Effectiveness of a Bioretention Cell Treating Stormwater Runoff in

Northeastern Kansas

BY

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Abstract

Stormwater runoff from paved surfaces, which contains high levels of heavy metals, suspended solids and organic contaminants, has been identified as one of the major causes of pollution in receiving waters. Recent studies have indicated that the use of ecologically-based methods for stormwater treatment, including bioretention systems, may provide increased pollutant removal and protection of downstream receiving waters. However, there is little data addressing the long-term performance of these systems in the field or the effects of contaminant accumulation over time on treatment effectiveness. In this study, we present results from a three year study of a bioretention site in northeastern Kansas.

The field study was conducted in Lenexa, KS at a bioretention cell treating stormwater runoff from a 4-lane roadway. A sediment mesh trap was installed in the sewer entrance to filter large particles in the runoff. Samples were collected and analyzed after each storm event for suspended solids (TSS), heavy metals (Cu and Zn) and nutrients (nitrogen and phosphorus). Study results showed that 90% of TSS had been reduced by the bioretention system, while reductions of 50% and 70% for total Cu and total Zn, respectively, were found. Moderate removal rates were observed for total nitrogen and total phosphorus. Accumulation and fate of nutrients in the bioretention cell are analyzed to aid in the design and planning of bioretention systems for better performance under climate and soil conditions found in the Great Plains region.

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Chapter 1

<u>Introduction and Background</u>

Non-point source pollution (NSP) is one of the leading current causes of water quality problem, especially where point source pollution has been reduced through regulatory control. Mitigating the impact of non-point source pollution to maintain surface water quality has become a significant EPA (Environmental Protection Agency) issue. The 2000 National Water Quality Inventory (USEPA, 2002) identified non-point source pollution, specifically runoff from agricultural and urban land, as the nation's leading cause of surface water degradation. Non-point source pollution is caused by rainfall or snowmelt through the ground and can include sediments, nutrients, metals and organic contaminants. Increased urbanization has aggregated this problem in many areas through reduced soil infiltration and interception storage. This results in increased runoff velocities, accelerated surface erosion, and more and more contaminants transported in the stormwater runoff to receiving water bodies. Because of these trends, treatment of stormwater pollutants has become more common and more necessary in United States.

Stormwater runoff, which is produced by precipitation or snow melting, can carry a significant amount of contaminants such as suspended solids, heavy metals, nutrients, organics and pathogens. It is well known that the pollutants transported in stormwater runoff can be more concentrated at the beginning of a storm event than later times during the same event. First flush is used to describe this phenomenon, and short duration, high intensity and long antecedent dry weather are the most important reasons leading to greater likelihood of first flush (Sansalone and Cristina, 2004). In addition, different land use will cause different contaminants. In urban areas, a large part of the precipitation from impervious areas like paved road, parking lots and building roofs forms runoff which flows to the drainage systems or receiving waters.

Suspended solids are the most basic pollutants in the water environment. In urbanized areas, suspended solids accumulate on impervious surface from everyday activities. These suspended solids are easily washed off by the rainfall flow and run into the sewer system or receiving water bodies. The concentrations of total suspended solids mostly depend on the storm characteristics and land use. A wide range of total suspended solids (TSS) concentrations was noted in urban and highway stormwater runoff in previous studies, from less than 1mg/L to more than 700mg/L (Davis and McCuen, 2005).

Heavy metals in the runoff are mostly from rooftops and roadways. Many heavy metals are toxic to humans and aquatic organisms. These metals include cadmium, chromium, copper, lead, mercury, nickel, and zinc. Most of these metals

are divalent cations, and are often complexed or bound to inorganic species or organic compounds, so suspended solids can contain high metal levels when the dissolved metal concentrations are low. This complexation can affect the behavior of a metal in a treatment practice or can alter its movement through the environment. Heavy metals cannot be degraded in the environment, but they can transform to more or less bioavailable forms depending on chemical and biological conditions.

Nutrient compounds include nitrogen compounds, phosphorus compounds and natural organic matter. The major source of these nutrients compounds in stormwater runoff is lawn fertilizers. Although these compounds have little direct toxicity to the humans and aquatic organisms in water, they can indirectly affect water quality by reducing D.O concentration and causing eutrophication. The most common inorganic forms of nitrogen found in the environment are ammonia and nitrate. Ammonia is toxic to many fish species and can also exert oxygen demand through microbial nitrification producing nitrate and nitrite. Nitrate is a regulated drinking water contaminant. Excess nitrate can cause high algal growth rate which is the major cause of lake eutrophication. Phosphorus is also a primary nutrient and a major cause of eutrophication. The most common forms of phosphorus in waters are ortho-phosphorus. Unlike nitrate, phosphorus has a strong affinity for soils and other particles, especially to clays, Al and Fe oxides.

Until recently, most stormwater controls were focused on the hydrological aspects, and designed to improve drainage and convey runoff away from the site. In

1972, the National Pollutant Discharge Elimination System (NPDES) was established under Clean Water Act (CWA). During phase I of NPDES, a stormwater discharge permit was required for companies in 11 industrial categories, large and medium municipal separate storm sewer systems (MS4s) and large construction sites. During phase II of NPDES, regulations were expanded to include discharges from all small MS4s within urban areas, and other designated small systems (USEPA, 2000). MS4s general permit requires that MS4s must design best management practices (BMPs) to implement minimum control measures in permit application. A minimum stormwater management program must reduce discharge of pollutants to the maximum extent practicable (MEP), protect water quality and satisfy Clean Water Act requirement. In some cases, total maximum daily loads (TMDL) from non-point source runoff are assigned as additional regulation of stormwater for specific targeted contaminants (USEPA, 2007).

Under NPDS regulations, best management practices are required to implement stormwater management plans aimed at flow control and pollutant removal in a cost effective manner. Best management practices are "schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants to waters of the United States" (MARC, 2003). They can be divided into two types: structural and non-structural. Non-structural BMPs are usually those educational or institutional activities that inform individuals and the public about ways to reduce

stormwater pollutions. Structural BMPs are engineered or constructed systems such as infiltration ditches and detention ponds. Removal rates of 60%-85% for total suspended solids in stormwater runoff have been reported by Shammaa and Zhu (2002) by using dry detention ponds. And a removal rate of 93% total suspended solids and 80% zinc were obtained with wet detention ponds by Wu et al (2002). Recently, the use of low impact development, or vegetated BMPs, has been applied in many places to manage stormwater runoff. Studies have indicated that the use of low impact BMPs provides superior pollutant removal to other treatment approaches (Weiss et al, 2007).

Low impact development (LID) emphasizes conservation and use of natural features. It emphasizes on planning, designing, constructing and maintaining a site such that runoff quantity and quality replicate pre-development characteristics as much as possible. In low impact development approaches, natural and topographic features are retained and land disturbances are minimized to encourage pollution prevention. The most common LID systems are swales, wetlands and bioretention cells. Existing reports (International stormwater BMPs database) showed that swales can provide about 50% removal for TSS, 30%-70% removal for total metals and moderate removal for nitrogen, while increased concentrations for total and dissolved phosphorus were found in the swales. Similar results were also observed for wetlands: suspended solids and metals are removed to a certain level, but dissolved phosphorus increased. For bioretention cells, studies have shown good potential for removal of suspended solids and metals, but poorer removal rates for

nutrients compounds (Hsieh et al, 2007). Because bioretention cells can serve relatively small watersheds and are not limited by available space, they have been more and more widely used in the treatment of urban road runoff.

Bioretention cells are depressions filled with natural materials like soil and mulch with a planted vegetative cover on the top and an underdrain in the bottom to collect effluent water. Sizing of bioretention cells is flexible, and is generally about 5%-15% of the runoff drainage area (MARC, 2008). It is common to find that several small bioretention cells are employed to serve one area. Engineers usually use porous soil or mixtures of sand, topsoil and leaf as the soil media to provide high infiltration rates. A mulch layer is used to prevent soil from drying and erosion. These natural materials function as filters to remove suspended soils, while dissolved species are removed through sorption.

The plants on the top can also take up contaminants and enhance site aesthetics. Local soil and climate conditions are the most important factor to select appropriate plant species. Studies showed that effluent quality is improved by incorporating plants with bioretention systems compared with non-vegetated soil media (Davis and McCuen, 2005). Plants in the bioretention system can provide a mechanism for the uptake of pollutants, especially for nutrients. Also, the plants can create a highly biologically active area near the root zone of a thriving plant population which can assist in pollutants removal (Davis and McCuen, 2005). In addition, the vegetation can also help increasing soil media permeability which encourages the soil filtration.

The choice of plants must be based not only on their treatment performance but also on their capacity of surviving in potentially stressful growth conditions (Read et al, 2007). Individual species were not usually universally effective at removing pollutants, so mixtures of species may be most suitable for biofilters to maximize the spectrum of pollutant removal (Read et al, 2007). All the components of the bioretention cell contribute their abilities in removing contaminants to achieve a good-excellent performance, especially for suspended solids, heavy metals, nutrients and organics.

Table 1 Some selected vegetation recommended for use in bioretention (DER 2001)

Perennials for Saturated Soil	Drought-Tolerant Perennials	Groundcovers	Shrubs	Trees
Swamp Milkweed	Willowleaf Bluestar	Moss Sandwort	Red, Black, Purple Chokeberry	Red Maple
New England Aster	Big Bluestem	Wild Ginger	Inkberry	River Birch
Tickseed Sunflower	Columbine	Switch Grass	Creeping Juniiper	Bitternut Hickory
March Marigold	Butterflyweed	Leadwort	Groundsei Tree	Green Ash
Fringed Sedge	Wood Aster	River Oats	Beautyberry	Honeylocust
White, Rose Turtlehead	Blue Wood Aster	Green and Gold	Buttonbush	American Holly
Rose Mallow	Smooth or Blue Bird Aster	Hay-Scent Fern	Pepperbush	Black gum
Mist Flower	New England Aster	Bishop's Hat	Red Twig Dogwood	Swamp White Oak
Joc Pye Weed	Boltonia	Purple Lovegrass	Hearts-a-bustin'	Paw Paw
Boneset	River Oats	Red Fescue	Witch Hazel	Common Hackberry

Bioretention cells have demonstrated excellent removal rates for total suspended solids (Davis et al. 2001; Hsieh and Davis, 2005a; Hunt et al. 2008). Hsieh and Davis (2005) used a synthetic stormwater runoff with an influent TSS concentration of 150 mg/L and obtained very good TSS removal (>96%) in most of the native-media bioretention columns. These native-media were all locally obtained and classified as sand and sandy loam. The mulch layer used in the study was from locally collected municipal leaves and grass clippings. In their research, some washout of media particles has been noted in field facilities, mostly from new installations. A top mulch layer over the soil media was suggested to filter incoming TSS and prevent the underlying media from clogging (Hsieh and Davis, 2005).

Field experiments in the city of Charlotte were conducted to investigate bioretention cells performance (Hunt et al. 2008). Monitoring of storm events occurred from February 2004 to March 2006. Results showed that TSS effluent concentrations were 59.5% lower than influent concentrations. This result were comparable to many prior field studies, but were not as high as reported in the lab studies (Hsieh and Davis, 2005). At the end of the study period, TSS effluent concentrations were not appreciably lower than those recorded at the study's beginning, which was explained by the hypothesis of the bioretention cells aging (Hunt et al, 2008). Laboratory and column experiments have also been conducted to study the limitations of infiltration for bioretention cells. Column test results (Li and Davis, 2008) suggested that bioretention TSS capture performance is limited by

clogging rather than breakthrough, and media depth of 5-20cm was recommended for particles capture in field bioretention facilities. Grab TSS concentrations from their field facility indicate good removal efficiencies (55% to >99%), which agree with previous studies. All these findings show that bioretention cells are generally effective at removing suspended solids.

The removal of metals in bioretention cells is mostly completed through the removal of solids. Investigations using pilot-plant laboratory bioretention systems and two existing bioretention facilities (Davis et al, 2003) showed effective removal of low levels of lead, copper, and zinc from synthetic stormwater runoff. The removal rate reached close to 100% for all metals under most conditions in these studies. A shallow bioretention depth was found to be less effective in metal removal, while minimum total depth of 30cm was required to properly support plant growth. They also mentioned that other parameters like runoff pH, duration, intensity, and pollutant concentration all had little effect on removal. Similar experiments at various scales had also shown high reductions in copper, lead, and zinc concentrations (>92%) using synthetic stormwater runoff (Davis, 2001). The mulch layer was considered to enhance metal attenuation. Removals of 98%, 36% and 16% of Cu, Pb, and Zn have been obtained in the mulch layer while plants only removed 0.1%, 0 and 0.2% of Cu, Pb, and Zn in studies reported by Dietz et al (2006).

Field removal rates tend to be somewhat lower than those reported in laboratory settings. Studies in the city of Charlotte have found reductions of 77.0%,

54.0% and 31.4% for Zn, Cu, and Pb respectively (Hunt, 2008). An experiment to investigate the cell performance during two seasons (later winter/early spring and full summer) was performed by Muthanna et al, 2007. Because of the frozen soil, dormant vegetation and low biological activity in cold season, the removal of metals could be different between cold and warm seasons. The research discovered that the mass removal of zinc was constant at 90% for both seasons, and mass removal of lead was slightly higher in August than in April, while copper was the only metal showing a significantly lower removal in April. This study also indicated both mulch and soil layers contributed to the removal of metals while the plants played a minor role.

Metals captured by the bioretention cell are left in the mulch and soil layer. The long-term accumulation of metals in the mulch and soil layer thus becomes a new potential concern for using bioretention cells. Studies (Davis et al, 2003) focused on heavy metal accumulation in bioretention media were carried out by calculating cumulative mass loading. Regulatory limits for biosolids application (EPA, 1993) were used to decide time requirement. The time required for metal accumulations to exceed the limits was 20, 77, 16 and 16 years for cadmium, copper, lead, and zinc, respectively. The studies also suggest that metal accumulation in bioretention cells should not be a significant problem within 15-20 years (Davis et al, 2003).

A relatively comprehensive investigation of nitrogen and phosphorus removal and fate in bioretention was done by Davis (2006). Excellent removal,

65±8% and 87±2%, were observed for total phosphorus in two different field sites, Greenbelt and Largo, respectively. 49±6% TN and 52±7% TKN removals were found at Greenbelt, with 59±6% TN and 67±9% TKN removals for the Largo site. These results agreed with previous studies (CWP, 2004; Davis, 2001) and were greater than 31.4% TP, 32.3% TN, and 32.2% TKN reduction reported by the study in the City of Charlotte (Hunt, 2008). Thicker vegetation and deeper soil depth of the bioretention cell can be explained for the high nutrient removal in the Davis study (2006). The Center for Watershed Protection in 2004 also listed median removals of total phosphorus and total nitrogen at 70% and 51%, respectively (CWP, 2004). Since nitrate is an anion, it will not attach to soils and other particles. As a result, it is very difficult to remove from waters. The only possible method to remove nitrate and nitrite by using bioretention cells is providing anaerobic zone to promote denitrification (reduce NO_x to N_2 gas). In Davis' 2001 paper, laboratory and pilot-scale bioretention box studies provided evidence of nutrient removal in bioretention. Moderate reductions of TKN (65 to 75%), ammonium (60 to 80%), and phosphorus (80%) were found. Little nitrate was removed, and nitrate production was noted in several cases. The concentration at each different depth of soil indicated that phosphorus and TKN showed a significant dependence with depth. Higher reduction rates were observed from the middle and lower ports of the bioretention systems than from the upper ports. Since there was a large range of effluent concentrations of nitrate, it was apparent that nitrate was formed from other nitrogen sources.

Vegetation, if properly designed and managed, may play a significant role in the bioretention nutrient mass balance. Several studies were conducted in increasing nitrate removal by incorporating a continuously submerged anoxic zone for nitrate removal through denitrification. Nitrate and nitrite removals of 70% to 80% were obtained in a pilot-scale study with the application of the anoxic zone (Kim et al, 2003). Newspaper was identified as the best electron-donor for biological nitrification process in this study. A field site in North Carolina constructed with an internal water storage (IWS) was used to perform the denitrification process (Hunt et al, 2006), and 75% of nitrate was successfully removed. The IWS in this study was simply created by installing an elbow in the outlet of the drain pipe instead of a regular underdrain pipe to make the bottom portion of the bioretention cell become anaerobic.

Oil and grease are hydrophobic organic compounds, and they can coat aquatic organisms, reducing their ability to transfer oxygen. As oils degrade, they can exert an oxygen demand. Oils often contain toxic substances, including metals, naphthalene and toluene which are toxic to the environment. Although oil and grease are considered as one of the principal contaminants in the urban stormwater runoff, they are not as well studied as metals or nutrients. However, there are still some published literatures for bioretention treating oil and grease. Results from published papers demonstrated that the mulch layer efficiently removed the hydrocarbon contaminants from the synthetic runoff (Hong et al, 2006). The removal rates for dissolved naphthalene was approximately 90%, for dissolved

toluene was approximately 83%, for dissolved motor oil was about 80% and for particulate associated naphthalene was about 97%. The contaminant concentrations showed that most contaminant biodegradation was completed in the mulch layer.

Polycyclic Aromatic Hydrocarbons (PAHs) are compounds with two or more common aromatic rings. PAHs have very low solubility and low biodegradation rates which make them hard to remove from water. Recent increase of PAHs input in runoff comes mostly from the vehicles. In storm flow, the majority of PAHs were associated with filterable particles (Hwang, 2005). A field study in Maryland demonstrated that bioretention is a promising management practice to control runoff PAH pollutants (an averaging reduction of 87%). This research indicated that PAHs were strongly affiliated with runoff TSS. Media core analyses suggested that a shallow cell design may be adequate for systems focusing on PAH removal (DiBlasi, 2008).

While these studies have shown the successful use of bioretention cells at treating stormwater runoff in batch, column and pilot scales, there is little available data showing the performance of the bioretention cells under the climate, meteorological, hydrological and traffic conditions typically found in Kansas and the Great Plain region. The purpose of this study is to provide stormwater runoff quality data and determine the effectiveness of bioretention cells in treating road runoff in Kansas City metropolitan area. A field study was conducted in Lenexa, KS at a bioretention cell treating stormwater runoff from the roadway. A sediment mesh trap was installed in the sewer entrance to filter large particles in the runoff.

Samples were collected after each storm events, and pollutants of suspended solids (TSS), heavy metals (Cu and Zn) and nutrients (nitrogen and phosphorus) were analyzed in the lab. About two years monitoring results of concentrations of contaminants were evaluated in influent and effluent for the bioretention cells. The results of this study, including characteristic of influent stormwater quality and bioretention cell performance are detailed in the remainder of this work.

Chapter 2

Site Description

Site Information

Mize Lake is an artificial lake created in 2005 by the city of Lenexa, Kansas for the purpose of controlling flooding and improving recreational opportunities. The lake has a surface area of about 5 acres and is located directly east of Cedar Creek Parkway, a 4-lane road that is primarily used by the residences and the construction vehicles. The surrounding area is undergoing rapid residence development and vehicles are expected to increase during the study time.

Two bioretention cells are located separately in the northwest and southwest sides of Mize Lake. Because of high sediment runoff from concentration on the south side of the lake, the southwest bioretention cell does not function well due to surface clogging of the soil mixture and it has not been used for treatment purposes since 2007. The northwest bioretention cell was constructed in 2005 while it first received runoff in 2006. This bioretention cell has a surface area approximately 0.1 acres, and it receives runoff from a 0.83 acres watershed which contains approximately 40% impervious surface with consist of roads and sidewalks. It consists of a 3 inch of wood chip mulch layer overlying a 2.5 foot layer of sandy loam soil. The top of the cell is covered by vegetation.

Fig. 2 An aerial photograph of the bioretention cell and surrounding area

Runoff from Mize Boulevard is collected in curbside sewers behind the road and drained to the bioretention cells through a single concrete pipe. A mesh bag trap is installed in the entrance of the curbside sewer to filter large particulates and trashes from the runoff before it enters the bioretention cell. Treated effluent from the bioretention cell is collected in an underdrain and then discharged into the Mize Lake at the surface level through a culvert pipe. When there is a high rainfall event, a portion of surface rainfall water is collected through an overflow sewer in the center of the bioretention cell. Several plastic pipes with small perforations directly connected to the underdrain are placed throughout the cell for additional short circuiting.

Rainfall data for storm events during the sampling period was obtained from the Cedar Creek site of the City of Overland Park Storm Watch rain gauge data network located about 2.5 miles west the field site. An on-site rain gage was used to determine site-specific precipitation amounts and an automated on-site camera was used to take pictures of the surface water depth at a staff gage every hour during each rainfall event. Figure 3 shows a photo taken by the on-site automated camera during the rainfall event on 5/24/2008. A pressure sensor attached to a datalogger was installed in the underdrain pipe to collect effluent water depth data.

Fig. 3 Photo taken by the on-site auto camera for 5/24/2008 storm

Previous Study

A preliminary study was conducted to determine the concentrations of heavy metals in the stormwater runoff from the road. Stormwater samples collected at the storm sewer entrance were carried out for a wide range of total and dissolved metals from March to May of 2007. Figure 4 shows the average dissolved and total concentrations of the five trace metals detected in these samples: Cd, Cr, Cu, Pb and Zn. Only Cu was detected in all eight samples collected during this period, while Cd, Cr and Pb were detected in less than four of the samples. Zn was the most common metal detected in total metal samples, followed by Cu and Pb. Based on the results of this initial sampling, we selected Cu and Zn for further monitoring in stormwater runoff and in the bioretention cell effluent.
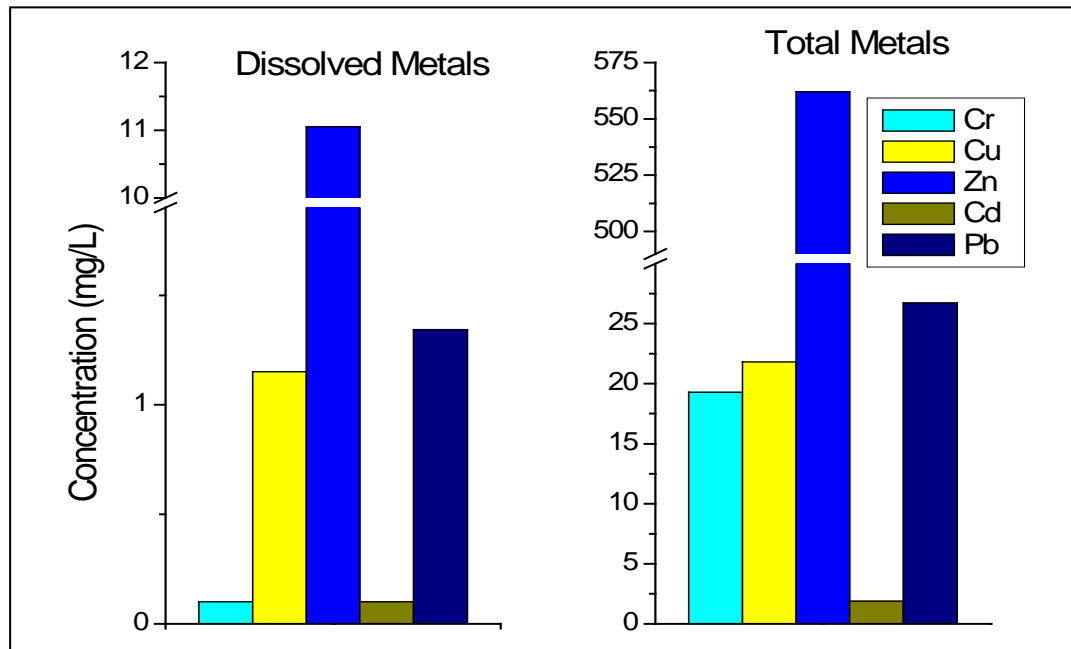
Fig. 4 Dissolved and total trace metals in road runoff. (Peltier, 2008)

Table 2 shows the average dissolved and total concentrations of Cu and Zn in the stormwater runoff and bioretention cell effluent for samples collected during the preliminary study, between June 1 and November 27, 2007 (Peltier, 2008). Total concentrations of both metals decrease substantially between the storm sewer and the bioretention cell influent, presumably due to removal of Cu and Zn associated with larger particles trapped in the storm sewer screen. Total copper continues to decrease between the influent and effluent of the bioretention cell, while total Zn concentrations remain essentially stable. Dissolved metal concentrations decrease much more slowly for Cu between the initial and final sampling locations, and not at all for Zn. Examination of the median concentrations for each sampling location (Table 2b) shows a decreasing total concentration for both Cu and Zn, but no discernable patters for dissolved metal values. A significant limitation for this preliminary study is that only composited samples were collected during the sampling periods, so there was no assessment of first flush effect and possible metal re-partitioning.

Table 2 Dissolved and Total Metal Concentrations. All values in µg/L.

a.) Mean values

	Cu		Zn	
	Dissolved	Total	Dissolved	Total
Storm Sewer	18.2	189	61.9	535
Influent	13.6	100	61.1	376
Effluent	4.1	46.4	67.5	366

b.) Median values

	Cu		Zn	
	Dissolved	Total	Dissolved	Total
Storm Sewer	2.3	78.9	45.5	421
Influent	6.9	62.5	64	354
Effluent	1.1	33.1	50.5	281

Chapter 3

Methods and Materials

Sample Collection

Runoff samples were collected at the following three locations at the field site: the influent to the curbside sewer (Figure 5), the influent to the bioretention cell (Figure 6) and the effluent from the bioretention cell (Figure 7). During each rainfall event, the stormwater runoff from the road was collected by a plastic tube which connected the road surface and a 1L plastic bottle. For most storms, the 1L plastic bottle was fully filled with the runoff. These will be referred to "sewer samples" in the following section. During some heavy or long-lasting rainfall events, samples in the bottle were diluted by the continuous inflow from the road.

After filtering through the mesh trap, the runoff was discharged from the storm sewer to the bioretention cell. The second collection site was at the point when water left the sewer. The samples collected at this location will be called "influent" in the following sections. Time-sequence samples at this location were collected using a programmable auto-sampler (ISCO 6700, `Teledyne Isco, Inc`) with an attached flow meter. Twenty-four 300mL glass bottles in the auto-sampler were used to temporarily store the samples. When the water depth at this collection

point reached 1 inch, the auto-sampler was triggered to collect samples. A program was set to collect both the first flush samples and the entire duration samples. For the first flush samples, the auto-sampler was set to collect 250mL samples every five minutes for half an hour. For the entire duration samples, it was set to collect 250mL samples every 15 minutes until all the 18 bottles were filled or no signal was sent to the auto-sampler.

The third collection site was at the underground drainage pipe before the treated runoff flows into Mize Lake. Composited samples were collected from this location using an automated sampler and flow meter (ISCO 4210, Teledyne Isco, Inc.). Time-sequence effluent samples were obtained also by using an ISCO 6700 between June 2009 and August 2009. Grab samples from the effluent pipe were also obtained, usually within 24 hours of rainfall event.

After each rainfall, all the samples were taken back to the laboratory within 24-48 hours of collection. For the time resolved sample sequences, every four samples were combined in a 1L plastic bottle, with each bottle representing one hour composite sample. All samples were stored at 4^oC until analysis.

Fig. 5 Collection bottle and the mesh trap

Fig. 6 The inlet to the bioretention cell

Fig. 7 Inside of the overflow structure and the drainage pipe

Analytical Methods

Particles and Metal Analysis

Total suspended solids were determined according to the standard method 2540D procedure (American Public Health Association et al, 2005). 50mL of each water sample was filtered through Whatman 0.7-µm GF/F glass-fiber filters (Fisher Scientific). Filters and weight plates were weighed before filtering. After filtering, the solids and filters were then placed in the oven at 95°C for at least one hour until the mass weight did not change. The solids and filters were then re-weighed after drying. For dissolved metal analysis, water samples were filtered through 47-mm diameter 0.45-µm nylon filters (Fisher Scientific) and preserved with trace metal grade, concentrated nitric acid. For total metal analysis, concentrated nitric acid was added into the filtered water samples at a 10:1 sample: acid ratio and then each sample was digested in a SCP Science DigiPrep MS digestion block for 60 minutes at 95°C. Each sample was allowed to cool to room temperature and then refrigerated at 4°C. These samples were analyzed through flame or graphite-furnace atomic absorption spectrophotomey (AA 240 and GTA 120, Varian Inc.) depending on their concentrations.

Nutrients Analysis

Anion analyses were performed using ion chromatography (ICS-2000, Dionex Corp.) for chloride, sulfate, nitrate and phosphate with a hydroxide eluent

column. Total Nitrogen, total Phosphorus and NH_4-N concentrations were analyzed by UV spectrophotometer (SHIMADZU, UV-1650PC spectrophotometer, Columbia, MD) following standard methods 4500-Nitrogen and 4500-Phosphorus (American Public Health Association et al, 2005). Total nitrogen standards were made using analytical grade potassium nitrate (KNO_3) at concentrations from 0 to 3000 µg-N/L. Reagent grade potassium monobasic phosphate (KH_2PO_4) at concentrations from 0 to 500 µg-P/L were prepared for TP standards. Total organic carbon (TOC) was not measured due to the disruption of the TOC machine from November, 2008 to October, 2009.

Chapter 4

Results and Discussion

Precipitation and Hydrology Analysis
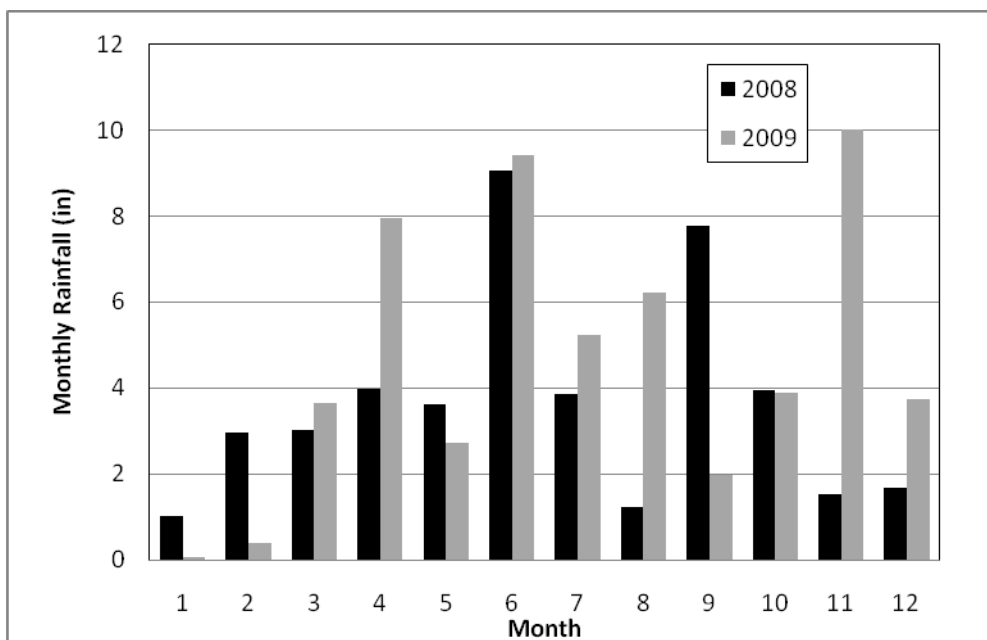
Fig. 8 Average monthly rainfall depth (in) from 2008 to 2009.

According to research reports of the National Climatic Data Center (Climate of Kansas, NCDC), the climate of Kansas is described as a continental climate which is not affected by any major bodies of water. The majority of the annual precipitation occurs during summer and spring. Floods are usually generated by intense rainfall events in these two seasons. Figure 8 shows the average monthly rainfall depth from 2008 to 2009. Rainfall in both years was greater than the typical yearly value of 39.7

inches, at 43.7 and 63.3 inches respectively. Our sampling period was from January 2008 to September 2009. Most of the time, the bioretention cell performed well in drainage. The only exception occurred on June 5, 2008 with about 5 inches total rainfall and near 0.7 feet standing water at the staff gage on site, which caused sustained inundation of the bioretention cell for about 40 hours and the only sustained use of the overflow sewer during the sampling period. Figure 9 shows the observed drawdown for this rainfall event. The average infiltration time was calculated to be 0.19 in/hr by observing this drawdown (Young, 2010).

Because of the perforated plastic pipes, a part of runoff and rainfall go into the underdrain pipe directly without treatment in the first few hours. A much longer time is needed for the runoff to filter through the bioretention cell to get treated. Figure 10 shows an example of the effluent water depth versus time since rainfall event for a storm that occurred on 10/14/2008. The steep peak occurred in the first 3 to 4 hours followed by a sharp decrease, which was due to the contribution of runoff from the perforated plastic pipe. Some settling and suspended solids got removed during this period. Flat flow which was treated by the bioretention cell lasted more than 20 hours after the peak. The area ratio of peak and flat flow is about 1.1 to 1.
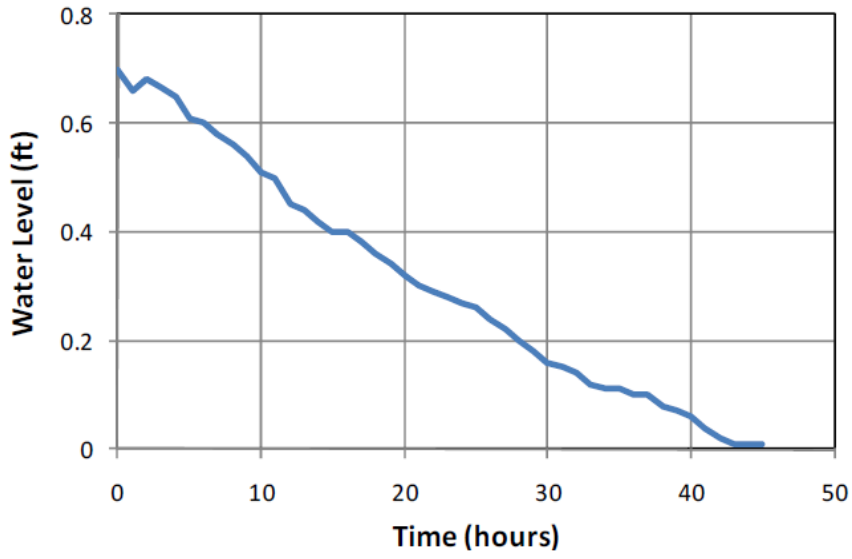
Fig. 9 Observed drawdown versus time for 6/5/08 storm (Young, 2010)
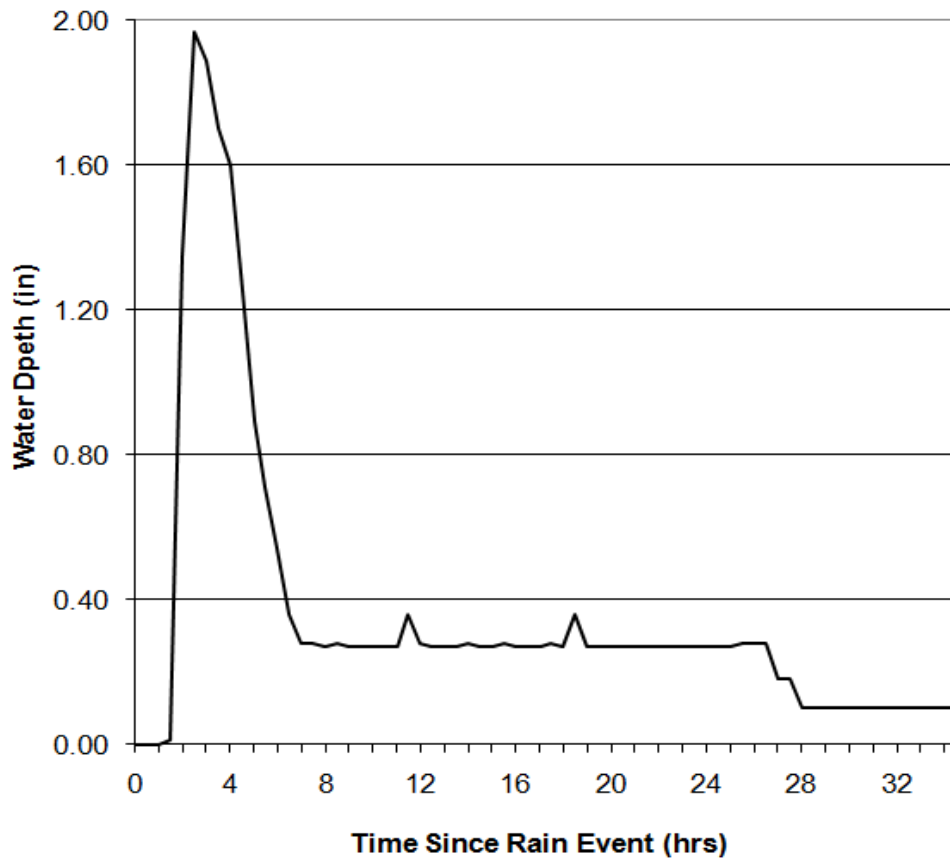
Fig. 10 Effluent water depth versus time for 10/14/2008 storm.

Stormwater quality

Particles and Heavy Metals

Table 3 Concentrations of suspended solid and metals at three sampling locations. (Unit: µm/L)

		TSS (mg/L)	Total Cu	Dissolved Cu	Total Zn	Dissolved Zn
sewer	median	108.6	67.3	11.0	205.2	29.5
	mean	310.2	98.4	11.0	293.0	58.8
	range	4.6-3130.4	24-293.2	7.0-16.0	45-1470.3	8.1-371.3
influent	median	24.5	29.0	5.9	115.3	23.8
	mean	55.7	50.1	7.4	134.5	28.2
	range	3-275.1	9.6-124.8	BDL-18	56-318	11.4-67.9
effluent	median	5.8	22.4	12.3	45.6	7.3
	mean	15.6	20.7	11.4	52.8	14.8
	range	BDL-234.8	BDL-48.0	BDL-18.0	24.1-186.6	BDL-83.7

Note: BDL means below the detection limit.

Table 4 Significant decreases in sewer, influent and effluent concentrations.

		Significant? ($P<0.05$)	
TSS	Sewer/Influent	Yes	($P<0.0005$)
	Influent/Effluent	Yes	($P<0.0005$)
	Sewer/Effluent	Yes	($P<0.0005$)
Total Cu	Sewer/Influent		No
	Influent/Effluent		No
	Sewer/Effluent	Yes	($P<0.005$)
Dissolved Cu	Sewer/Influent		No
	Influent/Effluent		No
	Sewer/Effluent		No
Total Zn	Sewer/Influent	Yes	($P<0.0005$)
	Influent/Effluent	Yes	($P<0.0005$)
	Sewer/Effluent	Yes	($P<0.0005$)
Dissolved Zn	Sewer/Influent		No
	Influent/Effluent	Yes	($P=0.0038$)
	Sewer/Effluent	Yes	($P=0.0031$)

Table 3 provides stormwater quality data obtained from all three collection sites from 2008 and 2009. Values of mean, median, and range for suspended solids, total and dissolved metals and nutrients are all listed in the table. Significant test results for the samples are noted in the Table 4. It is easy to see that TSS mean values for each sampling location are significantly larger than their median values. These mean values were strongly influenced by several storm events in April of 2008 during which the TSS concentrations at sewer location were more than 1000 mg/L. For one rainfall event, TSS was 30 times the median value. Excluding these storms from the results, TSS mean values at the sewer are similar to the median ones, and they are comparable to those from Characklis et al (1997) study which showed an average TSS concentration of 100-200mg/L. There was a significant ($P<0.0005$) decrease in the concentrations of TSS in each sampling location. Comparison of the TSS median concentrations in each location showed that the cell influent TSS concentration was, on average, 77 percent lower than those in sewer samples. The TSS concentration of the effluent samples was, on average, 96 percent lower than the sewer samples. The highest TSS values for effluent were from the samples collected in June 27 and 30, 2008, for which most of the suspended solid was contributed by biomass from the underdrain pipe. Since the only inundation and overflow occurred in the middle of June, the biomass could be from the bio-film coating of the drain pipe. Excluding these high TSS effluent values would decrease the mean value to a level much closer to the median.

Table 3 also shows dissolved and total copper and zinc concentrations at all three sample locations between 2008 and June 2009. Comparing the median values at each sampling location indicates that all concentrations decreased from one collection location to the next except for dissolved copper. The effluent concentration of total Cu was, on average, 65% lower than the sewer concentration while no obvious decrease was found between the influent and effluent concentrations. The influent concentration of total Zn was, on average, 44% lower than the sewer concentration while the effluent concentration was approximately 60% lower than the influent. Compared with the relatively large reduction of total metals by the mesh trap, the change for dissolved metals was much less. For dissolved copper, the sewer concentrations were similar to the effluent concentrations, and no significant decrease can be seen in this bioretention system for dissolved copper. Low influent and high effluent concentrations suggest that the system is already saturated for dissolved copper and the dissolved copper might be leaching from the bioretention cell. Similar results were observed by Hunt et al (2006) for iron. The dissolved Zn concentration for influent was 19% less than the sewer and the effluent was about 70% lower than the influent. These results suggest that most of copper and zinc was affiliated with total suspended solids and removed by the mesh trap in the sewer entrance, while the dissolved portion of metals went into the bioretention cell with the runoff. Similar results were observed in the study of Herngren (Herngren et al, 2006) which indicated that the 0.45-75µm particle size fraction had the dominant sediment loading and was the most polluted one.

<u>Nutrients</u>

Table 5 Concentrations of nutrients for three sampling locations.

(Unit: µg/L)

		TP*	Phosphate+	TN *	NO$_3$-N	NH$_4$-N*
	median	247.2	79.9	1624.1	496.3	166.8
Sewer	mean	296.6	127.4	1817.0	899.4	631.7
	range	75.3-895.2	188.8-1121	260-3782	204.7-3565.5	46-2489.6
	median	93.8	74.6	1571.4	772.4	641.5
Influent	mean	165.8	114.7	1969.9	905.7	537.8
	range	23.4-724.0	184.3-631	676.7-4607	271.1-2265.1	40.8-948.0
	median	91.4	81.3	815.2	238.9	154.4
Effluent	mean	99.9	108.5	1029.3	314.1	152.8
	range	28.9-371.4	187.1-582.9	640.8-3300	109.0-668.6	25-277.2

* 2009 only   + 2008 only

Table 6 Significant decreases in sewer, influent and effluent concentrations.

		Significant? (P<0.05)	
TP	Sewer/Influent	Yes	(P<0.0005)
	Influent/Effluent	Yes	(P=0.0020)
	Sewer/Effluent	Yes	(P=0.0010)
Phosphate	Sewer/Influent	No	
	Influent/Effluent	No	
	Sewer/Effluent	No	
TN	Sewer/Influent	No	
	Influent/Effluent	Yes	(P=0.0050)
	Sewer/Effluent	Yes	(P=0.0046)
NO$_3$-N	Sewer/Influent	No	
	Influent/Effluent	Yes	(P<0.0005)
	Sewer/Effluent	Yes	(P=0.0012)
NH$_4$-N	Sewer/Influent	No	
	Influent/Effluent	Yes	(P=0.043)
	Sewer/Effluent	No	

Table 5 provides nutrient data at each sampling location and the significant analyses are listed in the Table 6. The average concentrations of TP, TN and NH_4-N are from 2009 samples. Because of the below detection limit values for Phosphate concentrations in 2009 samples, Phosphate concentration presented here are only from 2008 samples. For total phosphorus, the influent concentration was significantly ($P<0.0005$) lower than the sewer concentration which indicated that phosphorus can affiliate with particulates which were filtered by the mesh trap. Although there was no distinct differences observed between influent and effluent concentrations for TP, reduction could be seen when comparing influent and effluent concentrations during individual storms. Dissolved phosphorus, which was determined as phosphate, had minimal differences in the concentrations between each sampling location.

Sewer and influent concentration were similar for total nitrogen, while the effluent concentration was about half of these values ($P=0.005$). The median NO_3-N concentrations in the effluent from the bioretention cell were about 70 percent lower than the bioretention influent, and the median sewer NO_3-N concentration was about 60 percent of the influent concentration. There was no obvious decrease in the concentrations for both NO_3-N and NH_4-N between the sewer and influent. The possible reason for the low sewer concentrations were that a long duration runoff would dilute the concentrations of the dissolved pollutants in the 1L sewer sampling bottles, which caused the concentrations determined in the lab to be reduced. The median sewer concentration of NH_4-N was comparatively lower than similar studies (Wu et al 1996) in which a range of 2390-220 µm/L for NH_4-N was observed. The

average sewer concentration for NH_4-N was comparable to the influent, although decreases were seen in individual storm event. Effluent NH_4-N concentration, on average, decreased 76 percent from the influent concentration. Nitrification is assumed to be the most possible way for the concentration reduction of NH_4-N in bioretention cell.

Time Resolved Samples

Trends of water quality in each storm were remarkably similar. Concentration peaks appeared within the first half hour and were followed by a relatively steady decrease in the following sampling hours. Figure 11 shows the trends of influent concentrations for total suspended solid, total and dissolved Zn and nutrients on March 30, 2009. This trend of concentration of pollutants exhibits a concentration-based first flush (CBFF) which is defined by high initial suspended solids concentrations in the early portion of a rainfall-runoff event with a subsequent rapid concentration decline (Sansalone et al, 2004). This characteristic of first flush implies that catching the early portion of the events is critical for controlling the high pollutants concentrations.

Figure 12 shows the trend of outlet concentrations for total suspended solids and nutrients on July 7, 2009. Similar trends were also observed in the effluent concentrations from other storms. High initial pollutant concentrations appeared in the early portion of effluent samples and no significant decrease were found in the followed sampling hours. The similarity between the trends of influent and effluent concentrations suggests that the effluent concentrations were highly correlated with influent concentrations. One difference between the trend of influent and effluent is that near the end of the sampling time the effluent pollutants concentrations increased a little. The reason for this phenomenon has not been found yet.
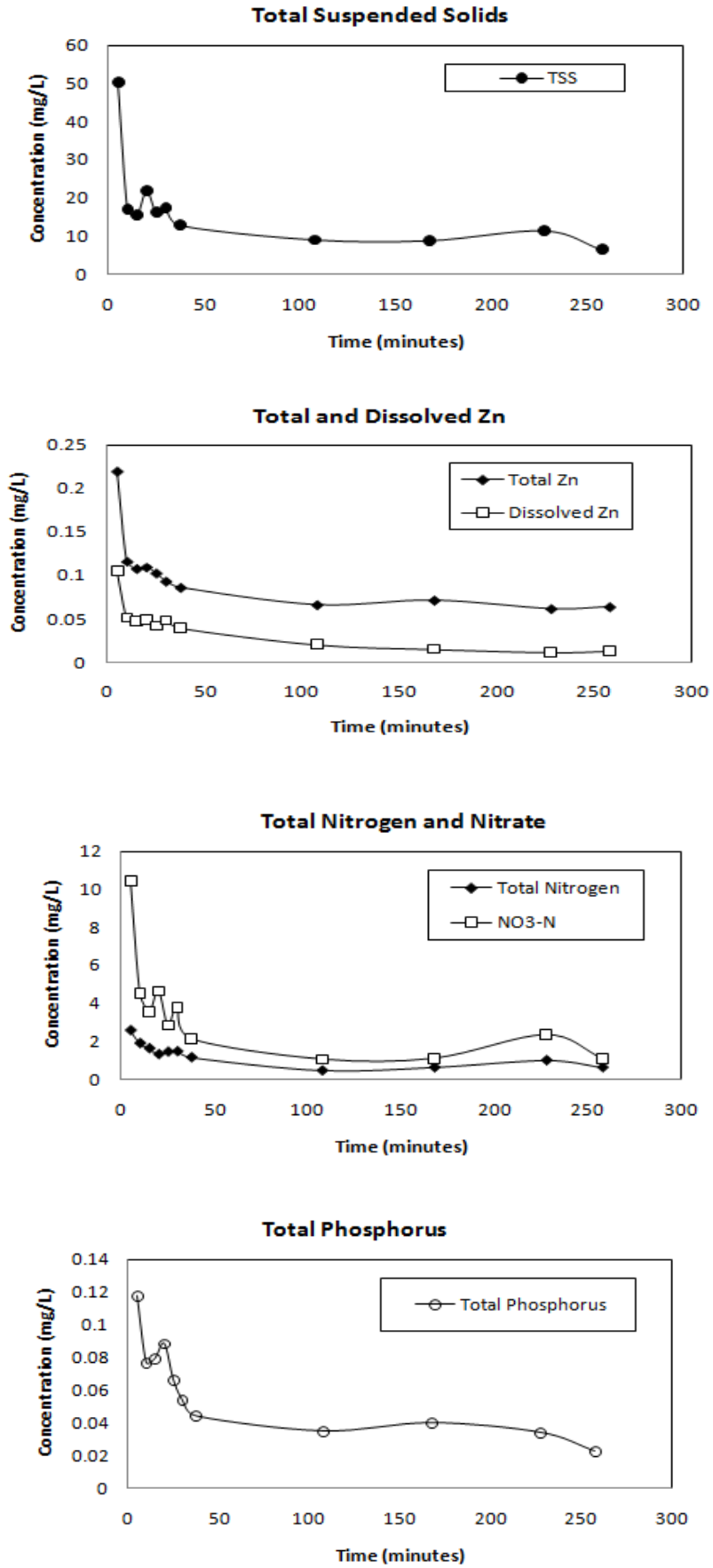
Fig. 11 Influent pollutants concentrations on March 30, 2009.
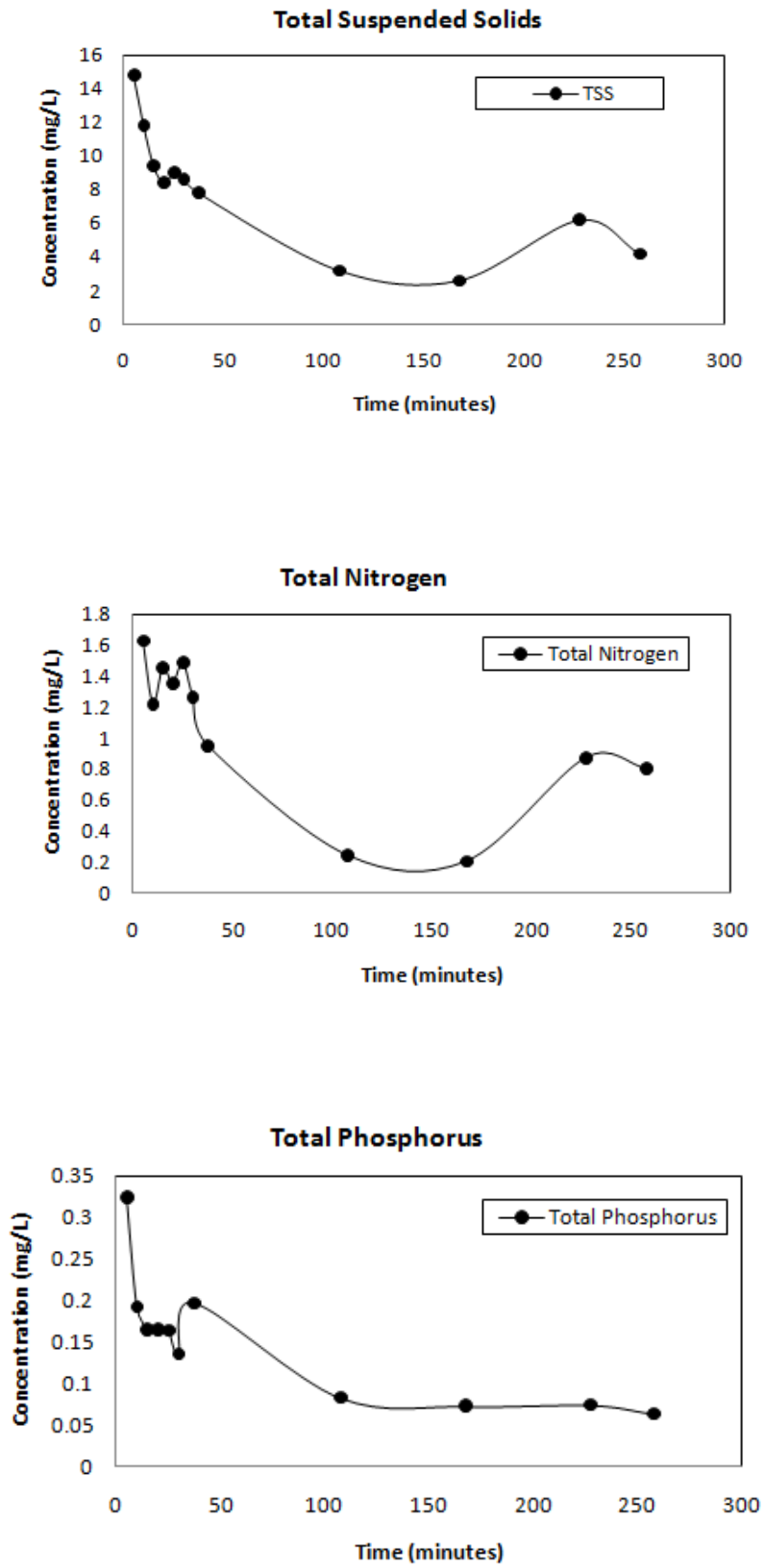
Fig. 12 Effluent pollutants concentrations on July 7, 2009.

Bioretention Cell Performance
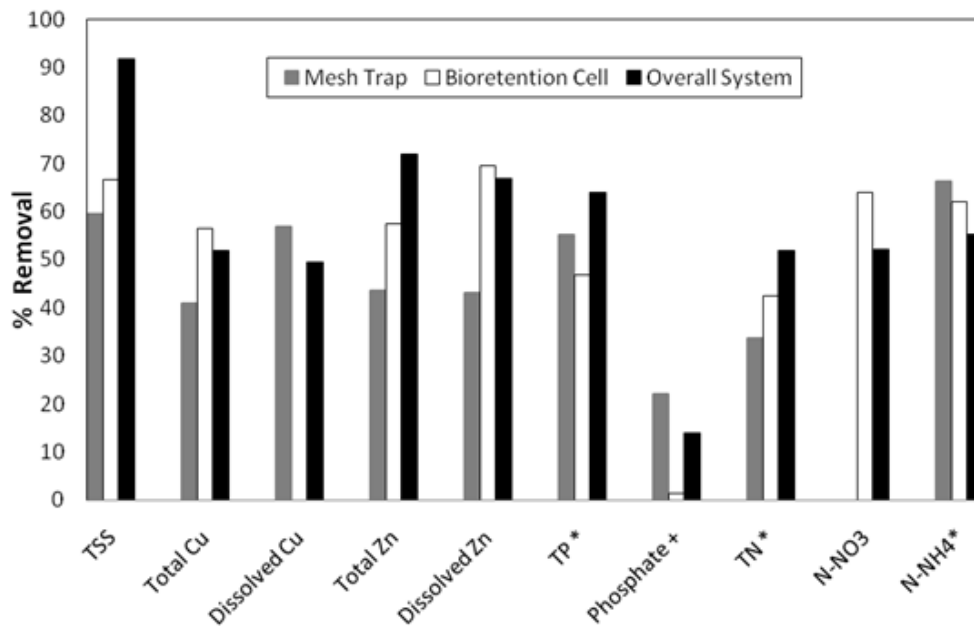
Fig.13 Pollutants removal rate in the each components of the bioretention system.

(+ 2008 only *2009 only)

Note: No removal was found for dissolve Cu by bioretention cell. Also, no removal was found for NO_3-N by mesh trap.

Sewer, influent and effluent concentrations of each pollutant were compared on a storm-by-storm basis, and average removal rates were calculated for each components of the bioretention system: mesh trap, bioretention cell and the overall system. TSS concentrations were reduced by 60%, 67% and 90% with the mesh trap, bioretention cell and the overall system, respectively. This result suggests that the mesh trap removed the majority of TSS. Low TSS effluent concentrations indicated that there was no media loss from the bioretention cell, which had been found in other site studies (W.F.Hunt 2008). Total Cu and Zn effluent concentrations were 50% and 68% lower, respectively, than sewer concentrations.

When only considering the performance of the bioretention cell itself, removal rates for total copper and zinc (56% and 60%) were both comparatively lower than those previous reported results (Davis et al, 2003); with the existing of the mesh trap, the total removals were comparable to those other findings. Because laboratory and pilot studies implicated that the mulch layer over the soil was the most important component for metals removal in bioretention cell (Davis et al. 2001), the possible reason for a low metal removal was that the mulch layer was redistributed after flood which would reduce the effect of removal. Another possible reason is that, because of the mesh trap, only small particles entered the cell, which are more difficult to capture.

Effluent concentrations of TP, Phosphate, TN, NO_3-N and NH_4-N were 68%, 15%, 55%, 52% and 55% lower, respectively, than sewer concentrations. Mesh trap removal was significant for TP and NH_4-N, and this can be explained that phosphorus and NH_4-N have a strong affinity for particulates, which can be removed by the mesh trap. The bioretention cell itself provided about 50 percent removal for total nitrogen, while the removal rates for NO_3-N and NH_4 –N were both approximately 70 percent. Since total nitrogen is assumed to be the sum of NH_4 –N, NO_3-N and organic nitrogen and there is a higher proportion of organic nitrogen in TN (Taylor et al, 2005), our results indicate that the removal rate for organic nitrogen in the cell would be lower than 50 percent. High removal for NO_3-N in the bioretention cell suggests that some denitrification may happen in the deeper level of the media where anoxic conditions exist. This result is better than

the previous field studies (Hunt, 2008; Davis et al, 2006) but not comparable to those findings of field sites with saturated zones (Dietz and Clausen, 2006) or internal water storage (Hunt, 2006) where denitrification can increase NO_3-N removal.

Phosphate removal (Figure 13) indicated that there was little removal for dissolved phosphorus by the mesh trap and bioretention cell, although there were several storm events in which a removal of phosphate was observed in the bioretention system. The result of no removal for dissolved phosphorus by bioretention cell was similar to other previous study (Hunt et al, 2006), in which it suggested that Phosphorus-index of the cell media was important for the phosphorus adsorption, and a lower P-index (4-12) would be more helpful in accepting phosphorus. Since the dissolved phosphorus cannot be removed by sedimentation or converted to gaseous form, the possible way for the dissolved phosphorus to be removed is uptake by vegetations, which means that removal of dissolved phosphorus will be a long-time issue.

Table 7 Removal rates of pollutants for year 2008 and 2009

	Year	Mesh Trap	Bioretention cell	Overall System
TSS	2007*	62%	78%	90%
	2008	63%	77%	91%
	2009	56%	56%	93%
Total Cu	2007*	66%	33%	77%
	2008	43%	57%	55%
	2009	39%	56%	49%
Dissolved Cu	2007*	25%	47%	41%
	2008	59%	2%	54%
	2009	55%	-109%	45%
Total Zn	2007*	50%	-4.5%	41%
	2008	49%	55%	74%
	2009	38%	60%	70%
Dissolved Zn	2007*	40%	-15%	21%
	2008	41%	52%	57%
	2009	46%	86%	77%

*2007 data are from previous study.

Table 7 shows the average removal rates of pollutants for each sampling year. No obvious overall trend was found in the bioretention cell with the exception of increasing removal effect for total and dissolved Zn year by year, especially for dissolved Zn. There was a decrease of the removal rate for total suspended solids and total metals in the mesh trap. The removal provided by mesh trap for TSS, total

Cu and Zn in each year were all moderately lower than the values of the year before, which might be caused by aging of the mesh trap. Therefore, periodic cleaning and maintenance is especially necessary for the mesh trap.

Plants are assumed to be an important factor for the performance of the bioretention cell, especially for long-term pollutants removal. It is hypothesized that bioretention cell would perform better in spring and summer than in other seasons because plants growth is maximum in these seasons. However, our data cannot provide evidence for this hypothesis.

Chapter 5

<u>Conclusion and Recommendation</u>

Results of stormwater samples collected in the field site showed that stormwater runoff from Mize Boulevard is typical paved surface runoff which contains elevated concentrations of suspended solids and total Cu and Zn. Large differences between the sewer concentrations of total and dissolved concentrations indicate that the majority of copper and zinc fond in road runoff is associated with particles. Removal rates of the overall system for suspended solids and total metals were comparable to other bioretention cell performances reported in many published literature, but was not as high as those from lab studies. Apparently, sediment trap in the storm sewer plays a substantial role in removing of solids and solids associated contaminants before they are loaded into the bioretention cell. Besides the removal effect for particles, the sediment trap may also help prolong the lifespan of the bioretention cell by preventing soil media clogging and metals accumulation in the mulch and soil layer. Decreases in the removal rates for particles of the sediment trap over time suggest that periodic clean and maintenance for the sediment trap is necessary to maintain the removal effect. For dissolved solids, good removal rates were observed for Zn, while removal rates were low or negative for Cu in the bioretention cell. Decreases in the removal effects for

dissolved copper in bioretention cell year by year indicated that there was washout of copper in the soil mixture.

The overall reductions for total phosphorus, total nitrogen, and NH_4-N in the whole system were comparable to many prior field studies. 60 and 70 percent removal for total phosphorus and NH_4-N by the sediment trap implies that phosphorus and NH_4-N are more readily removed along with particulates. The removal rates observed for nitrate by the bioretention cell were comparable to those obtained through denitrification, which indicates that anoxic zones existed in the bottom portion of the bioretention cell. Phosphate, which is assumed to be one of the most difficult pollutants to remove, saw almost no reduction by the bioretention cell. Use of soil mixture with a low Phosphorus-index is recommended for the phosphate adsorption. The lack of phosphate removal during the two-year study period suggests that phosphorus uptake by vegetations will be a long-time issue. Periodic cutting of plants in the bioretention cell may be helpful in eliminating the accumulation of nutrients.

Removal rates were calculated using the influent and effluent concentrations and were not adjusted for any water volume change in evaporation and/or transpiration within the bioretention cell. It could be more accurate to calculate the removal rates by comparing the entering and existing mass loadings of the contaminants in bioretention cell. Because of the total water volume change, the effluent concentrations of pollutants would be increased and the removal rates

would be reduced. However, mass loading was not determined during this study period due to insufficient flow rate data.

Hydrology results from the bioretention cell suggest that a large portion of the overflow will discharge pollutants into the Mize Lake directly without treatment. Longer drawdown time is necessary for the runoff to be treated as much as possible.

Further studies will be conducted to analyze accumulation and fate of nutrients in the bioretention cell, especially for nitrogen. The results of this study will aid in the design and planning bioretention systems for better performance under climate and soil conditions found in the Kansas and Great Plains region.

Chapter 6

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Appendix

Pollutants concentrations used to calculate removal rate of each locations.

	TSS (mg/L)			Total Cu (µg/L)			Dissolved Cu (µg/L)			Total Zn (mg/L)			Dissolved Zn (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent
01/16/08	514.6		18.6	7.180		2.430				0.3713		0.0772			
01/27/08	121.8		0.0	3.950		1.460				0.2457		0.0586			
02/03/08	52.2		7.4	3.990		1.350				0.2149		0.0593			
02/19/08	458.4		7.4												
02/24/08	170.8		7.0	8.520		2.180				0.4652		0.0532			
03/18/08	452.2		9.6	6.690		1.660				0.5198		0.0446			
04/04/08	1782.0	203.4	4.6	0.860	4.980	0.830				0.1521	0.3180	0.0550			
04/09/08	93.2	16.6	0.2	2.410	3.150	0.540				0.3267	0.0974	0.0335			
04/11/08	30.4	22.2	2.0	0.530	1.800	0.650				0.0747	0.1444	0.0542			
04/16/08				4.860	3.440	0.740				0.3470	0.2330	0.0370			
04/18/08	3130.4	153.6													
04/23/08	899.2	225.2	0.4	8.850	4.010	0.080				0.4560	0.2673	0.0241			
04/25/08		39.0	5.8		3.460	1.270					0.1170	0.0387			
04/30/08	41.8	11.8	4.6	2.350	4.470	2.700				0.0989	0.0736	0.0297			
05/02/08	112.4	75.2	0.2							0.1176	0.1712	0.0456			
05/14/08	182.0	41.4	1.4							0.3710	0.1063	0.0398			
05/23/08	294.0		5.4							0.2671		0.0460			
05/27/08		45.4	0.0			4.140				0.1738	0.0737	0.0390			
06/03/08	46.8		3.2	1.120	4.180	4.570				0.0997		0.0417			
06/06/08		108.8	10.9								0.0941	0.0358			
06/10/08	45.0	38.6	26.2	6.060	8.730	4.860	3.898	3.456	2.711	0.1515	0.0604	0.0406	0.0239	0.0151	0.0144
06/13/08	653.6	92.8	3.4	11.570	5.020	6.130	7.897	2.986	3.544	0.3788	0.0830	0.0474	0.0123	0.0123	0.01015
06/18/08	114.2	12.4	42.2	8.250	4.510	4.890	4.321	1.09	1.119	0.1782	0.0560	0.0412	0.0183	0.0191	0.0078
06/20/08	76.4	22.4	16.1	10.050	6.956	6.890	4.347	3.211	1.234	0.1490	0.0701	0.0584	0.0229	0.0127	0.0127

	TSS (mg/L)			Total Cu (µg/L)			Dissolved Cu (µg/L)			Total Zn (mg/L)			Dissolved Zn (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent
06/27/08	94.8	24.4	234.8	9.800	7.283	3.920	3.912	3.222	1.986	0.1482	0.1674	0.0470	0.0155	0.0357	0.0023
06/30/08	81.2	55.6	133.2	7.370	6.823	7.290	2.345	3.216	1.235	0.1622	0.1733	0.0485	0.0135	0.0243	
07/03/08	59.8	22.7	14.8	8.850	5.894	4.250	3.456	2.357	2.845	0.1420	0.1118	0.0420	0.0239	0.0151	0.0144
07/11/08	235.0	35.0	4.7	9.210	4.670	5.955	1.946	0.984	0.482	0.2930	0.0980	0.0323	0.0229		0.01015
07/16/08	38.8	30.7	1.2	6.120	1.884	0.000	2.997	0.476	0.012	0.0708	0.0828		0.0183	0.0191	0.0078
08/01/08	264.6	22.2	14.4	2.190	1.977	2.260	0.965	0.537	0.321				0.0567	0.0342	0.0127
08/27/08	4.6	16.3					0.0753	0.4632		0.0961	0.1085		0.0135	0.0357	0.0023
09/02/08							2.345	3.216	1.235				0.0123	0.0243	
09/05/08	118.6	14.4					3.456	2.357	2.845	0.1666	0.0880	0.0630	0.0764		0.0221
09/09/08		23.4	5.5				0.183	0.191	0.078		0.1226		0.0183	0.0191	0.0078
09/12/08	123.2		5.6				2.197	0.476	0.012	0.3819		0.0672	0.0567	0.0342	0.0127
09/15/08	23.0	11.3	6.9				0.965	0.537	0.321		0.1008	0.0821	0.0135	0.0357	0.0023
09/26/08	34.0	20.4					0.627	0.214		0.1825	0.1074		0.008	0.002	
09/30/08	88.0	24.2		1.510	1.946		0.0753	0.4632		0.0450	0.1655		0.0455	0.2340	
10/07/08	55.3	26.2	2.8	2.060	1.944	0.760	0.9840	0.8780	0.4440	0.3476	0.1949	0.0920	0.0980	0.0654	0.0112
10/14/08	18.6	6.3	0.4	0.670	1.257	0.440	0.112	0.332	0.11	0.1425	0.1272	0.0892	0.0135	0.0357	0.0023
10/17/08	37.8	8.3	0.6	0.240	2.265		0.093	0.022		0.1511	0.1768		0.0123	0.0243	
10/20/08				1.240	0.980	0.556	0.252		0.088	0.2750	0.1230	0.0980	0.0764		0.0226
10/23/08		11.4	1.8		6.540	3.450					0.9800	0.2313			
10/24/08					4.090	3.440					0.7645	0.1769			
10/28/08		24.5	6.8		8.130	3.450					0.1238	0.0342			
11/13/08	31.8	27.9		0.450	1.570					0.8983	0.7869				
12/01/08				0.980	0.990	0.120									

	Nitrate (mg/L)			Phosphate (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent
01/08/08	0.9066		0.4826	0.6203		0.5476
01/16/08	25.0637		1.6291			
01/27/08	3.0978		1.1534			
02/03/08	7.8651		3.1749			
02/19/08	1.4617		0.9835	0.6713		0.5298
02/24/08	4.4221		1.4258			
03/18/08	15.7904		1.01144	0.5667		0.5635
04/04/08		3.342	0.9086			
04/09/08	3.9586	15.1112	1.1162			
04/11/08	1.2669	1.9488	0.8198			
04/18/08	1.3625	2.5422	0.7167	0.5626		0.5276
04/23/08	2.2709	3.1753	0.8205	0.5330	0.5792	0.5790
04/25/08		5.9994	0.9588		0.5929	0.6079
04/30/08	3.9073	4.2631	1.4196	0.5416	0.5167	0.6067
05/02/08	2.1206	3.2211	0.7734	0.5436	0.5521	0.5547
05/14/08	1.6613	2.2983	2.28		0.5443	
05/23/08	5.5792		0.842			
05/27/08	1.9669	1.7259	2.2643	0.5697	0.5396	0.7896
06/03/08	1.4365		0.9589	0.6252		0.6385
06/06/08		1.515	0.90255		0.5745	0.6726
06/10/08	1.2499	1.2007	0.7598	2.4159	0.7279	0.9852
06/13/08	1.8004	4.665	0.58595	0.7543	0.5781	1.0926
06/18/08	1.8128	4.432	0.7157	0.6971		0.9164
06/20/08	2.5442	4.23688571	2.5007	1.0768	0.5984	0.9089

	Nitrate (mg/L)			Phosphate (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent
06/27/08	2.1855	4.50651429	1.83355	3.0000	1.7689	
06/30/08	2.8841	4.2419	1.7772			1.3958
07/03/08	2.2106	10.0310333	1.8105	1.4641	1.4041	1.7728
07/11/08	3.7674	1.83465	2.7002	1.8045	1.7603	1.5325
07/16/08	1.837	3.49922727	2.961	1.6108	1.5908	1.5325
08/01/08	1.8075	3.78157778	2.4246	1.5003	1.5146	0.5547
08/27/08	1.594	4.07535556			0.5443	0.8096
09/02/08	1.2669	2.001	0.8198	0.5697	0.5396	0.6385
09/05/08	1.3625	2.5422	0.7167	0.6252		
09/09/08	2.2709	3.1753	0.8205			
09/12/08		6.001	0.9588			
09/15/08	3.9073	4.2631	1.4196		0.5745	0.6726
09/26/08	2.1206	3.2211	0.7734	2.6159	0.7279	0.9852
09/30/08	1.6613	2.2983	2.28	0.7543	0.5781	1.0926
10/07/08	5.5792		0.842	0.7071		0.9164
10/14/08	2.001	1.7259	2.2643	1.0768	0.5984	0.9089
10/17/08	1.4365		1.011			
10/20/08	1.8128	4.432	0.7157			
10/23/08	2.5442	4.562	2.5007			
10/28/08				3.2580	1.7689	
11/13/08				1.4641	1.4041	1.3845
12/01/08				0.5330	0.5792	0.5790
12/11/08				0.5436	0.5521	0.2256

	TSS (mg/L)			Total Cu (µg/L)			Dissolve Cu (µg/L)			Total Zn (mg/L)			Dissolved Zn (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent
03/25/09	181.2	45.9	21.9	25.0	9.0	1.0	13.0	1.0	1.0	0.2481	0.1998	0.1866	0.0933	0.0679	0.0837
03/30/09	104.8	17.7	7.8	29.0	10.0	9.0	11.0	7.8	15.0	0.2111	0.1031	0.0570	0.0553	0.0417	0.0219
04/03/09	123.9	71.1	13.5	12.0	9.0		7.0	4.8		0.1860	0.1268	0.0400	0.0738	0.0238	
04/07/09	20.4	3.0	1.8		0.0			5.9			0.0677	0.0120		0.0304	
04/10/09	303.1	99.8		56.0	12.0	32.0	11.0	3.7	8.0	0.2682	0.2124		0.0667	0.0227	0.0006
04/15/09				20.0	0.0	10.6	10.0		9.5				0.0524		0.0033
04/22/09	709.5	275.1	34	33.0	23.0	20.0	9.0	11.4	17.0	0.1166	0.1376	0.0346	0.0295	0.0158	0.0001
04/28/09	376.8	186.4	16.9	76.0	34.0	23.0	16.0	17.5	18.0		0.1677	0.0418	0.0081	0.0119	0.0000
05/01/09	153.2	65.9								1.4703	0.1066	0.0380	0.0590	0.0114	0.0046
05/08/09	42.2	22.4					9.0	12.4	11.2	0.1780	0.1255		0.0291	0.0398	0.0043
05/14/09	60.3	19.8								0.1280	0.1153		0.0540	0.0503	
05/22/09	800.3	228.4					19.8	16.6	15.1	0.4540	0.2121				
05/27/09	50	22.2								0.1076	0.1133	0.0348			
06/01/09	76.5	14.5								0.3320	0.1136		0.0980	0.0040	
06/03/09	99.9	83.6		14.0	10.0	8.9				0.4490	0.1837		0.0120	0.0043	
06/08/09	88.4	71.3								0.1993	0.1763	0.0472			
06/09/09	263.8	90.7		48.0	37.0	30.0				0.2818	0.1744				
06/15/09	80.9	26.0	12.7	67.0		43.0	15.0		14.0				0.0122		0.0067
06/16/09	267.5		5.8	27.0		9.0	12.0		9.0	0.0980		0.0442	0.0111		0.0089
06/17/09	123.2		4.9	54.7		33.8	22.0		27.0	1.0600		0.0436	0.0980		0.0540
07/07/09	98.1		8.4	67.4		10.8									

	Total P (mg/L)			Total N (mg/L)			NH₄-N (mg/L)			NO₃-N (mg/L)		
	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent	sewer	influent	effluent
03/25/09	0.283	0.302		3.235	4.607					3.437	3.326	0.079
03/30/09	0.151	0.054	0.114	1.803	1.213	1.015				1.641	3.624	0.683
04/03/09	0.221	0.047	0.091	2.548	0.984	0.822				1.747	1.062	
04/07/09				1.303	1.213						2.793	
04/10/09	0.328	0.192	0.099	1.623	0.952	1.297				2.253	1.528	
04/15/09	0.075		0.097	0.832		0.677				1.050		
04/22/09	0.649	0.347	0.065	1.062	0.677	0.227	2.490	0.948	0.277		2.374	0.765
04/28/09	1.633	0.228	0.114	2.157	1.357	0.371	0.803	0.817	0.241		3.775	0.879
05/01/09	1.055	0.081	0.091	0.596	1.179	0.815					1.375	0.032
05/08/09	0.116	0.092	0.089	1.622	1.517	0.065				0.125	3.300	0.099
05/14/09	0.118	0.084		1.259	1.815							
05/22/09		0.316		2.475	1.737							
05/27/09	0.895	0.328	0.094	3.782	1.626	0.698	0.201	0.682	0.068	0.641	0.624	0.683
06/01/09	0.154	0.275		3.597	2.656					0.847	0.124	
06/03/09		0.163	0.091	1.420	3.227	2.044	0.133	0.600	0.025		1.283	
06/08/09	0.233	0.167	0.099	2.504	3.658	2.115	0.118	0.138		1.253	0.578	
06/09/09	0.267	0.724		2.238	3.100		0.046	0.041		1.050		
06/15/09		0.073	0.157	0.623		1.367					1.374	0.865
06/16/09		0.095	0.062	0.260		0.517					1.775	0.079
06/17/09			0.082	0.527		0.517						
07/07/09				1.626		1.059						
07/21/09	0.110		0.087									
07/29/09	0.317	0.461		1.968		3.301						
08/04/09				2.998		0.592						
08/09/09	0.270		0.045									
08/10/09	0.119			1.552								