal Concentration (μ g/m ²)													
	Median	Mean	Maximum											
Brick														
Lead	76	300	4500											
Copper	23	47	280											
Zinc	720	2100	23000											
Painted wood														
Lead	110	520	3000											
Copper	34	80	280											
Zinc	1600	2800	8400											
concrete														
Lead	20	26	89											
Copper	16	35	170											
Zinc	1400	1200	1900											
Metal														
Lead	4	10	31											
Copper	<1	2	5											
Zinc	120	690	2500											
Unpainted wood														
Lead	9	93	270											
Copper	23	120	320											
Zinc	200	330	730											
Vinyl														
Lead	8	11	17											
Copper	8	16	35											
Zinc	66	60	91											
All samples														
Lead	50	270	4500											
Copper	19	51	320											
Zinc	820	1900	23000											

Table 2: Metals found in runoff from building sidings. Adapted from Davis *et al.* 2001

Name	Amount of Soil (lbs)	Bulk Density (g/cm ³⁾
Series 1	35	1.1
Series 2	40	1.2
Series 3	45	1.4
Series 4	50	1.5
Series 5	55	1.7

Table 3: Amount of soil held by each column in the different series, and the bulk density of each series

Business	
Downtown Areas	0.70 – 0.95
Neighborhood Areas	0.50 - 0.70
Residential	
Single-family	0.30 - 0.50
Multi-family detached	0.40 - 0.60
Multi-family attached	0.60 – 0.75
Residential suburban	0.25 – 0.40
Apartments	0.50 - 0.70
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 – 0.35
Railroad yards	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Drives and walks	0.75 – 0.85
Roofs	0.75 – 0.95
Streets	
Asphalt	0.70 – 0.95
Concrete	0.80 – 0.95
Brick	0.70 – 0.85

Table 4: General runoff coefficients for the rational method, adapted from Thompson 2006.

Pollutant	Chemical	Concentration (mg/L)
Nutrients		
Nitrate	NaNO ₃	2 (as N)
Phosphate	Na ₂ HPO ₄	0.6 (as P)
Metals		
Copper	CuSO ₄	0.08 (as Cu)
Lead	PbCl ₂	0.08 (as Pb)
Zinc	ZnCl ₂	0.6 (as Zn)
Dissolved Solids	CaCl ₂	120
рН		7.0

Table 5: Target synthetic stormwater recipe modeled after the recipe used by Davis *et al.* 2001.

	Column 1, Series 1 Pb Cu Zn																		
				Pt	C					Cı	1				_	Z	n		
20-Oct	first sampling event	36.1	in ±	1.33	ND ND ND	out ± ± ±		69.7	in ±	3.05	16.5 21.1 18.6	out ± ± ±	2.54 1.56 2.12	533.5	in ±	0.91	6.5 3.9 2.3	out ± ± ±	1.81 0.23 0.44
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	13.2 10.1 10.2	± ± ±	1.29 1.25 0.78	217.1	±	0.71	22.3 11.1 4.0	± ± ±	0.87 0.65 0.31
17-Nov	third sampling event	24.6	±	0.96	ND ND ND	± ± ±		85.8	±	13.07	18.9 9.7 9.0	± ± ±	2.99 0.56 1.26	508.2	±	0.40	11.5 7.9 8.2	± ± ±	0.35 0.78 1.17
1-Dec	fourth sampling event	18.2	±	0.36	1.8 1.9 2.0	± ± ±	0.09 0.23 0.61	64.8	±	1.59	10.8 10.5 11.1	± ± ±	0.90 0.38 0.29	524.0	±	2.55	21.5 16.9 3.8	± ± ±	2.90 1.10 0.43
15-Dec	fifth sampling event	36.6	±	1.94	0.5 1.2 1.2	± ± ±	0.07 0.05 0.14	68.9	±	0.48	9.7 11.2 8.6	± ± ±	2.31 0.82 0.21	120.0	±	0.01	17.6 12.0 2.9	± ± ±	0.04 0.39 0.23
22-Dec	sixth sampling event	29.2	±	0.57	ND 0.4 5.2	± ± ±	0.25 0.58	60.6	±	1.37	9.8 9.7 9.5	± ± ±	2.09 0.22 0.30	226.0	±	3.35	8.6 9.8 5.4	± ± ±	0.46 1.18 0.67
29-Dec	seventh sampling event	9.4	±	0.69	ND 0.3 0.5	± ± ±	0.19 0.34	65.0	±	3.60	12.0 8.6 7.6	± ± ±	2.22 0.16 0.25	338.0	±	0.56	61.8 59.9 18.8	± ± ±	1.21 0.52 0.52
13-Feb	eighth sampling event		0		ND 0.4	± ±	0.14		0		8.4 6.0	± ±	1.97 0.13		0		22.1 10.2	± ±	1.29 0.64

Table 6: Metals data (μ g/L) for bioretention column 1, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.0 09 μ g/L).

		Column 2, Series 1																				
				Pt	C					Ci	L					Z	n					
20-Oct	first sampling event	36.1	in ±	1.33	ND ND ND	out ± ± ±		69.7	in ±	3.05	14.1 21.9 17.4	out ± ±	1.84 2.37 1.91	533.5	in ±	0.91	12.7 4.4 1.6	out ± ± ±	3.95 0.11 0.09			
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	15.7 12.7 12.3	± ± ±	0.82 0.42 0.21	217.1	±	0.71	29.8 8.0 5.5	± ± ±	0.75 0.15 0.09			
17-Nov	third sampling event	24.6	±	0.96	ND ND ND	± ± ±		85.8	±	13.07	19.6 15.3 13.7	± ± ±	1.49 0.58 0.92	508.2	±	0.40	13.2 9.8 11.3	± ± ±	0.20 0.08 0.23			
1-Dec	fourth sampling event	18.2	±	0.36	5.3 2.0 2.3	± ± ±	0.20 0.04 0.81	64.8	±	1.59	15.2 13.9 12.9	± ± ±	0.44 0.45 0.03	524.0	±	2.55	177.0 20.4 5.4	± ± ±	6.90 2.40 0.20			
15-Dec	fifth sampling event	36.6	±	1.94	0.5 0.9 0.8	± ± ±	0.16 0.16 0.06	68.9	±	0.48	11.4 10.3 10.3	± ± ±	0.61 0.03 0.12	120.0	±	0.01	25.6 8.4 6.3	± ± ±	0.18 0.26 0.72			
22-Dec	sixth sampling event	29.2	±	0.57	0.2 ND 1.4	± ± ±	0.18 0.44	60.6	±	1.37	11.1 11.4 9.4	± ± ±	1.13 0.33 0.38	226.0	±	3.35	43.6 22.4 10.7	± ± ±	1.18 0.49 0.56			
29-Dec	seventh sampling event	9.4	±	0.69	ND ND ND	± ± ±		65.0	±	3.60	13.2 11.2 13.4	± ± ±	0.51 0.40 0.19	338.0	±	0.56	76.3 66.1 32.0	± ± ±	0.35 0.91 0.44			
13-Feb	eighth sampling event		0		1.3 0.2	± ±	1.02 0.46		0		10.0 8.1	± ±	0.85 1.98		0		46.9 14.1	± ±	0.77 0.42			

Table 7: Metals data (μ g/L) for bioretention column 2, mean ± one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \mu$ g/L).

		Column 3, Series 1																				
				Pt)					Ci	l					Zı	า					
20-Oct	first sampling event	36.1	in ±	1.33	ND ND ND	out ± ± ±	:	69.7	in ±	3.05	25.2 28.1 25.0	out ± ±	0.10 1.10 1.80	533.5	in ±	0.91	3.6 8.6 4.3	out ± ± ±	1.24 2.83 0.03			
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	13.4 12.2 8.8	± ± ±	0.38 0.15 1.01	217.1	±	0.71	27.0 13.8 1.7	± ± ±	0.87 0.44 0.07			
17-Nov	third sampling event	24.6	±	0.96	ND ND ND	± ± ±		85.8	±	13.07	15.3 12.9 11.6	± ± ±	1.13 0.30 0.75	508.2	±	0.40	11.5 7.7 6.0	± ± ±	0.29 0.19 0.13			
1-Dec	fourth sampling event	18.2	±	0.36	2.1 2.2 1.8	± ± ±	0.04 0.49 0.13	64.8	±	1.59	11.3 10.8 9.3	± ± ±	1.03 0.10 0.20	524.0	±	2.55	59.6 18.7 2.5	± ± ±	0.43 0.36 0.42			
15-Dec	fifth sampling event	36.6	±	1.94	0.2 0.5 0.8	± ± ±	0.23 0.14 0.01	68.9	±	0.48	8.6 7.2 6.9	± ± ±	0.59 0.06 0.16	120.0	±	0.01	19.2 10.2 3.6	± ± ±	0.24 0.03 0.17			
22-Dec	sixth sampling event	29.2	±	0.57	0.2 0.1 0.8	± ± ±	0.16 0.14 0.46	60.6	±	1.37	8.2 8.4 11.1	± ± ±	0.89 0.75 0.31	226.0	±	3.35	44.1 4.2 1.3	± ± ±	9.11 0.68 0.37			
29-Dec	seventh sampling event	9.4	±	0.69	ND ND 0.4	± ± ±	0.13	65.0	±	3.60	9.8 7.7 7.2	± ± ±	0.68 0.16 0.10	338.0	±	0.56	81.8 39.4 18.5	± ± ±	1.47 0.49 0.63			
13-Feb	eighth sampling event		0		0.5 ND	± ±	0.25		0		6.7 6.6	± ±	0.87 1.27		0		25.9 14.9	± ±	1.09 0.41			

Table 8: Metals data (μ g/L) for bioretention column 3, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).

	Column 4, Series 2																		
				Pł)					Cı	L					Zı	า		
20-Oct	first sampling event	36.1	in ±	1.33	ND ND ND	out ± ± ±	:	69.7	in ±	3.05	21.1 18.5 14.9	out ± ±	0.71 1.33 2.43	533.5	in ±	0.91	6.3 4.3 3.2	out ± ±	0.55 0.16 0.14
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	11.6 14.1 12.4	± ± ±	0.20 0.20 0.61	217.1	±	0.71	23.7 9.6 3.5	± ± ±	0.27 0.18 0.13
17-Nov	third sampling event	24.6	±	0.96	ND ND 0.5	± ± ±	0.49	85.8	±	13.07	11.7 14.7 12.9	± ± ±	0.04 0.43 0.23	508.2	±	0.40	16.4 9.1 7.3	± ± ±	0.27 0.03 0.16
1-Dec	fourth sampling event	18.2	±	0.36	2.7 2.1 2.2	± ± ±	0.13 0.10 0.14	64.8	±	1.59	9.4 9.6 9.3	± ± ±	0.56 0.22 0.26	524.0	±	2.55	28.5 21.3 7.8	± ± ±	1.66 1.13 0.81
15-Dec	fifth sampling event	36.6	±	1.94	0.2 0.3 0.5	± ± ±	0.14 0.09 0.18	68.9	±	0.48	9.5 8.1 7.1	± ± ±	0.84 0.19 0.11	120.0	±	0.01	25.1 10.8 5.0	± ± ±	0.24 0.29 0.65
22-Dec	sixth sampling event	29.2	±	0.57	ND ND 0.1	± ± ±	0.67	60.6	±	1.37	11.3 10.8 8.6	± ± ±	0.88 0.33 1.17	226.0	±	3.35	26.0 6.2 0.9	± ± ±	2.32 2.15 0.50
29-Dec	seventh sampling event	9.4	±	0.69	ND ND 0.2	± ± ±	0.13	65.0	±	3.60	7.9 7.4 5.2	± ± ±	0.70 0.52 1.24	338.0	±	0.56	57.0 32.2 15.0	± ± ±	0.50 0.05 0.63
13-Feb	eighth sampling event		0		0.4 ND	± ±	0.45		0		15.4 5.1	± ±	0.40 0.41		0		17.1 10.7	± ±	0.51 0.17

Table 9: Metals data (μ g/L) for bioretention column 4, mean ± one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \mu$ g/L).

		Column 5, Series 2																	
				Pł	C					Cı	u					Zr	۱		
20-Oct	first sampling event	36.1	in ±	1.33	ND ND ND	out ± ± ±	Ī	69.7	in ±	3.05	20.7 14.1 13.5	out ± ±	1.41 1.05 2.61	533.5	in ±	0.91	3.1 8.5 3.2	out ± ± ±	0.26 0.12 0.26
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	10.6 10.4 11.1	± ± ±	0.10 0.28 0.35	217.1	±	0.71	23.0 5.3 21.4	± ± ±	1.37 0.28 0.67
17-Nov	third sampling event	24.6	±	0.96	ND ND 1.1	± ± ±	0.53	85.8	±	13.07	10.6 15.6 15.5	± ± ±	0.95 0.49 0.47	508.2	±	0.40	13.2 9.3 6.4	± ± ±	0.08 0.21 0.21
1-Dec	fourth sampling event	18.2	±	0.36	2.2 2.2 2.4	± ± ±	0.69 0.87 0.95	64.8	±	1.59	8.7 8.6 7.4	± ± ±	0.48 0.22 0.20	524.0	±	2.55	42.0 22.4 9.3	± ± ±	0.36 1.69 0.65
15-Dec	fifth sampling event	36.6	±	1.94	0.3 0.2 0.3	± ± ±	0.09 0.08 0.15	68.9	±	0.48	10.8 6.5 6.0	± ± ±	0.75 0.25 0.63	120.0	±	0.01	11.5 11.8 4.5	± ± ±	0.29 0.04 0.51
22-Dec	sixth sampling event	29.2	±	0.57	ND ND ND	± ± ±		60.6	±	1.37	12.3 13.6 11.3	± ± ±	0.25 0.19 0.16	226.0	±	3.35	20.8 9.8 2.4	± ± ±	1.61 2.44 0.68
29-Dec	seventh sampling event	9.4	±	0.69	ND ND 0.4	± ± ±	0.12	65.0	±	3.60	9.8 8.3 7.2	± ± ±	0.41 0.40 0.38	338.0	±	0.56	60.5 64.6 18.4	± ± ±	0.55 0.77 0.53
13-Feb	eighth sampling event		0		ND ND	± ±			0		6.0 5.5	± ±	0.59 1.48		0		30.8 11.2	± ±	1.21 0.43

Table 10: Metals data (μ g/L) for bioretention column 5, mean ± one standard deviation of triplicate analyses (ND = nondetectable ≤ 0.09 μ g/L).

								C	Colu	mn 6,	Serie	es 2	2						
				Pt	0					Ci	l					Zr	ו		
			in			out			in			out			in			out	
20-Oct	first sampling event	36.1	±	1.33	ND ND ND	± ± ±		69.7	±	3.05	23.4 17.7 20.7	± ± ±	1.56 1.37 4.20	533.5	±	0.91	3.3 3.8 1.2	± ± ±	0.58 0.12 0.04
3-Nov	second sampling event	8.1	±	0.74	ND ND ND	± ± ±		10.2	±	0.76	9.4 12.3 10.6	± ± ±	0.99 0.15 0.29	217.1	±	0.71	21.7 7.3 6.1	± ± ±	0.71 0.25 0.06
17-Nov	third sampling event	24.6	±	0.96	ND ND 0.7	± ± ±	0.59	85.8	±	13.07	9.8 13.9 15.3	± ± ±	0.33 0.53 0.44	508.2	±	0.40	16.3 10.4 10.7	± ± ±	0.21 0.05 0.04
1-Dec	fourth sampling event	18.2	±	0.36	2.1 2.9 4.6	± ± ±	0.07 0.49 1.17	64.8	±	1.59	8.9 9.9 10.4	± ± ±	0.27 0.15 0.41	524.0	±	2.55	33.8 21.8 4.4	± ± ±	0.52 2.55 1.03
15-Dec	fifth sampling event	36.6	±	1.94	0.6 0.7 0.5	± ± ±	0.09 0.07 0.10	68.9	±	0.48	8.5 6.0 6.3	± ± ±	0.31 0.30 0.63	120.0	±	0.01	39.0 12.6 6.1	± ± ±	0.31 0.51 0.08
22-Dec	sixth sampling event	29.2	±	0.57	ND ND ND	± ± ±		60.6	±	1.37	12.3 11.6 10.9	± ± ±	0.83 0.24 0.52	226.0	±	3.35	18.5 8.1 5.2	± ± ±	1.87 3.26 1.45
29-Dec	seventh sampling event	9.4	±	0.69	ND 0.4 0.5	± ± ±	0.05 0.05	65.0	±	3.60	7.3 6.7 6.2	± ± ±	0.32 0.03 0.32	338.0	±	0.56	54.1 39.7 21.8	± ± ±	0.96 0.61 1.04
13-Feb	eighth sampling event		0		ND ND	± ±			0		5.2 5.6	± ±	0.75 0.24		0		33.3 10.1	± ±	0.36 0.19

Table 11: Metals data (μ g/L) for bioretention column 6, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).

								С	olu	mn 7	Serie	es 3	3						
		Pb Cu in out in out														Zı	า		
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ± ±		29.6	in ±	0.92	21.5 21.5 21.5	out ± ±	1.35 1.54 1.62	565.7	in ±	2.32	4.6 4.3 2.3	out ± ± ±	0.42 0.23 0.07
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	8.8 11.7 13.6	± ± ±	0.24 0.16 0.78	147.5	±	0.11	11.6 7.6 5.4	± ± ±	0.44 0.54 0.06
17-Nov	third sampling event	36.3	±	1.42	ND ND 8.9	± ± ±	0.28	105.2	±	6.15	7.7 9.8 12.5	± ± ±	0.51 0.54 1.08	547.6	±	0.20	14.9 8.2 10.0	± ± ±	0.33 0.05 0.60
1-Dec	fourth sampling event	18.0	±	1.05	3.0 1.5 2.4	± ± ±	0.07 0.10 0.10	76.4	±	2.39	7.8 7.0 7.5	± ± ±	0.50 0.42 0.16	254.0	±	1.66	19.4 16.1 11.2	± ± ±	3.40 2.53 2.04
15-Dec	fifth sampling event	35.5	±	1.02	1.5 1.3 0.3	± ± ±	0.08 0.07 0.13	97.7	±	1.26	4.8 5.4 5.2	± ± ±	0.12 0.14 0.32	450.0	±	0.43	13.5 10.4 5.8	± ± ±	0.30 0.06 0.10
22-Dec	sixth sampling event	36.6	±	3.44	ND ND 4.3	± ± ±	0.15	59.9	±	3.23	10.2 5.9 6.6	± ± ±	1.13 0.29 0.34	208.0	±	2.30	18.7 16.5 13.3	± ± ±	1.04 2.48 1.31
29-Dec	seventh sampling event	13.5	±	0.48	ND 0.2 0.7	± ± ±	0.11 0.11	59.6	±	4.78	7.6 5.8 6.6	± ± ±	0.74 0.08 0.12	316.0	±	3.47	36.0 31.9 16.3	± ± ±	0.82 0.31 0.75
13-Feb	eighth sampling event		0		ND 0.9	± ±	0.91		0		4.1 5.7	± ±	0.63 1.92		0		37.7 27.0	± ±	0.30 0.33

Table 12: Metals data (μ g/L) for bioretention column 7, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).

								C	oluı	mn 8,	Seri	es 3	3						
				Pł)					Ci	1					Zı	า		
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ± ±		29.6	in ±	0.92	18.4 13.7 15.6	out ± ±	0.91 0.86 1.04	565.7	in ±	2.32	4.2 2.4 1.3	out ± ± ±	0.36 0.10 0.03
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	8.6 8.2 8.3	± ± ±	0.53 0.35 0.49	147.5	±	0.11	9.4 5.9 2.6	± ± ±	1.24 0.20 0.41
17-Nov	third sampling event	36.3	±	1.42	ND ND 3.3	± ± ±	0.80	105.2	±	6.15	6.7 6.6 7.3	± ± ±	0.42 0.24 0.72	547.6	±	0.20	11.9 4.7 5.1	± ± ±	0.02 0.11 0.23
1-Dec	fourth sampling event	18.0	±	1.05	3.1 3.0 3.1	± ± ±	0.35 0.40 0.35	76.4	±	2.39	6.8 6.8 6.5	± ± ±	0.26 0.02 0.01	254.0	±	1.66	15.8 19.4 14.3	± ± ±	3.01 1.53 1.03
15-Dec	fifth sampling event	35.5	±	1.02	0.8 1.1 0.2	± ± ±	0.02 0.09 0.13	97.7	±	1.26	6.3 6.1 8.5	± ± ±	0.20 0.38 1.04	450.0	±	0.43	14.0 9.2 2.3	± ± ±	1.84 0.77 0.12
22-Dec	sixth sampling event	36.6	±	3.44	ND ND 3.1	± ± ±	0.04	59.9	±	3.23	7.6 6.3 8.3	± ± ±	0.47 0.30 0.40	208.0	±	2.30	23.7 17.4 11.8	± ± ±	2.01 1.24 0.85
29-Dec	seventh sampling event	13.5	±	0.48	ND 0.3 1.5	± ± ±	0.20 0.13	59.6	±	4.78	4.9 5.3 6.6	± ± ±	0.80 0.27 0.22	316.0	±	3.47	61.6 28.5 16.6	± ± ±	0.52 0.06 0.66
13-Feb	eighth sampling event		0		0.8 0.1	± ±	0.66 0.46		0		4.7 4.0	± ±	0.10 0.21		0		26.7 20.6	± ±	0.59 1.07

Table 13: Metals data (μ g/L) for bioretention column 8, mean ± one standard deviation of triplicate analyses (ND = nondetectable ≤ 0.09 μ g/L).

								C	olui	mn 9,	Serie	es 3	3						
				Pt	D					Cı	l					Zn			
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ± ±		29.6	in ±	0.92	18.4 13.7 15.6	out ± ± ±	0.22 0.48 0.56	565.7	in ±	2.32	5.5 3.9 2.7	out ± ± ±	0.73 0.13 0.04
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	9.1 8.2 8.3	± ± ±	0.94 0.35 0.49	147.5	±	0.11	9.4 3.5 1.8	± ± ±	0.14 0.16 0.09
17-Nov	third sampling event	36.3	±	1.42	ND ND 1.7	± ± ±	0.52	105.2	±	6.15	6.7 6.6 7.3	± ± ±	0.42 0.24 0.72	547.6	±	0.20	9.6 6.7 8.2	± ± ±	0.16 0.06 0.30
1-Dec	fourth sampling event	18.0	±	1.05	1.7 1.8 1.6	± ± ±	0.10 0.20 0.10	76.4	±	2.39	6.8 6.8 6.5	± ± ±	0.26 0.02 0.01	254.0	±	1.66	15.0 23.9 5.4	± ± ±	1.56 1.42 0.67
15-Dec	fifth sampling event	35.5	±	1.02	0.6 0.7 0.1	± ± ±	0.02 0.07 0.07	97.7	±	1.26	6.3 6.1 8.5	± ± ±	0.20 0.38 1.04	450.0	±	0.43	11.9 16.0 5.1	± ± ±	0.10 2.05 0.12
22-Dec	sixth sampling event	36.6	±	3.44	ND ND 2.5	± ± ±	0.10	59.9	±	3.23	7.6 6.3 8.3	± ± ±	0.47 0.30 0.40	208.0	±	2.30	17.8 31.3 19.2	± ± ±	0.74 1.06 0.68
29-Dec	seventh sampling event	13.5	±	0.48	ND 0.1 0.7	± ± ±	0.10 0.07	59.6	±	4.78	4.9 5.3 6.6	± ± ±	0.80 0.27 0.22	316	±	3.47	33.8 64.9 17.4	± ± ±	0.86 0.28 0.65
13-Feb	eighth sampling event		0		ND ND	± ±			0		4.7 4.9	± ±	1.11 1.49		0		54.5 14.0	± ±	0.23 0.64

Table 14: Metals data (μ g/L) for bioretention column 9, mean ± one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \ \mu$ g/L).

								Co	olun	nn 10	, Ser	ies	4						
				Pł	D						Zı	n							
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ±	t	29.6	in ±	0.92	20.8 21.0 26.3	out ± ±	1.95 1.16 0.87	565.7	in ±	2.32	0.8 6.9 1.8	out ± ± ±	0.09 0.37 0.04
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	10.0 9.6 11.2	± ± ±	0.26 1.06 0.26	147.5	±	0.11	35.4 10.5 2.7	± ± ±	0.18 0.53 0.35
17-Nov	third sampling event	36.3	±	1.42	ND ND 1.2	± ± ±	0.43	105.2	±	6.15	10.7 10.4 8.5	± ± ±	0.44 0.62 0.79	547.6	±	0.20	10.5 20.4 6.2	± ± ±	0.02 0.14 0.17
1-Dec	fourth sampling event	18.0	±	1.05	0.8 1.1 1.5	± ± ±	0.33 0.24 0.15	76.4	±	2.39	11.0 8.5 5.0	± ± ±	0.37 0.05 0.14	254.0	±	1.66	18.7 25.7 48.5	± ± ±	0.81 1.09 1.25
15-Dec	fifth sampling event	35.5	±	1.02	ND 0.2 ND	± ± ±	0.02	97.7	±	1.26	4.6 3.6 7.2	± ± ±	0.32 0.23 0.14	450.0	±	0.43	13.6 13.1 12.9	± ± ±	0.29 0.18 0.73
22-Dec	sixth sampling event	36.6	±	3.44	ND ND ND	± ± ±		59.9	±	3.23	13.2 5.2 4.3	± ± ±	1.13 1.08 0.35	208.0	±	2.30	27.6 18.3 12.4	± ± ±	0.54 1.08 0.76
29-Dec	seventh sampling event	13.5	±	0.48	ND ND ND	± ± ±		59.6	±	4.78	8.7 2.9 3.3	± ± ±	0.79 0.28 0.26	316.0	±	3.47	30.2 33.8 27.5	± ± ±	0.25 1.29 1.17
13-Feb	eighth sampling event		0		ND 0.8	± ±	0.23		0		4.0 5.1	± ±	1.16 1.12		0		64.9 20.5	± ±	1.24 0.32

Table 15: Metals data (μ g/L) for bioretention column 10, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).

								Co	olur	nn 11	L, Ser	ies	4						
				Pł	C						Z	n							
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ± ±		29.6	in ±	0.92	31.7 37.4 49.1	out ± ±	1.58 1.26 1.79	565.7	in ±	2.32	4.3 3.8 2.1	out ± ±	0.36 0.16 0.07
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	13.9 15.8 16.2	± ± ±	0.37 0.12 0.48	147.5	±	0.11	11.4 10.0 2.6	± ± ±	0.22 0.55 0.51
17-Nov	third sampling event	36.3	±	1.42	ND ND 2.8	± ± ±	0.40	105.2	±	6.15	11.5 12.6 16.8	± ± ±	0.24 0.58 0.68	547.6	±	0.20	12.0 15.9 11.8	± ± ±	0.28 0.25 0.09
1-Dec	fourth sampling event	18.0	±	1.05	1.3 1.8 0.7	± ± ±	0.14 0.19 0.12	76.4	±	2.39	8.1 8.6 11.4	± ± ±	0.35 0.26 0.56	254.0	±	1.66	20.0 34.1 21.4	± ± ±	1.43 0.28 0.51
15-Dec	fifth sampling event	35.5	±	1.02	0.1 0.6 0.1	± ± ±	0.09 0.17 0.09	97.7	±	1.26	6.8 11.3 7.2	± ± ±	0.21 0.22 0.98	450.0	±	0.43	17.6 25.5 12.5	± ± ±	1.01 0.27 0.30
22-Dec	sixth sampling event	36.6	±	3.44	ND ND 0.7	± ± ±	0.09	59.9	±	3.23	11.6 9.3 12.0	± ± ±	0.74 0.56 1.05	208.0	±	2.30	31.8 19.3 15.6	± ± ±	0.45 0.76 1.03
29-Dec	seventh sampling event	13.5	±	0.48	ND ND 0.3	± ± ±	0.11	59.6	±	4.78	8.3 8.0 10.7	± ± ±	0.67 0.19 0.82	316.0	±	3.47	43.8 43.0 15.3	± ± ±	0.90 0.95 1.16
13-Feb	eighth sampling event		0		0.5 0.6	± ±	0.10 0.34		0		8.8 9.6	± ±	1.97 2.59		0		109.0 32.1	± ±	0.50 0.21

Table 16: Metals data (μ g/L) for bioretention column 11, mean \pm one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \mu$ g/L).

								Co	lun	nn 12	, Seric	es 4	ł						
				Pł	С				l		Zn	1							
20-Oct	first sampling event	41.9	in ±	3.14	ND ND ND	out ± ± ±	-	29.6	in ±	0.92	27.2 101.0 39.6	out ± ±	1.36 2.73 1.58	565.7	in ±	2.32	7.6 4.7 2.8	out ± ± ±	0.89 0.03 0.04
3-Nov	second sampling event	10.6	±	0.83	ND ND ND	± ± ±		11.1	±	0.07	11.4 14.1 16.6	± ± ±	0.91 0.47 0.74	147.5	±	0.11	12.7 8.0 5.1	± ± ±	0.28 0.13 0.23
17-Nov	third sampling event	36.3	±	1.42	ND ND 2.8	± ± ±	0.40	105.2	±	6.15	8.1 12.6 13.9	± ± ±	0.18 0.24 0.24	547.6	±	0.20	14.9 11.8 10.9	± ± ±	0.07 0.04 0.95
1-Dec	fourth sampling event	18.0	±	1.05	2.5 2.3 1.4	± ± ±	0.30 0.50 0.10	76.4	±	2.39	7.6 6.9 8.2	± ± ±	0.54 0.12 0.21	254.0	±	1.66	22.5 23.2 15.6	± ± ±	6.31 0.14 3.13
15-Dec	fifth sampling event	35.5	±	1.02	0.3 0.7 ND	± ± ±	0.05 0.12	97.7	±	1.26	5.5 7.0 6.9	± ± ±	0.37 0.32 0.56	450.0	±	0.43	15.0 18.7 7.3	± ± ±	0.96 0.13 0.54
22-Dec	sixth sampling event	36.6	±	3.44	ND ND 0.5	± ± ±	0.12	59.9	±	3.23	10.8 8.1 9.0	± ± ±	0.83 0.20 1.10	208.0	±	2.30	26.4 31.9 17.8	± ± ±	0.81 0.57 0.67
29-Dec	seventh sampling event	13.5	±	0.48	ND ND 0.6	± ± ±	0.11	59.6	±	4.78	9.5 6.5 9.6	± ± ±	0.44 0.63 0.41	316.0	±	3.47	37.3 36.6 32.3	± ± ±	0.83 0.54 0.49
13-Feb	eighth sampling event		0		ND 0.5	± ±	0.12		0		4.8 4.7	± ±	1.45 0.55		0		62.8 22.4	± ±	1.03 0.37

Table 17: Metals data (μ g/L) for bioretention column 12, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).

								C	olu	mn 13	, Seri	ies	5						
				Pł	כ					Cı	l					Zn			
20-Oct	first sampling event	34.5	in ±	2.24	ND ND ND	out ± ± ±	:	36.6	in ±	0.79	30.8 20.6 27.8	out ± ± ±	1.36 1.78 1.94	609.2	in ±	1.73	3.8 10.1 6.9	out ± ± ±	0.42 0.66 0.45
3-Nov	second sampling event	6.3	±	0.82	3.7 ND ND	± ± ±		22.1	±	1.55	13.0 13.5 15.0	± ± ±	0.49 0.87 0.61	109.9	±	2.45	38.5 26.2 12.9	± ± ±	0.40 0.38 0.31
17-Nov	third sampling event	24.9	±	1.64	ND ND 2.4	± ± ±	0.77	77.5	±	12.84	12.6 9.1 12.1	± ± ±	0.53 0.55 0.66	478.8	±	1.11	20.1 15.1 13.7	± ± ±	0.34 0.35 0.29
1-Dec	fourth sampling event	8.2	±	0.95	3.4 2.1 2.4	± ± ±	0.31 0.22 0.11	66.1	±	3.04	8.5 5.9 5.7	± ± ±	0.31 0.20 0.14	476.0	±	6.36	37.8 37.6 37.5	± ± ±	3.36 0.42 2.48
15-Dec	fifth sampling event	15.7	±	0.33	ND ND ND	± ± ±		48.6	±	0.83	4.6 3.9 11.3	± ± ±	0.10 0.16 0.11	140.0	±	0.07	24.0 20.7 21.9	± ± ±	0.17 0.24 0.14
22-Dec	sixth sampling event	5.2	±	0.70	ND ND ND	± ± ±		11.7	±	1.74	8.1 5.1 4.5	± ± ±	0.92 0.38 0.36	284.0	±	7.83	42.6 36.8 29.3	± ± ±	2.11 1.06 1.23
29-Dec	seventh sampling event	23.6	±	0.97	ND ND ND	± ± ±		62.2	±	6.17	4.9 3.3 4.5	± ± ±	0.68 0.22 0.19	260.0	±	2.97	48.6 53.5 50.6	± ± ±	0.73 0.06 1.05
13-Feb	eighth sampling event		0		ND 0.2	± ±	0.79		0		4.8 4.8	± ±	1.87 0.46		0		93.0 91.0	± ±	0.75 0.96

Table 18: Metals data (μ g/L) for bioretention column 13, mean \pm one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \mu$ g/L).

								C	olu	mn 14	, Ser	ies	5						
			•	Pł	2		_		•	Ci	u	. .			•	Zr	ו	I	
20-Oct	first sampling event	34.5	in ±	2.24	ND ND ND	out ± ± ±		36.6	ın ±	0.79	45.1 45.9 45.3	out ± ±	1.55 1.37 1.63	609.2	in ±	1.73	2.8 5.0 8.2	out ± ± ±	0.98 0.96 0.36
3-Nov	second sampling event	6.3	±	0.82	ND ND ND	± ± ±		22.1	±	1.55	20.0 21.5 26.6	± ± ±	0.20 2.86 1.36	109.9	±	2.45	11.4 10.4 18.4	± ± ±	3.25 3.11 0.14
17-Nov	third sampling event	24.9	±	1.64	ND ND ND	± ± ±		77.5	±	12.84	19.0 19.8 25.8	± ± ±	0.97 1.39 4.74	478.8	±	1.11	15.7 13.6 20.4	± ± ±	0.65 0.32 0.17
1-Dec	fourth sampling event	8.2	±	0.95	3.1 2.5 3.8	± ± ±	0.29 0.26 0.51	66.1	±	3.04	14.4 15.3 15.1	± ± ±	0.33 0.35 0.74	476.0	±	6.36	68.9 30.1 9.8	± ± ±	1.34 1.48 0.12
15-Dec	fifth sampling event	15.7	±	0.33	ND ND ND	± ± ±		48.6	±	0.83	4.2 11.6 13.9	± ± ±	0.19 0.28 1.11	140.0	±	0.07	31.0 12.4 13.6	± ± ±	2.91 0.32 0.06
22-Dec	sixth sampling event	5.2	±	0.70	ND ND ND	± ± ±		11.7	±	1.74	15.0 16.8 16.1	± ± ±	1.87 0.31 0.17	284.0	±	7.83	45.7 36.5 22.1	± ± ±	0.99 0.58 1.07
29-Dec	seventh sampling event	23.6	±	0.97	ND ND ND	± ± ±		62.2	±	6.17	12.5 12.4 11.9	± ± ±	0.06 0.21 0.20	260.0	±	2.97	38.5 34.0 60.7	± ± ±	0.17 0.20 0.17

Table 19: Metals data (μ g/L) for bioretention column 14, mean \pm one standard deviation of triplicate analyses (ND = nondetectable $\leq 0.09 \ \mu$ g/L).

				Pł	C					Cı	1					Z	n		
			in			out			in			out			in			out	
20-Oct	first sampling event	34.5	±	2.24	ND ND ND	± ± ±		36.6	±	0.79	30.6 28.3 27.0	± ± ±	0.64 0.73 0.84	609.2	±	1.73	2.9 6.2 8.2	± ± ±	0.75 2.66 0.81
3-Nov	second sampling event	6.3	±	0.82	ND ND ND	± ± ±		22.1	±	1.55	16.3 14.3 14.2	± ± ±	0.32 0.35 0.81	109.9 MDI	±	2.45	20.4 11.9 23.3	± ± ±	0.59 0.22 1.16
17-Nov	third sampling event	24.9	±	1.64	ND ND 0.6	± ± ±	0.10	77.5	±	12.84	11.7 11.6 13.8	± ± ±	0.32 0.60 0.50	478.8	±	1.11	13.7 14.4 24.8	± ± ±	0.47 0.45 0.07
1-Dec	fourth sampling event	8.2	±	0.95	1.8 2.3 2.9	± ± ±	0.48 0.92 0.87	66.1	±	3.04	11.9 10.1 9.1	± ± ±	0.23 0.15 0.08	476.0	±	6.36	27.3 34.3 31.8	± ± ±	0.49 1.15 1.48
15-Dec	fifth sampling event	36.6	±	1.94	ND ND ND	± ± ±		48.6	±	0.83	12.4 9.1 7.7	± ± ±	0.30 0.43 0.39	140.0	±	0.07	18.4 17.3 17.6	± ± ±	0.21 0.23 0.14
22-Dec	sixth sampling event	5.2	±	0.70	ND ND ND	± ± ±		11.7	±	1.74	12.0 14.7 11.2	± ± ±	0.40 1.20 0.56	284.0	±	7.83	27.7 31.3 33.8	± ± ±	0.78 0.52 0.89
29-Dec	seventh sampling event	23.6	±	0.97	ND ND ND	± ± ±		62.2	±	6.17	8.6 9.7 9.0	± ± ±	0.23 1.36 0.18	260.0	±	2.97	66.9 72.7 72.2	± ± ±	0.22 0.08 0.56
13-Feb	eighth sampling event		0		ND ND	± ±			0		5.9 5.9	± ±	1.43 1.05		0		74.1 129.0	± ±	1.19 0.80

Table 20: Metals data (μ g/L) for bioretention column 15, mean \pm one standard deviation of triplicate analyses (ND = nondetectable \leq 0.09 μ g/L).
Column 1, Series 1

				NC)⁻₃ - N					PO ³	⁸⁻ 4-P		
			in		5	out			in			out	
20-0ct	first sampling event	0.67	±	0.001	13.53	±	0.153	0.15	±	0.010	0.37	±	0.003
3-Nov	second sampling event	0.39	±	0.008	1.94	±	0.006	0.09	±	0.001	0.83	±	0.002
17-Nov	third sampling event	2.02	±	0.010	9.00	±	0.025	0.46	±	0.001	1.50	±	0.006
1-Dec	fourth sampling event	2.08	±	0.015	6.19	±	0.275	1.12	±	0.000	1.92	±	0.000
15-Dec	fifth sampling event	1.72	±	0.012	4.31	±	0.020	0.62	±	0.014	2.42	±	0.006
22-Dec	sixth sampling event	1.68	±	0.015	6.09	±	0.057	0.51	±	0.006	1.51	±	0.006
29-Dec	seventh sampling event	2.24	±	0.083	4.44	±	0.075	0.52	±	0.002	1.48	±	0.006
13-Feb	eighth sampling event		0		13.10	±	0.008		0		1.14	±	0.006

Table 21: Nutrient data (mg/L) for bioretention column 1, mean \pm one standard deviation of triplicate analyses.

Column 2, Series 1

				NC)⁻₃-N					PO	³⁻ 4-P		
			in			out			in			out	:
20-Oct	first sampling event	0.67	±	0.001	7.41	±	0.051	0.15	±	0.010	0.44	±	0.001
3-Nov	second sampling event	0.39	±	0.008	2.48	±	0.012	0.09	±	0.001	0.34	±	0.004
17-Nov	third sampling event	2.02	±	0.010	10.30	±	0.058	0.46	±	0.001	0.60	±	0.002
1-Dec	fourth sampling event	2.08	±	0.015	13.00	±	0.153	1.12	±	0.000	0.52	±	0.002
15-Dec	fifth sampling event	1.72	±	0.012	8.56	±	0.040	0.62	±	0.014	0.47	±	0.002
22-Dec	sixth sampling event	1.68	±	0.015	6.42	±	0.110	0.51	±	0.006	0.42	±	0.002
29-Dec	seventh sampling event	2.24	±	0.083	6.29	±	0.015	0.52	±	0.002	0.54	±	0.013
13-Feb	eighth sampling event		0		23.00	±	0.208		0		0.38	±	0.010

Table 22: Nutrient data (mg/L) for bioretention column 2, mean \pm one standard deviation of triplicate analyses.

Column 3, Series 1

				NO	з - N					PO ³⁻	4-P		
	c .		in			out			in			out	
20-Oct	first sampling event	0.67	±	0.001	12.47	±	0.116	0.15	±	0.010	0.46	±	0.008
3-Nov	second sampling event	0.39	±	0.008	1.26	±	0.006	0.09	±	0.001	0.91	±	0.001
17-Nov	third sampling event	2.02	±	0.010	7.58	±	0.025	0.46	±	0.001	1.45	±	0.001
1-Dec	fourth sampling event	2.08	±	0.015	7.58	±	0.057	1.12	±	0.000	1.67	±	0.006
15-Dec	fifth sampling event	1.72	±	0.012	7.81	±	0.044	0.62	±	0.014	1.80	±	0.006
22-Dec	sixth sampling event	1.68	±	0.015	5.46	±	0.060	0.51	±	0.006	1.13	±	0.000
29-Dec	seventh sampling event	2.24	±	0.083	5.66	±	0.010	0.52	±	0.002	1.39	±	0.000
13-Feb	eighth sampling event		0		13.30	±	0		0		1.04	±	0.006

Table 23: Nutrient data (mg/L) for bioretention column 3, mean \pm one standard deviation of triplicate analyses.

Column 4, Series 2

				NO	⁻₃ -N					PO ³⁻	4-P		
	firct		In	Ì		out			in			out	:
20-Oct	sampling event	0.67	±	0.0012	8.81	±	0.0379	0.15	±	0.01	0.342	±	0.0046
3-Nov	second sampling event	0.39	±	0.008	2.57	±	0.006	0.087	±	0.0006	0.802	±	0.0006
17-Nov	third sampling event	2.02	±	0.01	8.56	±	0.023	0.462	±	0.001	1.65	±	0
1-Dec	fourth sampling event	2.08	±	0.015	6.39	±	0.062	1.12	±	0	1.95	±	0.0057
15-Dec	fifth sampling event	1.72	±	0.012	1.89	±	0.023	0.619	±	0.014	2.07	±	0.0153
22-Dec	sixth sampling event	1.68	±	0.015	4.76	±	0.015	0.506	±	0.0057	1.18	±	0
29-Dec	seventh sampling event	2.24	±	0.083	7.29	±	0.059	0.515	±	0.002	1.46	±	0
13-Feb	eighth sampling event		0		9.96	±	0.046		0		1.23	±	0.0057

Table 24: Nutrient data (mg/L) for bioretention column 4, mean \pm one standard deviation of triplicate analyses.

Column 5, Series 2

				NO	з - N					PO ³	³⁻ 4-P		
	_		in	1		ou	t		in			out	t
20-Oct	first sampling event	0.67	±	0.001	9.04	±	0.015	0.15	±	0.010	0.30	±	0.023
3-Nov	second sampling event	0.39	±	0.008	2.23	±	0.000	0.09	±	0.001	1.00	±	0.000
17-Nov	third sampling event	2.02	±	0.010	7.57	±	0.012	0.46	±	0.001	1.67	±	0.000
1-Dec	fourth sampling event	2.08	±	0.015	13.10	±	0.058	1.12	±	0.000	2.44	±	0.000
15-Dec	fifth sampling event	1.72	±	0.012	3.73	±	0.006	0.62	±	0.014	2.45	±	0.006
22-Dec	sixth sampling event	1.68	±	0.015	6.98	±	0.055	0.51	±	0.006	1.20	±	0.006
29-Dec	seventh sampling event	2.24	±	0.083	4.87	±	0.012	0.52	±	0.002	1.83	±	0.000
13-Feb	eighth sampling event		0		21.00	±	0.115		0		0.71	±	0.012

Table 25: Nutrient data (mg/L) for bioretention column 5, mean \pm one standard deviation of triplicate analyses.

Column 6, Series 2

				NC)⁻₃-N					PO ³	³⁻ ₄-P		
			in		5	out			in		·	out	:
20-0ct	first sampling event	0.67	±	0.001	11.33	±	0.058	0.15	±	0.010	0.27	±	0.001
3-Nov	second sampling event	0.39	±	0.008	2.30	±	0.006	0.09	±	0.001	0.61	±	0.003
17-Nov	third sampling event	2.02	±	0.010	4.94	±	0.015	0.46	±	0.001	1.53	±	0.000
1-Dec	fourth sampling event	2.08	±	0.015	9.32	±	0.060	1.12	±	0.000	2.20	±	0.006
15-Dec	fifth sampling event	1.72	±	0.012	7.92	±	0.035	0.62	±	0.014	2.22	±	0.000
22-Dec	sixth sampling event	1.68	±	0.015	5.18	±	0.000	0.51	±	0.006	1.47	±	0.021
29-Dec	seventh sampling event	2.24	±	0.083	7.68	±	0.012	0.52	±	0.002	1.78	±	0.000
13-Feb	eighth sampling event		0		21.60	±	0.115		0		1.20	±	0.026

Table 26: Nutrient data (mg/L) for bioretention column 6, mean \pm one standard deviation of triplicate analyses.

Column 7, Series 3

				NC)⁻₃-N					PO	³⁻ 4-P		
	_		in			out			in			out	
20-Oct	first sampling event	0.38	±	0.021	0.84	±	0.001	0.07	±	0.005	0.51	±	0.005
3-Nov	second sampling event	0.37	±	0.001	0.63	±	0.002	0.09	±	0.000	1.07	±	0.000
17-Nov	third sampling event	2.36	±	0.006	3.81	±	0.006	0.56	±	0.002	1.75	±	0.006
1-Dec	fourth sampling event	2.03	±	0.010	5.80	±	0.042	0.48	±	0.001	1.61	±	0.000
15-Dec	fifth sampling event	2.34	±	0.022	0.94	±	0.022	0.74	±	0.003	2.19	±	0.006
22-Dec	sixth sampling event	1.71	±	0.021	0.70	±	0.276	0.52	±	0.004	2.32	±	0.006
29-Dec	seventh sampling event	1.90	±	0.029	1.77	±	0.104	0.46	±	0.002	1.87	±	0.000
13-Feb	eighth sampling event		0		11.30	±	0.100		0		0.64	±	0.004

Table 27: Nutrient data (mg/L) for bioretention column 7, mean \pm one standard deviation of triplicate analyses.

Column 8, Series 3

				NO	⁻ ₃-N					PO ³	³⁻ ₄-P		
			in		-	out	t		in			out	:
20-0ct	first sampling event	0.38	±	0.021	2.23	±	0.040	0.07	±	0.005	0.27	±	0.003
3-Nov	second sampling event	0.37	±	0.001	1.45	±	0.006	0.09	±	0.000	1.31	±	0.000
17-Nov	third sampling event	2.36	±	0.006	4.13	±	0.006	0.56	±	0.002	2.36	±	0.006
1-Dec	fourth sampling event	2.03	±	0.010	5.43	±	0.067	0.48	±	0.001	2.57	±	0.006
15-Dec	fifth sampling event	2.34	±	0.022	5.65	±	0.000	0.74	±	0.003	2.26	±	0.000
22-Dec	sixth sampling event	1.71	±	0.021	1.15	±	0.010	0.52	±	0.004	2.47	±	0.012
29-Dec	seventh sampling event	1.90	±	0.029	8.24	±	0.015	0.46	±	0.002	1.48	±	0.006
13-Feb	eighth sampling event		0		7.48	±	0.042		0		0.69	±	0.031

Table 28: Nutrient data (mg/L) for bioretention column 8, mean \pm one standard deviation of triplicate analyses.

Column 9, Series 3

		$\begin{array}{c ccccccccccccccccccccccccccccccccccc$)⁻₃-N					PO	³⁻ 4-P		
		in 0.38 ± 0.0 0.37 ± 0.0				out			in			out	:
20-Oct	first sampling event	0.38	±	0.021	1.86	±	0.023	0.07	±	0.005	0.40	±	0.017
3-Nov	second sampling event	0.37	±	0.001	0.57	±	0.000	0.09	±	0.000	0.36	±	0.001
17-Nov	third sampling event	2.36	±	0.006	2.68	±	0.006	0.56	±	0.002	0.87	±	0.014
1-Dec	fourth sampling event	2.03	±	0.010	9.67	±	0.049	0.48	±	0.001	0.70	±	0.002
15-Dec	fifth sampling event	2.34	±	0.022	1.65	±	0.012	0.74	±	0.003	1.47	±	0.000
22-Dec	sixth sampling event	1.71	±	0.021	0.87	±	0.001	0.52	±	0.004	1.01	±	0.000
29-Dec	seventh sampling event	1.90	±	0.029	1.07	±	0.006	0.46	±	0.002	0.91	±	0.002
13-Feb	eighth sampling event		0		22.80	±	0.058		0		0.81	±	0.017

Table 29: Nutrient data (mg/L) for bioretention column 9, mean \pm one standard deviation of triplicate analyses.

Column 10, Series 4

				NC)⁻₃-N					PO	³⁻ 4-P		
			in			out			in			out	:
20-Oct	first sampling event	0.38	±	0.021	1.07	±	0.006	0.07	±	0.005	0.73	±	0.008
3-Nov	second sampling event	0.37	±	0.001	1.41	±	0.006	0.09	±	0.000	1.16	±	0.000
17-Nov	third sampling event	2.36	±	0.006	1.09	±	0.006	0.56	±	0.002	1.43	±	0.000
1-Dec	fourth sampling event	2.03	±	0.010	9.59	±	0.090	0.48	±	0.001	1.26	±	0.006
15-Dec	fifth sampling event	2.34	±	0.022	0.88	±	0.008	0.74	±	0.003	1.65	±	0.000
22-Dec	sixth sampling event	1.71	±	0.021	0.78	±	0.001	0.52	±	0.004	1.27	±	0.000
29-Dec	seventh sampling event	1.90	±	0.029	0.86	±	0.002	0.46	±	0.002	1.20	±	0.000
13-Feb	eighth sampling event		0		39.40	±	0.503		0		0.13	±	0.014

Table 30: Nutrient data (mg/L) for bioretention column 10, mean \pm one standard deviation of triplicate analyses.

Column 11, Series 4

				NC)⁻₃ - N					PO	³⁻ 4-P		
			in			out			in			out	:
20-Oct	first sampling event	0.38	±	0.021	1.78	±	0.023	0.07	±	0.005	0.96	±	0.004
3-Nov	second sampling event	0.37	±	0.001	1.22	±	0.000	0.09	±	0.000	0.39	±	0.010
17-Nov	third sampling event	2.36	±	0.006	5.25	±	0.010	0.56	±	0.002	0.56	±	0.000
1-Dec	fourth sampling event	2.03	±	0.010	21.80	±	0.153	0.48	±	0.001	0.43	±	0.003
15-Dec	fifth sampling event	2.34	±	0.022	3.49	±	0.035	0.74	±	0.003	0.59	±	0.013
22-Dec	sixth sampling event	1.71	±	0.021	1.56	±	0.025	0.52	±	0.004	0.42	±	0.032
29-Dec	seventh sampling event	1.90	±	0.029	1.64	±	0.000	0.46	±	0.002	0.45	±	0.001
13-Feb	eighth sampling event		0		47.20	±	1.800		0		0.32	±	0.012

Table 31: Nutrient data (mg/L) for bioretention column 11, mean \pm one standard deviation of triplicate analyses.

Column 12, Series 4

				NC)⁻ ₃ -N					PO	³⁻ 4-P		
	a .		in			out			in			out	:
20-Oct	first sampling event	0.38	±	0.021	1.41	±	0.000	0.07	±	0.005	0.35	±	0.016
3-Nov	second sampling event	0.37	±	0.001	0.59	±	0.002	0.09	±	0.000	0.48	±	0.002
17-Nov	third sampling event	2.36	±	0.006	4.40	±	0.012	0.56	±	0.002	1.48	±	0.000
1-Dec	fourth sampling event	2.03	±	0.010	14.30	±	0.321	0.48	±	0.001	0.88	±	0.001
15-Dec	fifth sampling event	2.34	±	0.022	0.60	±	0.012	0.74	±	0.003	2.47	±	0.000
22-Dec	sixth sampling event	1.71	±	0.021	0.55	±	0.010	0.52	±	0.004	2.42	±	0.000
29-Dec	seventh sampling event	1.90	±	0.029	0.60	±	0.004	0.46	±	0.002	2.29	±	0.000
13-Feb	eighth sampling event		0		47.00	±	2.300		0		0.29	±	0.003

Table 32: Nutrient data (mg/L) for bioretention column 12, mean \pm one standard deviation of triplicate analyses.

Column 13, Series 5

				NO	_з -N					PO ³	³⁻ 4-P		
			in			out	t		in			out	:
20-Oct	first sampling event	0.54	±	0.008	0.88	±	0.003	0.10	±	0.027	0.59	±	0.003
3-Nov	second sampling event	0.42	±	0.001	0.72	±	0.002	0.09	±	0.000	0.72	±	0.001
17-Nov	third sampling event	1.74	±	0.006	1.02	±	0.006	0.49	±	0.002	1.05	±	0.006
1-Dec	fourth sampling event	1.96	±	0.017	0.61	±	0.008	0.52	±	0.001	1.41	±	0.000
15-Dec	fifth sampling event	1.68	±	0.023	0.85	±	0.004	0.67	±	0.002	1.75	±	0.000
22-Dec	sixth sampling event	1.12	±	0.006	0.31	±	0.008	0.90	±	0.002	1.39	±	0.006
29-Dec	seventh sampling event	2.14	±	0.035	0.34	±	0.017	0.63	±	0.001	1.71	±	0.006
13-Feb	eighth sampling event		0		6.18	±	0.021		0		0.45	±	0.009

Table 33: Nutrient data (mg/L) for bioretention column 13, mean \pm one standard deviation of triplicate analyses.

Column 14, Series 5

				NO	_з -N					PO ³	³⁻ ₄-P		
	_		in			out	t		in			out	:
20-Oct	first sampling event	0.54	±	0.008	2.53	±	0.015	0.10	±	0.027	0.31	±	0.002
3-Nov	second sampling event	0.42	±	0.001	3.52	±	0.055	0.09	±	0.000	0.23	±	0.001
17-Nov	third sampling event	1.74	±	0.006	2.21	±	0.010	0.49	±	0.002	0.27	±	0.001
1-Dec	fourth sampling event	1.96	±	0.017	1.59	±	0.010	0.52	±	0.001	0.33	±	0.000
15-Dec	fifth sampling event	1.68	±	0.023	1.30	±	0.006	0.67	±	0.002	0.30	±	0.016
22-Dec	sixth sampling event	1.12	±	0.006	1.96	±	0.000	0.90	±	0.002	0.21	±	0.001
29-Dec	seventh sampling event	2.14	±	0.035	0.98	±	0.006	0.63	±	0.001	0.26	±	0.001

Table 34: Nutrient data (mg/L) for bioretention column 14, mean \pm one standard deviation of triplicate analyses.

Column 15, Series 5

				NO	3 -N					PO ³	4-P		
			in			ou	t		in			out	:
20-Oct	first sampling event	0.54	±	0.008	1.07	±	0.021	0.10	±	0.027	0.45	±	0.006
3-Nov	second sampling event	0.42	±	0.001	2.49	±	0.006	0.09	±	0.000	0.52	±	0.001
17-Nov	third sampling event	1.74	±	0.006	2.47	±	0.015	0.49	±	0.002	0.48	±	0.002
1-Dec	fourth sampling event	1.96	±	0.017	1.41	±	0.006	0.52	±	0.001	0.66	±	0.002
15-Dec	fifth sampling event	1.68	±	0.023	0.88	±	0.004	0.67	±	0.002	0.63	±	0.002
22-Dec	sixth sampling event	1.12	±	0.006	0.52	±	0.003	0.90	±	0.002	1.16	±	0.000
29-Dec	seventh sampling event	2.14	±	0.035	0.57	±	0.006	0.63	±	0.001	0.58	±	0.001
13-Feb	eighth sampling event		0		1.35	±	0.058		0		0.76	±	0.019

Table 35: Nutrient data (mg/L) for bioretention column 15, mean \pm one standard deviation of triplicate analyses.

Averages (µg/L)	
Series 1 Series 2 Series 3 Series 3	eries 4 Series 5
in out out in out o	out in out
U < 0.1 < 0.1 < 0.1 < 0.1	< 0.1 < 0.1
$36.1 \pm 1.33 < 0.1 < 0.1$	< 0.1 34.5 ± 2.24 < 0.1
< 0.1 < 0.1 < 0.1	< 0.1 < 0.1
	< 0.1 3.7 + 0.00
2 8.1 ± 0.74 < 0.1 < 0.1 10.6 ± 0.83 < 0.1	6.3 \pm 0.82 < 0.1
	< 0.1 < 0.1
> < 0.1 < 0.1 < 0.1 <	< 0.1 < 0.1
$\frac{2}{5}$ 24.6 ± 0.96 < 0.1 < 0.1 36.3 ± 1.42 < 0.1 <	< 0.1 24.9 ± 1.64 < 0.1
(-1) < 0.1 0.8 ± 0.31 4.6 ± 3.78 2.3	± 0.92 1.5 ± 1.27
3.1 ± 1.94 2.3 ± 0.32 2.6 ± 0.78 1.5	± 0.87 2.8 ± 0.85
\vec{P} 18.2 ± 0.36 2.0 ± 0.15 2.4 ± 0.44 18.0 ± 1.05 2.1 ± 0.79 1.7	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
2.0 ± 0.25 3.1 ± 1.33 2.4 ± 0.75 1.2	± 0.44 3.0 ± 0.71
	+
$0.4 \pm 0.17 = 0.4 \pm 0.21$ 0.4 ± 0.21 $1.0 \pm 0.47 = 0.2$	+ 0.14 < 0.1 + 0.26 15.7 + 0.33
$30.0 \pm 1.54 0.9 \pm 0.35 0.4 \pm 0.26$ $35.3 \pm 1.02 1.0 \pm 0.31 0.5 = 0.4$	± 0.26
$0.9 \pm 0.23 = 0.4 \pm 0.12 = 0.2 \pm 0.10 = 0.1 = 0.1$	- 0.00 < 0.1
y 0.2 ± 0.00 < 0.1 < 0.1	< 0.1 < 0.1
$\tilde{\Theta}$ 29.2 ± 0.57 0.3 ± 0.21 < 0.1 36.6 ± 3.44 < 0.1 <	< 0.1 5.2 ± 0.70 < 0.1
\sim 2.5 ± 2.39 0.1 ± 0.00 3.3 ± 0.92 0.6	± 0.14 < 0.1
v < 0.1 < 0.1 < 0.1 <	< 0.1 < 0.1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	< 0.1 23.6 ± 0.97 < 0.1
$^{\circ} 0.5 \pm 0.07 0.4 \pm 0.15 \qquad 1.0 \pm 0.46 0.5 \pm 0.5 \pm 0.5 \pm 0.15 \qquad 0.5 \pm 0.15 0.5 $	± 0.21 < 0.1
⊕ 0.9 ± 0.57 0.4 ± 0.00 0.8 ± 0.00 0.5 ±	± 0.00 < 0.1
\dot{n} 03 ± 0.14 < 0.1 05 ± 0.57 0.6	+ 0.15 0.2 + 0.00

Table 36: Table showing the averages of the three samples from the three columns in each of the five series for lead.

											Ave	Cu crages (ua/L)											
				Se	eries	1		Serie	es 2			. ages (Se	ries	3	5	erie	s 4				S	eries	5
		in			out		1	ou	t		in			out			out			in			out	
t				18.8	±	6.12	21	.7 ±	1.46				19.4	±	1.79	26.6	±	5.48				35.5	±	8.31
0-0	69.7	±	3.05	23.7	±	3.83	16	.8 ±	2.34	29.6	±	0.92	16.3	±	4.50	53.1	±	42.26	36.6	±	0.79	31.6	±	12.97
2				20.3	±	4.09	16	.4 ±	3.82				17.6	±	3.41	38.3	±	11.45				33.4	±	10.34
,				14.1	±	1.39	10	.5 ±	1.10				8.8	±	0.25	11.8	±	1.98				16.4	±	3.50
-Nov	10.2	±	0.76	11.7	±	1.38	12	.3 ±	1.85	11.1	±	0.07	9.4	±	2.02	13.2	±	3.20	22.1	±	1.55	16.4	±	4.41
ò				10.4	±	1.76	11	.4 ±	0.93				10.1	±	3.06	14.7	±	3.01				18.6	±	6.94
				47.0											0.50			4 70						
Νον	85.8	+	13 07	17.9	±	2.31	10	./ ±	0.95	105 2	+	6 15	7.0	±	0.58	10.1	±	1.78	77 5	+	12 84	14.4	±	3.98
17-	05.0	-	15.07	12.6	±	2.81	14	·./ ±	0.85	105.2	-	0.15	/./	±	1.85	11.9	±	1.27	//.5	-	12.04	13.5	±	5.60
				11.4	т	2.35	14	.0 I	1.45				9.0	т	5.00	15.1	т	4.21				17.2	т	/.4/
Ŋ				12.4	±	2.41	9	.0 ±	0.36				7.1	±	0.58	8.9	±	1.84				11.6	±	2.96
1-De	64.8	±	1.59	11.7	±	1.88	9	.4 ±	0.68	76.4	±	2.39	6.9	±	0.12	8.0	±	0.95	66.1	±	3.04	10.4	±	4.71
				11.1	±	1.80	9	.0 ±	1.52				6.8	±	0.58	8.2	±	3.20				10.0	±	4.76
U				99	+	1 41	9	6 ±	1 15				58	±	0.87	5.6	±	1 11				71	±	4 62
-De	68.9	±	0.48	9.6	- +	2.10	6	.9 ±	1.10	97.7	±	1.26	5.9	±	0.40	7.3	±	3.86	48.6	±	0.83	8.2	±	3.93
15				8.6	±	1.70	6	.5 ±	0.57				7.4	±	1.91	7.1	±	0.17				11.0	±	3.11
Dec	~~ ~		4 07	9.7	±	1.45	12	.0 ±	0.58			2 22	8.5	±	1.50	11.9	±	1.22				11.7	±	3.46
22-I	60.6	±	1.37	9.8	±	1.50	12	.0 ±	1.44	59.9	±	3.23	6.2	±	0.23	7.5	±	2.11	11./	±	1.74	12.2	±	6.24
				10.0	±	0.95	10	.3 ±	1.46				7.7	±	0.98	8.4	±	3.88				10.6	±	5.82
Sec				11.7	±	1.72	8	.3 ±	1.31				5.8	±	1.56	8.8	±	0.61				8.7	±	3.80
9-D	65.0	±	3.60	9.2	±	1.82	7	5 ±	0.80	59.6	±	4.78	5.5	±	0.29	5.8	±	2.62	62.2	±	6.17	8.5	±	4.67
2				9.4	±	3.47	6	2 ±	1.00				6.6	±	0.00	7.9	±	3.99				8.5	±	3.73
3-Fet		0		8.4	±	1.65	8	9 ±	5.67		0		4.5	±	0.35	5.9	±	2.57		0		5.4	±	0.78
13				6.9	±	1.08	5	.4 ±	0.26				4.9	±	0.85	6.5	±	2.72				5.4	±	0.78

Table 37: Table showing the averages of the three samples from the three columns in each of the five series for copper.

												Ave	Zn rages (j	n/L)											
				S	erie	51		S	eries	2		/	ruges (r	.g/ _) S	eries	3	S	eries	; 4				s	eries	5
		in			out				out			in			out			out			in			out	
t				7.6	±	4.63		4.2	±	1.78				4.8	±	0.67	4.2	±	3.44				3.2	±	0.53
20-C	533.5	±	0.91	5.6	±	2.59		5.5	±	2.58	565.7	±	2.32	3.6	±	1.02	5.1	±	1.60	609.2	±	1.73	7.1	±	2.64
				2.8	±	1.40		2.5	±	1.13				2.1	±	0.71	2.2	±	0.50				7.8	±	0.75
				26.4		2.01		<u> 0</u>		1 02				10.1		1 20	10.0		12.40				<u>ээ г</u>		12.01
Nov	217.1	÷	0 71	20.4	±	3.81	ſ,	22.8	±	1.02	147.5	±	0 1 1	10.1	±	1.28	19.8	Ŧ	13.48	109.9	+	2 45	16.2	±	13.81
3-1		_	017 1	2 Q	т +	2.09		7. 4 10.3	т +	2.12			0111	5./ 3.3	т +	2.09	9.5 3.4	т +	1.52	20010	_	2115	10.2	т +	0.74 5.21
				5.0	Ŧ	1.91		10.5	т	9.00				5.5	-	1.91	J.7	т	1.77				10.2	-	J.21
2				12.1	±	0.95		15.3	±	1.81				12.2	±	2.66	12.5	±	2.20				16.5	±	3.29
7-N	508.2	±	0.40	8.5	±	1.17		9.6	±	0.71	547.6	±	0.20	6.5	±	1.78	16.0	±	4.33	478.8	±	1.11	14.4	±	0.74
1				8.5	±	2.66		8.1	±	2.28				7.8	±	2.45	9.6	±	3.01				19.6	±	5.59
Jec	E24 0	+	2 55	86.0	±	81.05		34.8	±	6.80	254.0	+	1 66	16.7	±	2.34	20.4	±	1.93	476.0	+	6 36	44./	±	21.63
1-1	524.0	Ŧ	2.55	18.7	±	1.75	•	21.8	±	0.55	254.0	т	1.00	19.8	±	3.92	27.7	±	5./1	470.0	Т	0.50	34.0	±	3.76
				3.9	±	1.45		7.2	±	2.51				10.3	±	4.52	28.5	±	17.56				26.4	±	14.63
Ŋ				20.8	±	4.23		25.2	±	13.75				13.1	±	1.10	15.4	±	2.03				24.5	±	6.31
5-De	120.0	±	0.01	10.2	±	1.80		11.7	±	0.90	450.0	±	0.43	11.9	±	3.63	19.1	±	6.21	140.0	±	0.07	16.8	±	4.17
1				4.3	±	1.80		5.2	±	0.82				4.4	±	1.85	10.9	±	3.12				17.7	±	4.15
Dec	226.0		2.25	32.1	±	20.35		21.8	±	3.84	202.0		2 20	20.1	±	3.18	28.6	±	2.84	204.0		7 0 2	38.7	±	9.62
22-I	226.0	Ŧ	3.35	12.1	±	9.32		8.0	±	1.80	208.0	Ŧ	2.30	21.7	±	8.30	23.2	±	7.58	284.0	Ŧ	7.83	34.9	±	3.09
				5.8	±	4.71		2.8	±	2.18				14.8	±	3.91	15.3	±	2.72				28.4	±	5.90
U				73.3	±	10.33		57.2	±	3.20				43.8	±	15.45	37.1	±	6.80				51.3	±	14.40
)-De	338.0	±	0.56	55.1	±	13.97		45.5	±	16.96	316.0	±	3.47	41.8	±	20.11	37.8	±	4.72	260.0	±	2.97	53.4	±	19.35
20				23.1	±	7.71		18.4	±	3.40				16.8	±	0.57	25.0	±	8.76				61.2	±	10.81
Feb		•		31.6	±	13.36		27.1	±	8.72		•		39.6	±	14.00	78.9	±	26.09		~		83.6	±	13.36
13-ŀ		U		17.1		2 51		10 7		0 55		U		20 F		6 50	25.0		6.22		U		110.0		26.07
				13.1	±	2.51		10./	±	0.55				20.5	±	0.50	25.0	±	0.22				110.0	Ŧ	/۵.۵

Table 38: Table showing the averages of the three samples from the three columns in each of the five series for zinc.

								Ν	IO⁻₃-N									
				_			_	Avera	ges (mg	/L)	-			_				
		Se	eries	51	Se	eries	52		Se	ries	3	Se	eries	5 4		Serie	es 5	
	in		out			out		in		out			out		in		out	
20-Oct	0.67	11.14	±	3.270	9.73	±	1.393	0.38	1.64	±	0.720	1.42	±	0.355	0.54	1.49	±	0.903
3-Nov	0.39	1.89	±	0.611	2.37	±	0.180	 0.37	0.88	±	0.493	1.07	±	0.429	0.42	2.24	±	1.416
17-Nov	2.02	8.96	±	1.360	7.02	±	1.871	2.36	3.54	±	0.762	3.58	±	2.198	1.74	1.90	±	0.773
1-Dec	2.08	8.92	±	3.598	9.60	±	3.364	 2.03	6.97	±	2.348	15.23	±	6.158	1.96	1.20	±	0.523
15-Dec	1.72	6.89	±	2.268	4.51	±	3.090	 2.34	2.75	±	2.538	1.65	±	1.596	1.68	1.01	±	0.253
22-Dec	1.68	5.99	±	0.488	5.64	±	1.179	 1.71	0.91	±	0.226	0.96	±	0.531	1.12	0.93	±	0.899
29-Dec	2.24	5.46	±	0.941	6.61	±	1.522	1.90	3.69	±	3.953	1.03	±	0.543	2.14	0.63	±	0.324
13-Feb	0.00	16.47	±	5.659	17.52	±	6.554	0.00	13.86	±	7.974	44.53	±	4.447	0.00	3.77	±	3.415

Table 39: Table showing the averages for the three columns in each of the five series for nitrate.

									PC) ³⁻ 4-P											
				-					_Average	es (mg/	L)							_			
		S	erie	s 1		Sei	ries 2			S	erie	s 3		S	erie	s 4			S	erie	s 5
	in out out in out out out															in		out			
20-Oct	0.15	0.42	±	0.049	0.3	3	± 0.0)37	0.07	0.39	±	0.119		0.68	±	0.309		0.10	0.45	±	0.141
3-Nov	0.09	0.69	±	0.31	0.8	1	± 0.1	193	0.09	0.91	±	0.493		0.68	±	0.42		0.09	0.49	±	0.245
17-Nov	0.46	1.18	±	0.504	1.6	2	± 0.0)76	0.56	1.66	±	0.749		1.16	±	0.516		0.49	0.6	±	0.404
1-Dec	1.12	1.37	±	0.746	2.2	2	± 0.2	245	0.48	1.63	±	0.933		0.85	±	0.418		0.52	0.8	±	0.552
15-Dec	0.62	1.56	±	0.998	2.2	5	± 0.1	191	0.74	1.97	±	0.437		1.57	±	0.944		0.67	0.89	±	0.761
22-Dec	0.51	1.02	±	0.556	1.2	8	± 0.1	162	0.52	1.93	±	0.803		1.37	±	1.004		0.90	0.92	±	0.623
29-Dec	0.52	1.14	±	0.519	1.6	9	± 0.2	201	0.46	1.42	±	0.481		1.31	±	0.924		0.63	0.85	±	0.762
13-Feb	0.00	0.85	±	0.414	1.0	5	± 0.2	295	0.00	0.71	±	0.09		0.25	±	0.102		0.00	0.61	±	0.221

Table 40: Table showing the averages for the three columns in each of the five series for phosphate.

							lea	d (µg	J/mL)									
		inpu	ıt	9	Serie	s 1	9	Serie	s 2	9	Serie	s 3	9	Serie	s 4	9	Serie	s 5
20-Oct	$ \begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$				< 0	.1		< 0	.1		< 0	.1		< 0.	1		< 0.	1
3-Nov	8.3	±	2.16		< 0.1 < 0.1 < 0.1			< 0	.1		< 0	.1		< 0.	1	1.2	±	2.13
17-Nov	28.6	±	6.67		< 0.1 < 0.1 2.4 ± 0.60			±	0.18	1.5	±	2.68	0.8	±	1.31	0.5	±	0.87
1-Dec	14.8	±	5.72	2.4	±	0.60	2.6	±	0.41	2.4	±	0.25	1.5	±	0.27	2.7	±	0.37
15-Dec	29.3	±	11.76	0.7	±	0.29	0.4	±	0.03	0.7	±	0.46	0.3	±	0.21		< 0.	.1
22-Dec	23.7	±	16.42	1.0	±	1.30		< 0	.1	1.1	±	1.91	0.2	±	0.35		< 0.	1
29-Dec	15.5	±	7.31	0.4	0.4 ± 0.11		0.3	±	0.02	0.4	±	0.54	0.2	±	0.26		< 0.	.1
13-Feb	0.0	±	0.00	$\begin{array}{rrrrr} 0.4 & \pm & 0.11 \\ 0.6 & \pm & 0.42 \end{array}$			0.2	±	0.28	0.7	±	0.21	0.6	±	0.09	0.1	±	0.14

Table 41: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the five series for lead.

							C	oppe	er (µg/L)								
Date		inpu	ut	S	eries	; 1	S	eries	; 2	S	eries	; 3	9	Serie	s 4	S	eries	5
20-Oct	45.3	±	21.42	20.9	±	2.52	18.3	±	2.99	17.8	±	1.58	39.3	±	13.31	33.5	±	1.95
3-Nov	14.5	±	6.63	12.1	±	1.87	11.4	±	0.87	9.4	±	0.63	13.2	±	1.45	17.2	±	1.25
17-Nov	89.5	±	14.22	14.0	±	3.46	13.3	±	2.28	7.9	±	1.02	11.7	±	1.49	15.1	±	1.94
1-Dec	69.1	±	6.36	11.8	±	0.67	9.1	±	0.20	6.9	±	0.16	8.4	±	0.47	10.7	±	0.84
15-Dec	71.7	±	24.67	9.4	±	0.68	7.6	±	1.71	6.4	±	0.91	6.7	±	0.91	8.7	±	2.01
22-Dec	44.1	±	28.03	9.8	±	0.15	11.4	±	0.99	7.5	±	1.17	9.3	±	2.29	11.5	±	0.82
29-Dec	62.3	±	2.70	10.1	±	1.38	7.3	±	1.07	6.0	±	0.58	7.5	±	1.55	8.5	±	0.12
13-Feb	0.0	±	0.00	7.6	±	1.04	7.1	±	2.45	4.7	±	0.26	6.2	±	0.42	5.4	±	0.00

Table 42: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the series for copper.

							:	zinc	(µg/L)									
Date		inpı	ıt	S	Serie	s 1	5	Serie	s 2	5	Serie	s 3	S	Serie	s 4	S	Serie	s 5
20-Oct	569.5	±	37.99	5.3	±	2.44	4.1	±	1.50	3.5	±	1.33	3.9	±	1.49	6.0	±	2.50
3-Nov	158.2	±	54.39	13.7	±	11.54	13.5	±	8.20	6.3	±	3.47	10.9	±	8.27	19.3	±	3.75
17-Nov	511.5	±	34.52	9.7	±	2.08	11.0	±	3.80	8.8	±	2.96	12.7	±	3.21	16.8	±	2.65
1-Dec	418.0	±	144.04	36.2	±	43.78	21.3	±	13.81	15.6	±	4.85	25.5	±	4.46	35.0	±	9.19
15-Dec	236.7	±	185.02	11.8	±	8.38	14.0	±	10.20	9.8	±	4.72	15.1	±	4.11	19.7	±	4.19
22-Dec	239.3	±	39.72	16.7	±	13.73	10.9	±	9.78	18.9	±	3.64	22.3	±	6.70	34.0	±	5.19
29-Dec	304.7	±	40.22	50.5	±	25.42	40.4	±	19.90	34.1	±	15.06	33.3	±	7.18	55.3	±	5.18
13-Feb	0.0	±	0.00	22.4	±	13.13	18.9	±	11.60	30.1	±	13.51	52.0	±	38.11	96.8	±	18.70

Table 43: Table showing the averages of the averages of the first, second, and third samples combined for the columns in each of the five series for zinc.

	ANOVA Test	for the	three sam	ples of	the three c	olumns	within eac	h of th	e five series	s: lead	
Sample	F	Se	ries One	Se	ries Two	Ser	ies Three	Sei	ries Four	Sei	ries Five
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-Oct		-	-	-	-	-	-	-	-	-	_
3-Nov		-	_	-	_	-	-	-	-	-	_
17-Nov		-	_	-	_	-	-	-	_	-	-
1-Dec	5.14	0.83	0.480	0.72	0.526	0.31	0.743	0.50	0.632	0.98	0.429
15-Dec		3.68	0.091	0.08	0.925	5.91	0.038	4.96	0.054	-	_
22-Dec		2.73	0.143	-	_	-	-	-	-	-	_
29-Dec		2.29	0.182	3.06	0.121	9.06	0.015	l –		_	
13-Feb	7.71	1.21	0.333	-	_	0.01	0.930	_	_	-	_

Table 44: Analysis of variance (ANOVA) tests to see whether or not the three sample results (concentration) from each column for each sampling event could be combined into one sample result for lead, for each of the fifteen columns, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

ANOVA Test for the three samples of the three columns within each of the five series: copper											
Sample	F	Series One		Ser	ies Two	Ser	ies Three	Ser	ies Four	Series Five	
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-Oct		0.83	0.480	3.63	0.093	0.64	0.561	0.82	0.485	0.10	0.907
3-Nov		4.52	0.064	1.23	0.357	0.25	0.783	0.82	0.486	0.18	0.842
17-Nov		5.74	0.040	12.58	0.007	0.74	0.517	0.89	0.459	0.33	0.731
1-Dec	5.14	0.32	0.739	0.13	0.882	0.36	0.713	0.14	0.873	0.12	0.890
15-Dec		0.44	0.662	9.16	0.015	1.62	0.273	0.46	0.651	0.78	0.500
22-Dec		0.04	0.962	1.95	0.223	3.80	0.086	2.24	0.188	0.07	0.932
29-Dec		0.94	0.442	3.10	0.119	1.21	0.361	0.93	0.444	0.00	0.998
13-Feb	7.71	1.66	0.267	1.12	0.350	0.48	0.527	0.08	0.795	0.20	0.677

Table 45: Analysis of variance (ANOVA) test to see whether or not the three sample results (concentration) from each column for each sampling event could be combined into one sample result for copper, for each of the fifteen columns, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

	ANOVA Test for the three samples of the three columns within each of the five series: zinc											
Sample	F	Ser	ies One	Seri	ies Two	Serie	es Three	Seri	ies Four	Series Five		
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	
20-Oct		1.77	0.248	1.81	0.242	8.01	0.020	1.37	0.324	7.17	0.026	
3-Nov		45.13	2.4E-04	6.10	0.036	11.22	0.009	3.32	0.107	0.43	0.668	
17-Nov		4.18	0.073	14.41	0.005	4.84	0.056	2.84	0.136	1.48	0.300	
1-Dec	5.14	2.62	0.152	32.46	0.001	5.13	0.050	0.52	0.620	1.09	0.394	
15-Dec		25.89	0.001	4.91	0.055	11.26	0.009	2.89	0.132	2.12	0.201	
22-Dec		3.24	0.111	37.82	4.0E-04	1.26	0.348	5.55	0.043	1.77	0.249	
29-Dec		16.09	0.004	11.52	0.009	3.17	0.115	3.19	0.114	0.35	0.721	
13-Feb	7.71	5.60	0.077	10.57	0.031	4.59	0.099	12.12	0.025	1.55	0.339	

Table 46: Analysis of variance (ANOVA) test to see whether or not the three sample results (concentration) from each column for each sampling event could be combined into one sample result for zinc, for each of the fifteen columns, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

	ANOVA Test for the three columns within each of the five series: lead											
Sample	F	Series One		Se	Series Two		Series Three		Series Four		Series Five	
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	
20-Oct		-	-	-	-	-	-	-	-	-	_	
3-Nov		-	_	-	-	-	-	-	-	_	_	
17-Nov		-	_	-	_	-	_	-	-	_	-	
1-Dec	5.14	1.36	0.326	1.40	0.318	7.24	0.025	2.98	0.126	1.24	0.355	
15-Dec		1.65	0.268	7.64	0.022	1.00	0.420	0.69	0.539	_	_	
22-Dec		0.71	0.530	-	_	-	-	-	-	_	-	
29-Dec		1.29	0.343	1.22	0.360	0.38	0.699		_		_	
13-Feb	9.55	0.62	0.594	_	_	0.50	0.647	_	_	-	_	

Table 47: Analysis of variance (ANOVA) test to see whether or not the sample results (concentration) from the three columns could be combined into one result for lead, for each of the five series, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

ANOVA Test for the three columns within each of the five series: copper											
Sample	F	Ser	ies One	Ser	ries Two	Seri	es Three	Ser	ies Four	Serie	es Five
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-Oct		8.33	0.019	1.35	0.328	8.42	0.018	1.51	0.295	31.45	0.001
3-Nov		1.26	0.350	2.99	0.126	4.17	0.073	6.88	0.028	14.54	0.005
17-Nov		0.78	0.499	0.12	0.891	4.85	0.056	1.73	0.255	15.10	0.005
1-Dec	5.14	13.68	0.006	5.02	0.052	7.22	0.025	0.60	0.580	32.74	0.001
15-Dec		7.91	0.021	0.38	0.699	2.77	0.141	2.39	0.172	0.65	0.557
22-Dec		1.21	0.361	2.78	0.140	0.01	0.989	8.67	0.018	29.93	0.001
29-Dec		5.29	0.047	5.29	0.047	1.43	0.311	2.78	0.140	133.17	1.1E-05
13-Feb	9.55	2.02	0.278	0.82	0.518	0.33	0.740	44.59	0.006	8.92	0.055

Table 48: Analysis of variance (ANOVA) test to see whether or not the sample results (concentration) from the three columns could be combined into one result for copper, for each of the five series, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , mean \pm one standard deviation of triplicate analyses. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \ \mu g/L$.

ANOVA Test for the three columns within each of the five series: zinc												
Sample	Sample F Series C		ries One	Series Two		Ser	ies Three	Sei	ries Four	Se	Series Five	
Date	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	
20-Oct		0.20	0.823	0.87	0.464	0.87	0.467	0.53	0.615	0.24	0.793	
3-Nov		0.02	0.976	0.23	0.801	0.70	0.531	0.57	0.593	1.62	0.274	
17-Nov		1.47	0.302	0.39	0.691	1.16	0.376	0.03	0.969	0.07	0.933	
1-Dec	5.14	0.70	0.531	0.13	0.884	0.06	0.941	0.78	0.500	0.12	0.893	
15-Dec		0.08	0.921	0.53	0.616	0.18	0.842	1.02	0.415	0.42	0.673	
22-Dec		0.82	0.485	0.00	0.998	1.10	0.391	0.44	0.665	0.35	0.721	
29-Dec		0.18	0.839	0.30	0.751	0.22	0.810	0.21	0.820	7.59	0.023	
13-Feb	9.55	0.49	0.656	0.23	0.806	0.21	0.819	0.33	0.744	0.12	0.761	

Table 49: Analysis of variance (ANOVA) test to see whether or not the sample results (concentration) from the three columns could be combined into one result for zinc, for each of the five series, for each of the eight sampling events. The shaded areas indicate the tests that have a p-value ≤ 0.05 , mean \pm one standard deviation of triplicate analyses. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

Two-way ANOVA Test for the three columns within each of the five series: lead												
Sample	Row or	F	Ser	ies One	Ser	ries Two	Serie	es Three	Ser	ies Four	Series Five	
Date	Column	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-0ct	rows		-	-	-	_	-	_	-	_	-	_
20 000	columns		-	—	_	_	-	-	-	-	_	-
3-Nov	rows		-	_	—	-	-	-	-	-	-	-
5-100	columns		-	_	_	_	-	-	-	-	_	-
17-Nov	rows		-	_	—	-	-	-	-	-	-	-
17-1000	columns		-	_	—	_	-	-	-	-	_	-
1-Dec	rows	6.04	0.92	0.468	0.79	0.515	0.95	0.460	0.79	0.514	1.06	0.426
I-Dec	columns	0.94	1.33	0.362	1.30	0.368	7.12	0.048	2.77	0.176	1.26	0.376
15-Dec	rows		11.69	0.021	0.20	0.826	15.44	0.013	6.53	0.055	-	-
13-Dec	columns		7.54	0.044	5.60	0.069	5.84	0.065	1.95	0.257	_	_
22-Dec	rows		2.86	0.169	-	_	-	_	-	_	_	_
22-Dec	columns		1.14	0.405	_	_	-	-	-	-	_	_
20 Doc	rows		3.25	0.145	4.90	0.084	11.04	0.024	-	-	-	-
29-Dec	columns		2.25	0.221	2.80	0.174	1.65	0.299	-	-	_	_
12-Eab	rows	10 51	0.98	0.427	-	-	0.01	0.946	_	-	_	-
12-LED	columns	10.51	0.62	0.618	_	-	0.34	0.748	-	-	-	-

Table 50: Two way analysis of variance (ANOVA) tests to see whether or not the three sample results (concentration) from each column (rows) and the results (concentration) from the three columns (columns) could be combined into one result for lead for each event. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \,\mu g/L$.

Two-way ANOVA Test for the three columns within each of the five series: copper												
Sample	Row or	F	Ser	ies One	Seri	es Two	Serie	es Three	Seri	es Four	Ser	ies Five
Date	Column	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-Oct	rows		9.05	0.033	7.70	0.043	4.00	0.111	0.95	0.459	1.17	0.398
20-000	columns		30.69	0.004	4.37	0.099	16.83	0.011	1.48	0.330	33.25	0.003
3-Nov	rows		11.56	0.022	2.77	0.176	0.46	0.661	4.75	0.088	0.96	0.456
5-1100	columns		5.68	0.068	4.75	0.088	3.42	0.136	15.48	0.013	14.36	0.015
17-Nov	rows		9.61	0.030	10.43	0.026	2.13	0.234	1.13	0.408	2.97	0.162
17-1100	columns		3.03	0.158	0.49	0.647	6.67	0.053	1.81	0.276	25.03	0.005
1-Dec	rows	6 94	2.28	0.218	0.25	0.794	1.14	0.406	0.11	0.897	1.66	0.298
I-Dec	columns	0.54	19.54	0.009	3.75	0.121	7.56	0.044	0.42	0.683	39.98	0.002
15-Dec	rows		1.75	0.284	11.22	0.023	4.16	0.105	0.63	0.578	0.67	0.562
13-Dec	columns		9.88	0.028	1.67	0.297	5.69	0.068	2.10	0.238	0.57	0.604
22-Dec	rows		0.04	0.965	6.30	0.058	2.55	0.193	2.54	0.194	0.68	0.556
ZZ-DEC	columns		0.82	0.502	7.70	0.043	0.02	0.983	1.41	0.345	26.76	0.005
20-Dec	rows		3.84	0.117	11.20	0.023	1.48	0.330	1.68	0.296	0.08	0.929
29-Dec	columns		10.28	0.027	8.85	0.034	1.65	0.300	3.40	0.137	92.11	4.5E-04
13-Eab	rows	18 51	4.41	0.171	1.02	0.418	0.30	0.639	2.77	0.238	1.00	0.423
12-LED	columns	10.51	4.32	0.188	0.83	0.546	0.26	0.796	70.88	0.014	8.92	0.101

Table 51: Two way analysis of variance (ANOVA) test to see whether or not the three sample results (concentration) from each column (rows) and the results (concentration) from the three columns (columns) could be combined into one result for copper for each event. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

Two-way ANOVA Test for the three columns within each of the five series: zinc												
Sample	Row or	F	Ser	ies One	Ser	ies Two	Serie	es Three	Ser	ies Four	Ser	ies Five
Date	Column	critical	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
20-0ct	rows		1.31	0.365	1.90	0.264	30.15	0.004	1.17	0.399	6.39	0.057
20-000	columns		0.22	0.810	1.14	0.407	9.29	0.031	0.56	0.612	0.67	0.560
3-Nov	rows		34.62	0.003	5.19	0.077	75.00	0.001	3.33	0.141	0.48	0.650
5-1404	columns		0.30	0.755	0.55	0.615	18.06	0.010	1.01	0.440	1.34	0.359
17 Nov	rows		13.10	0.018	29.29	0.004	11.85	0.021	1.93	0.259	1.02	0.438
17-1100	columns		7.39	0.045	4.10	0.108	5.34	0.074	0.04	0.959	0.07	0.933
1-Dec	rows	6.04	2.72	0.180	41.27	0.002	3.62	0.127	3.62	0.127	0.77	0.522
I-Dec	columns	0.94	1.11	0.414	1.81	0.275	0.12	0.893	0.12	0.893	0.11	0.901
15-Dec	rows		23.35	0.006	5.39	0.073	10.20	0.027	3.85	0.117	1.79	0.278
13-Dec	columns		0.70	0.547	1.29	0.368	0.72	0.541	1.99	0.251	0.53	0.623
22-Doc	rows		3.90	0.115	25.41	0.005	1.36	0.353	5.81	0.066	1.41	0.344
ZZ-DEC	columns		1.61	0.307	0.02	0.985	1.24	0.382	1.14	0.406	0.39	0.699
20 Doc	rows		16.80	0.011	13.72	0.016	2.46	0.202	2.45	0.202	1.15	0.403
29-Dec	columns		1.13	0.407	1.57	0.313	0.32	0.741	0.30	0.753	7.97	0.040
12-Eab	rows	19 51	6.80	0.121	10.31	0.085	3.14	0.218	21.75	0.043	0.86	0.523
12-LED	columns	10.51	1.43	0.412	0.95	0.512	0.37	0.732	2.59	0.279	0.11	0.794

Table 52: Two way analysis of variance (ANOVA) test to see whether or not the three sample results (concentration) from each column (rows) and the results (concentration) from the three columns (columns) could be combined into one result for zinc for each event. The shaded areas indicate the tests that have a p-value ≤ 0.05 , or an F statistic > the F critical. The dotted is there to separate the last sampling event from the others because the influent concentration of that sampling event was $0 \mu g/L$.

	Series 1	Series 2	Series 3	Series 4	Series 5
Count	8	8	8	8	8
Average	0.63	0.51	0.95	0.48	0.65
Standard deviation	0.803	0.860	0.939	0.546	1.054
Coefficient. of variation	126%	167%	98%	112%	162%
Minimum	0.0	0.0	0.0	0.0	0.0
Maximum	2.4	2.6	2.4	1.5	2.7
Range	2.4	2.6	2.4	1.5	2.7
Standardized skewness	2.00	3.00	0.95	1.32	1.74
Standardized. kurtosis	1.99	4.07	-0.42	0.10	0.52

Table 53: Statistics summary table for lead.

	Series 1	Series 2	Series 3	Series 4	Series 5
Count	8	8	8	8	8
Average	20.77	16.75	15.88	21.96	35.35
Standard deviation	15.281	10.875	11.179	15.225	28.986
Coefficient of variation	73%	64%	70%	69%	81%
Minimum	5.32	4.10	3.46	3.86	6.02
Maximum	50.51	40.37	34.11	51.95	96.78
Range	45.19	36.27	30.65	48.09	90.76
Standardized skewness	1.46	1.84	0.87	1.24	1.80
Standardized kurtosis	0.51	1.97	-0.45	0.69	1.48

Table 54: Statistics summary table for copper.

	Series 1	Series 2	Series 3	Series 4	Series 5
Count	8	8	8	8	8
Average	20.78	16.76	15.88	21.96	35.36
Standard deviation	15.276	10.889	11.183	15.235	28.992
Coefficient of variation	73%	64%	70%	69%	81%
Minimum	5.3	4.1	3.5	3.9	6.0
Maximum	50.5	40.4	34.1	52.0	96.8
Range	45.2	36.3	30.6	48.1	90.8
Standardized skewness	1.46	1.84	0.87	1.25	1.80
Standardized kurtosis	0.50	1.96	-0.46	0.70	1.48

Table 55: Statistics summary table for zinc.

	Series 1	Series 2	Series 3	Series 4	Series 5
Count	8	8	8	8	8
Average	8.21	7.87	4.28	8.68	1.64
Standard deviation	4.343	4.604	4.344	15.27	1.007
Coefficient of variation	52%	58%	101%	175%	61%
Minimum	1.89	2.37	0.88	0.96	0.63
Maximum	16.47	17.52	13.86	44.53	3.77
Range	14.58	15.15	12.98	43.57	3.14
Standardized skewness	0.80	1.55	2.14	2.72	1.73
Standardized. kurtosis	0.73	1.46	2.05	3.24	1.40

Table 56: Statistics summary table for nitrate.

	Series 1	Series 2	Series 3	Series 4	Series 5
Count	8	8	8	8	8
Average	1.03	1.38	1.32	1.00	0.71
Standard deviation	0.381	0.670	0.589	0.459	0.180
Coefficient. of variation	36%	48%	44%	45%	25%
Minimum	0.4	0.3	0.4	0.2	0.5
Maximum	1.6	2.2	2.0	1.6	0.9
Range	1.2	1.9	1.6	1.4	0.4
Standardized. skewness	-0.27	-0.31	-0.57	-0.57	-0.05
Standardized kurtosis	-0.05	-0.45	-0.76	-0.21	-1.31

Table 57: Statistics summary table for phosphate.

Source	Sum of Squares		Mean Square	F-Ratio	P-Value
Between groups	1.0835	4	0.270875	0.37	0.8297
Within groups	25.7563	35	0.735893		
Total (Corr.)	26.8398	39			

Table 58: ANOVA table for all five series for lead.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1957.51	4	489.378	1.58	0.2013
Within groups	10841.5	35	309.757		
Total (Corr.)	12799.0	39			

Table 59: ANOVA table for all five series for copper.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1957.65	4	489.412	1.58	0.2016
Within groups	10848.1	35	309.946		
Total (Corr.)	12805.8	39			

Table 60: ANOVA table for all five series for zinc.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	299.519	4	74.8798	1.28	0.2976
Within groups	2051.99	35	58.6282		
Total (Corr.)	2351.5	39			

Table 61: ANOVA table for all five series for nitrate.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2.3765	4	0.594125	2.50	0.0600
Within groups	8.31125	35	0.237464		
Total (Corr.)	10.6877	39			

Table 62: ANOVA table for all five series for phosphate.

Pollutant Removal Efficiencies for Lead (%)								
Date	Series 1	Series 2	Series 3	Series 4	Series 5			
10/20/2006	100	100	100	100	100			
11/03/2006	99	99	99	99	41			
11/17/2006	100	99	87	90	94			
12/01/2006	87	86	87	92	67			
12/15/2006	98	99	98	99	99			
12/22/2006	97	99	91	100	98			
12/29/2006	97	96	93	98	100			
Averages	97	97	94	98	86			

Table 63: Pollutant removal efficiencies (PREs) for lead, including the averages (not including 2/13/2006).

Pollutant Removal Efficiencies for Copper (%)								
Date	Series 1	Series 2	Series 3	Series 4	Series 5			
10/20/2006	70	74	40	-33	9			
11/03/2006	-18	-12	15	-19	22			
11/17/2006	84	84	92	89	81			
12/01/2006	82	86	91	89	84			
12/15/2006	86	89	93	93	82			
12/22/2006	84	81	88	85	2			
12/29/2006	84	89	90	87	86			
Averages	67	70	73	56	52			

Table 64: Pollutant removal efficiencies (PREs) for copper, including the averages (not including 2/13/2006).

Pollutant Removal Efficiencies for Zinc (%)									
Date	Series 1	Series 2	Series 3	Series 4	Series 5				
10/20/2006	99	99	99	99	99				
11/03/2006	94	94	96	93	82				
11/17/2006	98	98	98	98	96				
12/01/2006	93	96	94	90	93				
12/15/2006	90	88	98	97	86				
12/22/2006	93	95	91	89	88				
12/29/2006	85	88	89	89	79				
Averages	93	94	95	94	89				

Table 65: Pollutant removal efficiencies (PREs) for zinc, including the averages (not including 2/13/2006).

Pollutant Removal Efficiencies for Nitrate (%)								
Date	Series 1	Series 2	Series 3	Series 4	Series 5			
10/20/2006	-1563	-1352	-332	-274	-177			
11/03/2006	-385	-507	-139	-191	-441			
11/17/2006	-344	-248	-50	-52	-9			
12/01/2006	-329	-362	-243	-650	39			
12/15/2006	-301	-162	-17	29	40			
12/22/2006	-257	-236	47	44	17			
12/29/2006	-144	-195	-94	46	71			
Averages	-474	-437	-118	-149	-65			

Table 66: Pollutant removal efficiencies (PREs) for nitrate, including the averages (not including 2/13/2006).

Pollutant Removal Efficiencies for Phosphate (%)								
Date	Series 1	Series 2	Series 3	Series 4	Series 5			
10/20/2006	-180	-103	-463	-872	-350			
11/03/2006	-693	-826	-975	-696	-448			
11/17/2006	-156	-250	-194	-105	-24			
12/01/2006	-22	-96	-238	-77	-53			
12/15/2006	-152	-263	-167	-112	-34			
12/22/2006	-101	-154	-275	-165	-3			
12/29/2006	-121	-228	-212	-188	-36			
Averages	-204	-274	-361	-317	-135			

Table 67: Pollutant removal efficiencies (PREs) for phosphate, including the averages (not including 2/13/2006).

Metal	Stormwater Median (90th Percentile)	Mean (sd)	Urban Stormwater Median (COV)	Parking Lot Runoff Range	Highway Runoff Range
Lead	144 (350)	70 (48)	15.9 (1.89)	73-1780	10-59
Copper	134 (93)	33 (19)	16.0 (2.24)	22-7033	8.9-78
Zinc	160 (500)	215 (141)	112.0 (4.59)	56-929	51-960
Sources:	NURP, 1983 (USEPA)	Driscoll <i>et al</i> ., 1990	Pitt <i>et al</i> ., 2004	Barrett <i>et al</i> ., 1998.	Little <i>et al.</i> 1983

Table 68: Typical levels of metals found in stormwater runoff (ug/L). Note: sd = standard deviation, COV = coefficient of variation.



Figure 1: New Jersey's watersheds (WMAs) and Water Regions (Source NJDEP 2000).



Figure 2: A hydrograph showing the effects development has on both the discharge and the timeframe of that discharge and also what a detention basin does to both.



Figure 3: Schematic of bench containing six experimental Bioretention System columns



Figure 4: Graph showing the lead influent and the average lead effluent, for each of the three samples, of the three columns making up Series One, for each sample event.



Figure 5: Graph showing the lead influent and the average lead effluent, for each of the three samples, of the three columns making up Series Two, for each sample event.



Figure 6: Graph showing the lead influent and the average lead effluent, for each of the three samples, of the three columns making up Series Three, for each sample event.



Figure 7: Graph showing the lead influent and the average lead effluent, for each of the three samples, of the three columns making up Series Four, for each sample event.


Figure 8: Graph showing the lead influent and the average lead effluent, for each of the three samples, of the three columns making up Series Five, for each sample event.



Figure 9: Graph showing the copper influent and the average copper effluent, for each of the three samples, of the three columns making up Series One, for each sample event.



Figure 10: Graph showing the copper influent and the average copper effluent, for each of the three samples, of the three columns making up Series Two, for each sample event.



Figure 11: Graph showing the copper influent and the average copper effluent, for each of the three samples, of the three columns making up Series Three, for each sample event.



Figure 12: Graph showing the copper influent and the average copper effluent, for each of the three samples, of the three columns making up Series Four, for each sample event.



Figure 13: Graph showing the copper influent and the average copper effluent, for each of the three samples, of the three columns making up Series Five, for each sample event.



Figure 14: Graph showing the zinc influent and the average zinc effluent, for each of the three samples, of the three columns making up Series One, for each sample event.



Figure 15: Graph showing the zinc influent and the average zinc effluent, for each of the three samples, of the three columns making up Series Two, for each sample event.



Figure 16: Graph showing the zinc influent and the average zinc effluent, for each of the three samples, of the three columns making up Series Three, for each sample event.



Figure 17: Graph showing the zinc influent and the average zinc effluent, for each of the three samples, of the three columns making up Series Four, for each sample event.



Figure 18: Graph showing the zinc influent and the average zinc effluent, for each of the three samples, of the three columns making up Series Five, for each sample event.



Figure 19: Average % removal of lead versus bulk density.



Figure 20: Average % removal of copper versus bulk density.



Figure 21: Average % removal of zinc versus bulk density.



Figure 22: Average lead inputs and outputs for all sampling events for all five series.



Figure 23: Average copper inputs and outputs for all sampling events for all five series.



Figure 24: Average copper inputs and outputs for all sampling events for all five series.



Figure 25: Average influent and effluent lead concentrations over the series of columns (bulk density) for all sampling events.



Figure 26: Average influent and effluent copper concentrations over the series of columns (bulk density) for all sampling events.



Figure 27: Average influent and effluent zinc concentrations over the series of columns (bulk density) for all sampling events.



Figure 28: Average nitrate-N input and outputs for all sampling events for all five series of columns.



Figure 29: Average phosphate-P input and outputs for all sampling events for all five series of columns.



Figure 30: Average influent and effluent nitrate-N concentrations over the series of columns and all of the sampling events.



Figure 31: Average influent and effluent phosphate-P concentrations over the series of columns and all of the sampling events.



Figure 32: Correlation between the effluent and the influent for five of the eight sampling events for lead.



Figure 33: Correlation between the effluent and the influent for five of the eight sampling events for copper.



Figure 34: Correlation between the effluent and the influent for five of the eight sampling events for zinc.



Figure 35: Correlation between the effluent and the influent for five of the eight sampling events for nitrate.



Figure 36: Correlation between the effluent and the influent for five of the eight sampling events for phosphate.



Figure 37: Picture of an actual Bioretention System



Figure 38: Schematic of a typical Bioretention System (Source: NJDEP 2004).



Figure 39: Schematic of a cross-sectional view of a typical Bioretention System (Source: NJDEP 2004).



Figure 40: Bioretention System that serves as a rain garden.



Figure 41: Functioning Bioretention System.



Figure 42: Bioretention System in ultra-urban setting. Note curb cut, gravel energy dissipater, and clean out/observation wells (Source: VDCR 1999).



Figure 43: Bioretention System located in required parking lot green space (Source: VDCR 1999).



Figure 44: Bioretention System in multi-family residential setting (Source: VDCR 1999).



Figure 45: Bioretention System in office setting parking lot (Source: VDCR 1999).