# ASSESSING HYDROLOGIC IMPACTS OF STREET-SCALE GREEN INFRASTRUCTURE INVESTMENTS FOR SUBURBAN PARMA, OHIO

A thesis submitted

to Kent State University in partial

fulfillment of the requirements for the

degree of Masters of Science

by

Kimberly M Jarden

May 2015

Thesis written by

Kimberly M. Jarden

B.B.A, The University of Akron, 2006

B.S., The University of Akron, 2013

M.S., Kent State University, 2015

Approved by

Anne Jefferson, Advisor, Department of Geology

Daniel Holm, Department of Geology, Chair

James L. Blank, Dean of A&S, College of Arts and Science

**Table of Contents**

## List of Figures

## List of Tables

**Acknowledgements**

Throughout the course of my thesis work it took the help from many people to achieve the goal of finishing. I would like to express my sincere appreciation to my advisor Anne Jefferson for her support and encouragement throughout this process. She was always able to point me in the right direction and encouraged me to meet my goals. Thank you to my committee, David Singer and Reid Coffman for their review of my research and helpful insights.

I would like to give a huge thank you to everyone on my "ancillary" committee. David Costello and Lauren Kinsman-Costello were a huge help teaching me about water quality sampling, processing, and analysis. Kelly Turner helped immensely on the homeowner survey section of this thesis, helping to bridge hydrology and social science. Thank you to John Peck for all of your support with my magnetics analysis and the use of the lab at the University of Akron.

A special thank you to the Cleveland Metroparks. Without their execution of the West Creek Ecosystem Restoration Project, this thesis research would not have been possible. I truly appreciated the opportunity to be a part of this unique project. Thank you to Jenn Greiser, from the Metroparks, for all of your help. Your input to this project was a big part of getting this research completed.

Thank you to Laurel Cope, Sidney Bush, and Sean Robertson. Without your help field and lab work would have been extremely difficult. Especially when needing to lift samplers out of manholes. Seth Hothem, from the sewer district, thank you for always being available to deploy and fix field equipment in the storm drains.

Most importantly I would like to thank my family for their continued support. They have been my biggest cheerleaders throughout grad school. A very special thank you to Erik, without out your support and encouragement, this journey would not have been possible.

**Summary**

Impervious surfaces in urban environments lead to greater runoff from storm events, overwhelm storm sewer systems, and degrade aquatic ecosystems. Disconnecting impervious surfaces from storm water systems and redirecting the flow to decentralized green infrastructure treatments can lessen the detrimental effects on urban streams. Most research on green infrastructure has focused on the performance of individual elements, whereas this project addressed the question of hydrologic impacts and pollution reduction of street-scale investments using green infrastructure, such as front yard rain gardens, street side bioretention gardens, and rain barrels. The West Creek Watershed is a 36 $km^2$ subwatershed of the Cuyahoga River that contains ~35% impervious surface. Before-after-control-impact design paired two streets with 0.1-0.2 ha. lots and two streets with 0.05-0.075 ha. lots. Flow meters were installed to measure storm sewer discharge pre– and post- green infrastructure implementation. Peak discharge and total storm volume have been reduced with the addition of green infrastructure. Results for centroid lag-to-peak, centroid lag, lag-to-peak, and peak lag-to-peak show that lag times increased on the treatment streets. For peak discharge, total storm volume, and lag time, the presence or absence of underdrains from the design of the green infrastructure appeared to have an effect on the results. Water samples collected at the end of one set of treatment and control streets' storm sewers were analyzed for heavy metal (Fe, Cu, Mn, Ni, Pb, and Zn) concentrations using ICP-OES. The pollution reduction potential of the green infrastructure treatments could not be determined due to the lack of pre-treatment sampling. However, concentrations of trace metals on both the treatment and control street were on the low end for typical urban runoff. Magnetics sampling concluded that

anthropogenic inputs were present in both tree lawns and bioretention gardens. A survey of homeowners of both treatment streets was used to contribute to the understanding of social acceptability of large-scale green infrastructure implementation and the drivers of homeowner participation. Differences in attitudes, perception, and behaviors toward green infrastructure and stormwater management were observed between residents with green infrastructure on their property versus those without. Ultimately age, education, and years lived in home were the largest predictors to positive attitudes and perceptions toward green infrastructure and its implementation to help with stormwater management.

## 1.1 - Introduction

### Hydrology

Urbanization is rapidly changing the natural landscape all around the world. Over 83% of the population in the United States resided in metropolitan urban areas in 2010 and growth in these urban areas occurred almost twice as fast as other non-metropolitan areas (US Census Bureau, 2014). All land use changes have effects on the hydrology of an area, but urbanization is among those with the most intense impact (Leopold, 1968). Urbanization causes four interrelated but separable effects on the hydrology of an area: change in peak flow characteristics; changes in total runoff; changes in quality of water; and changes in aesthetics (Leopold, 1968). As urban areas continue to expand so have the alterations of headwater streams and increases in pollution and connectivity to streams. These alterations are done through pipe networks, gutters, swales, and ditches. The changes taking place in urban environments have significant impacts on the geomorphology, ecosystems, and chemistry that distinguish urban stream networks from stream networks draining rural areas, creating what has been called “the urban stream syndrome” (Walsh et al., 2005). As the negative effects of urbanization on streams are increasingly recognized, efforts are being made to reduce such degradation through multi-billion dollar investments in stream restoration, stormwater management, and green infrastructure. This research contributes to the understanding of the effects of urbanization and ways in which green infrastructure retrofits can impact the hydrology of a watershed, by describing the hydrologic improvements that resulted from green infrastructure retrofits on two streets in Parma, Ohio.

Stormwater consists of rainwater and melted snow that runs off streets, lawns and other sites. (EPA.gov, 2014a). Imperviousness is the proportion of the watershed covered by surfaces impermeable to water (Novotny and Olem, 2003) and in urban areas, hydrologic flowpaths are correlated to urban landscape attributes such as impervious cover (Kaushal and Belt, 2012). Developed land increases impervious surfaces, including roads, driveways, buildings, and managed lands, thus creating higher flows and contributing pollutants to stormwater runoff (Davis et al., 2003). Stormwater systems also lead to an increase in the imperviousness of the catchment to precipitation, which will lead to a decrease in the infiltration of surface runoff (Dunne and Leopold, 1978). Due to the impervious nature of streets and roofs, runoff will be quicker from these surfaces than runoff from vegetated areas (Leopold, 1968). Increased runoff can cause a multitude of detrimental effects to a watershed, which include downstream flooding, stream bank erosion, increased turbidity, habitat destruction, changes in the hydrograph, infrastructure damage, and contaminated waterways (EPA.gov, 2014a).

Current stormwater management involves catching all runoff into central stormwater drainage systems to quickly remove water from an area. Many storm drain systems are separated from sanitary sewers and designed to drain untreated stormwater directly into streams, lakes and other bodies of water, which can lead to the deterioration of the quality of receiving waters (Lee and Bang, 2000). Combined storm sewer systems are directly connected with sanitary sewer systems, and are designed to convey rainwater runoff, domestic sewage, and industrial waste water, in the same pipe, to a centralized location where water is treated and returned downstream to natural bodies of water (EPA.gov, 2014b). Increases in flow affect both systems negatively and storm sewer systems are often overwhelmed and are exceeding their functional capacity (Dietz, 2007). When functional capacity of combined sewers is reached, during periods of heavy rainfall or snowmelt, combined sewer overflows (CSOs) occur because the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant (EPA.gov, 2014b). To help eliminate CSOs, many cities have constructed underground tunnels designed to capture and retain excess flow until after a storm event when the waste water treatment plant can handle treating the combined wastewater (Mayer et al, 2012). However, these sorts of fixes can cost hundreds of millions of dollars and take years to construct (Mayer et al., 2012). Separate sewer systems may not reach their functional capacity the way combined sewers do, but can become inundated with the amount of untreated stormwater leading directly to natural waterways. This excess untreated stormwater can lead to the degradation of natural systems (Shuster and Rhea, 2013).

In urban areas, headwater streams are being replaced by headwater streets. Kaushal and Belt (2012) refer to “engineered headwaters” as storm drains, swales, and ditches and consider them to be upstream of an urban stream. However, runoff into drains, swales, and ditches originates from impervious surfaces such as roads, driveways, and parking lots. Even before stormwater enters engineered headwaters, it originates on a headwater street. By creating a buffer between headwater streets and engineered headwaters, stormwater can be controlled closer to the source and show downstream ecological benefits (Mayer et al., 2012). Decentralization of stormwater management can be done in a variety of ways, including traditional stormwater control measures (SCMs) and more novel approaches like low impact development (LID), both of which intercept or divert stormwater runoff before it reaches separate or combined sewers. Traditional SCMs manage stormwater between the engineered headwaters and the stream, while LID practices manage stormwater between the street and the engineered headwaters.

Traditional SCMs can include retention ponds, wetlands, swales, infiltration systems and catch basins. These sorts of systems can be used individually or together in a "treatment train," depending on the nature of the pollutants being targeted, scale of runoff being captured and available space (Wong et al., 2006). Retention ponds are one of the most common forms of stormwater management. In contrast to detention or "dry" ponds, retention ponds hold water from storm events for extended periods of time, effectively treating the stormwater (sustainablecitiesinstitute.org, 2014). Catch basins and retention ponds allow sediment to be captured and settle to the bottom, reducing nutrients and the amount of material transported to nearby streams and lakes (Tornes, 2005). However, problems can arise from retention ponds, including mosquito infestation, poor water quality from standing water, and human hazards such as drowning. All of these SCMs often require large amounts of land for construction and can take away from valuable building space, especially in densely populated urban areas (EPA.gov, 2014a).

As opposed to traditional SCMs, LID can not only help to reduce peak flow rates, but also help restore a watershed to pre-development runoff volume (Dietz, 2007). LID referring to green infrastructure can include green roofs, porous pavements, rain gardens, rain barrels (Mayer et al., 2012), and bioretention (Hood et al., 2007). Green infrastructure focuses on disconnecting impervious surfaces from stormwater systems and redirecting the flow to decentralized treatments that can help lessen the detrimental effects to the local watershed. Returning a watershed to pre-development hydrologic conditions can have positive effects on local ecology, human health, and water quality (Wong et al., 2012). By implementing LID principles and practices, water can be managed in a way that reduces the effects of built areas and promotes the natural movement of water in an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions and provide numerous other environmental, economic, and social benefits (US EPA, 2009). There are many benefits to using LID methods over traditional engineered stormwater management approaches including addressing stormwater at the source, preserving streams and watersheds, promoting groundwater recharge and allowing for more flexible site layouts (US EPA, 2009).

Several studies have been conducted to examine the effects of green infrastructure at a larger scale. One study, conducted in southeastern Connecticut, compared the stormwater runoff quality, quantity, and lag time parameters for a traditional (2.0 ha) and a LID (1.7 ha) neighborhood watershed (Bedan and Clausen, 2009 and Hood et al., 2007). The traditional and LID watersheds had approximately 29% and 22% imperviousness, respectively (Bedan and Clausen, 2009). The lots in the traditional watershed were 0.15 ha and in the LID watershed 0.10 ha. The traditional watershed used standard curb and gutter street design with paved asphalt roadway, whereas the LID development replaced curbs and gutters with grassed bioretention swales and the asphalt road with a pervious concrete paver road (Bedan and Clausen, 2009). As opposed to the traditional development, where roof runoff was directed to lawns or driveways, the LID development incorporated individual bioretention areas on each lot to detain roof and lot runoff (Bedan and Clausen, 2009). The researchers of this study found that total stormflow was reduced in the LID development by as much as 30% as compared to the traditional development, and they also reported reductions of mass exports of pollutants (Pb and Zn) by 67 and 77% in stormwater relative to the traditional development (Bedan and Clausen, 2009). In this same study, the LID development had increased lag times between rainfall and hydrograph parameters as compared to the traditionally-developed watershed by at least 30 – 47 minutes (Hood et al., 2007).

A study conducted in Cincinnati, Ohio focused on LID green infrastructure retrofits to an existing neighborhood, and it incorporated a voluntary participation approach (Shuster and Rhea, 2013). This study used a reverse auction to recruit homeowners to participate in the project and have front yard rain gardens and rain barrels installed on their property. The reverse auction resulted in 83 rain gardens and 170 rain barrels on 30% of the 350 eligible properties in the headwaters of the study catchment (Shuster and Rhea, 2013). The total impervious area of the study catchment was 13%, with the catchment being 1.8 $km^2$ (Roy et al., 2014). The green infrastructure retrofits in this study lead to a small but significant reduction in stormwater runoff, but concluded that having direct connections to transportation surfaces could have resulted in greater reductions (Shuster and Rhea, 2013).

There is a greater need for studies on the effects of green infrastructure at the headwater street scale. Being able to understand and fix the problems of stormwater at the source can lead to greater improvements downstream. **The goal of this research is to determine the effectiveness of LID green infrastructure treatments such as rain**

**gardens, street side bioretention gardens, and rain barrels at reducing overall stormwater runoff, reducing peak flows, and increasing stormwater lag times at the street scale.**

## 1.2 - Methods

### Research Site Background

The West Creek Watershed is a 36 $km^2$ subwatershed of Ohio's Cuyahoga River that contains ~35% impervious surface, with urbanization patterns that are typical of the greater Northeast Ohio area. West Creek runs from its headwaters in Broadview Heights to its confluence with the Cuyahoga River in Independence, Ohio, through the cities of Parma, Independence, Seven Hills, and Brooklyn Heights (Munroe, 2013). The green infrastructure retrofit is located in the city of Parma, which is near the center of the West Creek watershed. Parma, Ohio became a city in 1931 and prior to that time largely comprised rural agricultural areas. During the 1960's Parma was considered one of the fastest growing cities in the U.S. and much of Parma's development dates to that era (U.S. Census Bureau, 2014). Parma is currently Ohio's seventh largest city, with a population of 81,601 in a total area of 52 $km^2$ (U.S. Census Bureau, 2014).

Mean annual precipitation is approximately 99 cm/year with average temperatures ranging from approximately 10 – 23 °C from the April through October growing season (Figure 1-1) (NOAA.gov, 2014). The study site is located approximately 13 km from Cleveland Hopkins International Airport, where the NOAA data were collected for temperature and precipitation averages. Soils on the study streets are classified generally as Mahoning-Urban land complex, undulating (Web Soil Survey, 2014). This soil consists of being somewhat poorly drained, with slopes of 2 to 6 percent over glacial till parent material (Web Soil Survey, 2014). The combination of poorly drained soils and

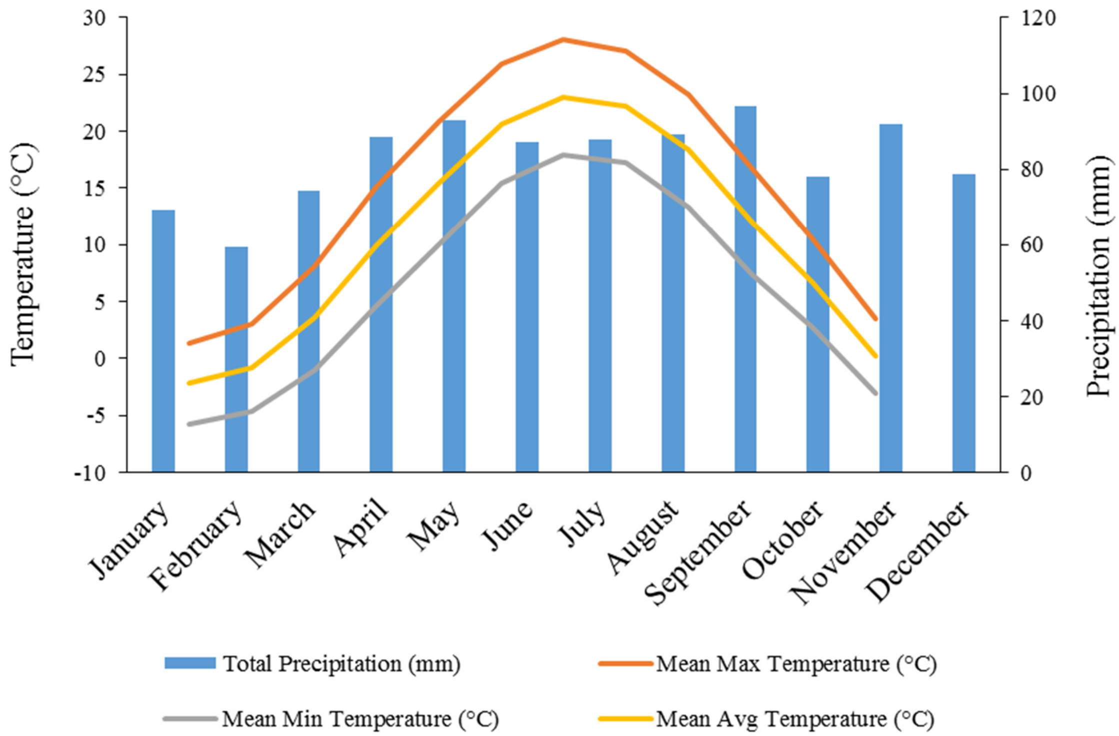



Figure 1-1. Monthly climate normal for precipitation and temperature (1981- 2010) at Cleveland Hopkins International Airport. Study sites are located approximately 13 km for the data collection site at Cleveland Hopkins International Airport.

high amounts of imperviousness contribute to high levels of stormwater runoff and low infiltration capability.

This project is referred to as the West Creek Ecosystem Restoration Project. A double paired watershed study, with a before-after-control-impact design, has paired two streets with 0.05-0.075 ha lots (Klusner Ave. and Hetzel Dr.) and paired two streets with 0.1-0.2 ha lots (Parkhaven Dr. and Mazepa Trail) (Figure 1-2). The storm sewer outfalls at the end of the treatment streets are approximately 0.7 km apart, across the valley containing West Creek. A total of 91 rain gardens, street side bioretention gardens, and rain barrels have been installed on the two treatment streets (Figure 1-3). Rain gardens were installed in front and back yards and were connected to nearby roof downspouts where available. Street side bioretention gardens were installed in the tree lawn area, between the sidewalk and road, and contain curb cuts that allow for runoff from the road to be directed into the bioretention gardens. Rain barrels were installed primarily at the homes participating in the installation of rain gardens or street side bioretention gardens, though one home received only rain barrels, with no gardens. Rain barrels collect runoff from down spouts connected to home and garage rooftops. Monitoring began in April 2012 on Klusner and Hetzel, and October 2012 on Parkhaven and Mazepa. The first phase of green infrastructure treatments were installed and planted on Klusner in May 2013. The second phase of green infrastructure treatments were installed on Parkhaven and Klusner in November 2013 and were planted in March 2014 (Table 1-1 and 1-2).

The specific sites for green infrastructure installation were determined by soliciting landowners through public meetings, mailings, and direct contact. Once homeowners volunteered to participate in the program, the green infrastructure treatments

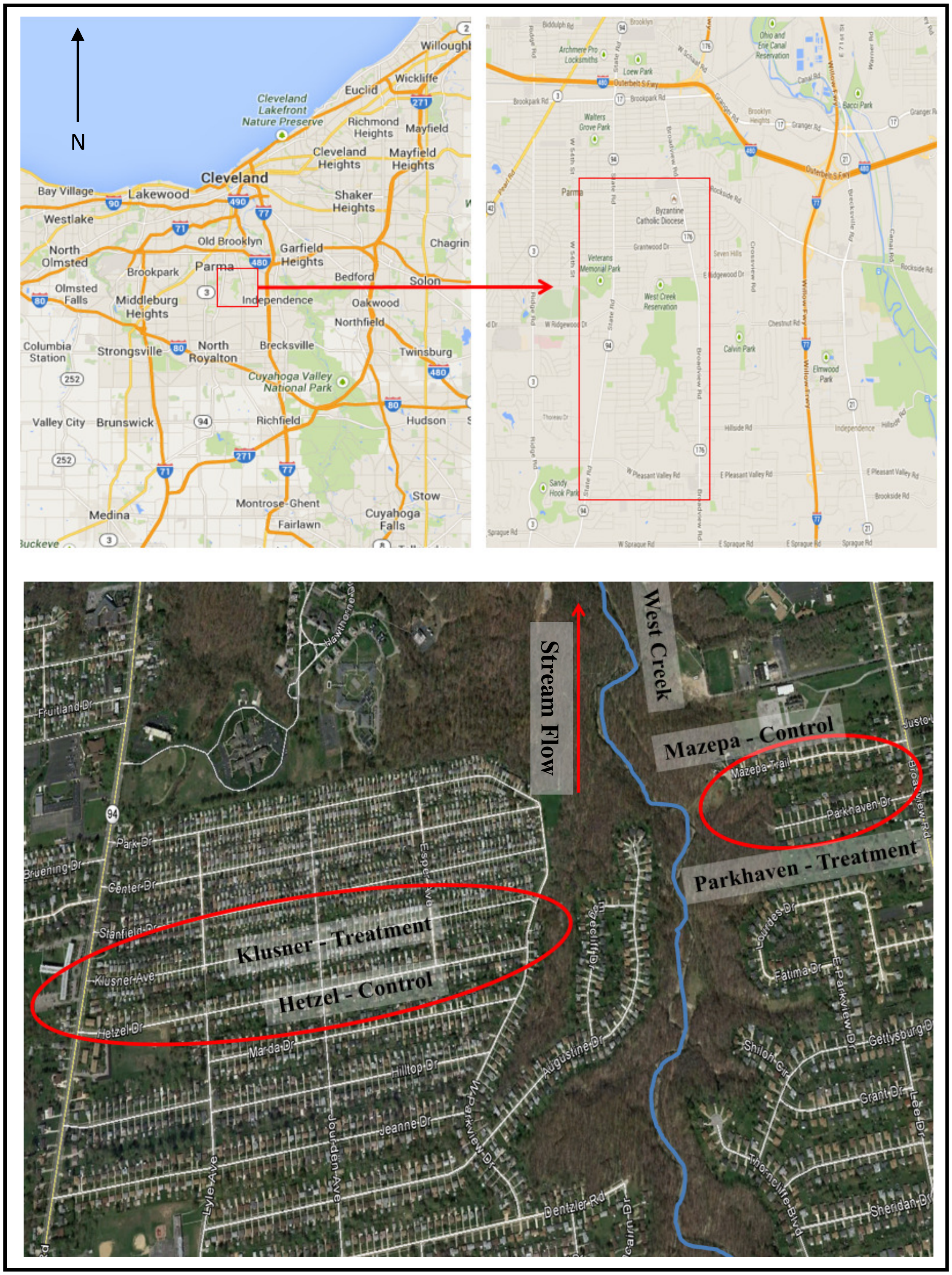



Figure 1-2. Overview map of the research locations for the stormwater monitoring on Klusner, Hetzel, Parkhaven, and Mazepa in Parma, Ohio.

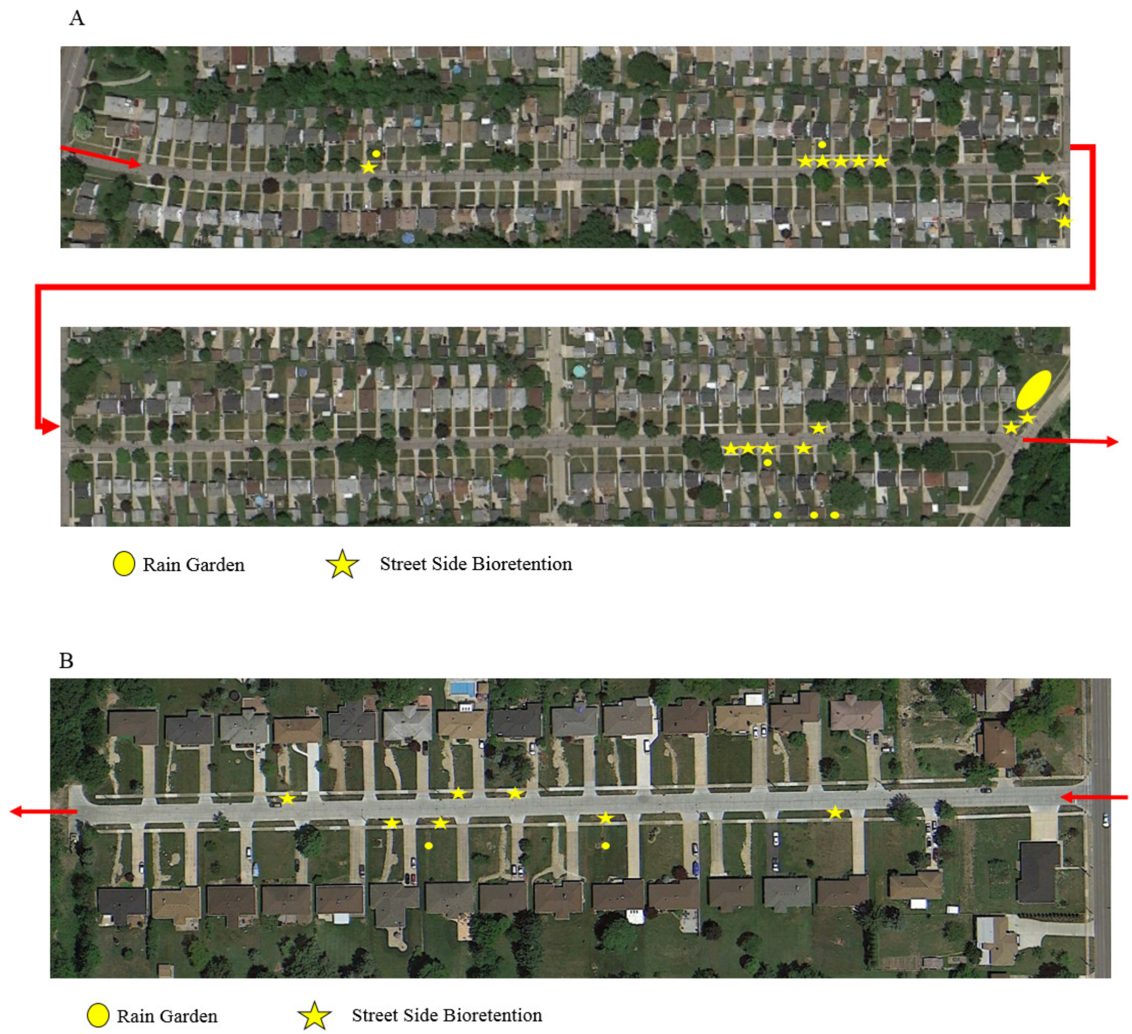



Figure 1-3. Overview map showing locations for rain gardens and street side bioretention gardens on (A) Klusner and (B) Parkhaven (Red arrows indicate the general direction of stormwater flow on each street).

Table 1-1. Site characteristics for West Creek watershed green infrastructure project

| Street | Study Type | Lot Size (ha) | Houses per street* (#) | Number of Treatments (#) | Percent of Street with Treatment** (%) | Treatment Area*** ($km^2$) | Pre-Treatment Imperviousness (%) |
|---|---|---|---|---|---|---|---|
| Klusner Ave | Treatment | 0.05 | 174 | 37 rain barrels, 7 rain gardens, 16 street side bioretention gardens | 12.50% | 0.063 | 55.5 |
| Hetzel Dr. | Control | 0.075 | 114 | - | - | | |
| Parkhaven Dr. | Treatment | 0.1 | 31 | 21 rain barrels, 3 rain gardens, 7 street side bioretention gardens | 32.20% | 0.030 | 26.4 |
| Mazepa Trail | Control | 0.2 | 42 | - | - | | |

*Note: Some houses on Klusner and Hetzel drain to storm sewers that drain away from the monitoring point at the end of the street.
** Percent of Street with Treatment is the total number of homes participating as compared to the total number of homes on each street.
** Treatment Area calculations are estimates of drainage capture areas for streetside bioretention gardens as specified by URS.

Table 1-2. Timeline of green infrastructure construction and monitoring at West Creek watershed, Parma, Ohio.

| Street | Apr-12 | Oct-12 | May-13 | Fall 2013 | Nov-13 | Mar-14 | Oct-14 | Dec-14 |
|---|---|---|---|---|---|---|---|---|
| Klusner Ave | Began monitoring flow data | - | Installed 12 street side bioretention gardens, 22 rain barrels, and 2 rain gardens | - | Installed 4 street side bioretention gardens, 15 rain barrels, and 5 rain gardens | Finalized construction and planting on street side bioretention gardens and rain gardens | End study period | Present Results |
| Hetzel Dr. | Began monitoring flow data | - | - | - | - | - | End study period | Present Results |
| Parkhaven Dr. | - | Began monitoring flow data | - | Private residences begin hooking up to sanitary sewer, road repaired with surface and curbs | Installed 7 street side bioretention gardens, 21 rain barrels, and 3 rain gardens | Finalized construction and planting on street side bioretention gardens and rain gardens | End study period | Present Results |
| Mazepa Trail | - | Began monitoring flow data | - | - | - | - | End study period | Present Results |

were installed at no cost to them. General maintenance of the green infrastructure including weeding and plant upkeep was provided for the duration of the study by Metroparks staff and volunteers. The construction was conducted by licensed contractors and landscapers according to design drawings and specifications written by URS Corporation (Figure 1-4).

Soils selected for the installations were specified to be sandy loam having no less than 72% sand, between 5 and 28% organic material, and no greater than 10% clay (URS, 2013). A layer of mulch was added atop the bioretention gardens and rain gardens. Plants were selected based on URS design specifications. Plant selections included perennials, grasses, shrubs, and trees. Plant selections needed to be able to withstand large amounts of water during storm events and be drought tolerant between storm events. Due to a large population of deer (50-70 deer/sq.mi.) (Cleveland Metroparks, 2014) in Cleveland Metroparks West Creek Reservation, which runs adjacent to the end of the treatment streets, plant species were chosen based on perceived palatability to deer. For these reasons, the landscape design depends primarily on grasses, sedges and ferns and less on flowering perennials.

During Phase 1 construction on Klusner, underdrains were installed in ten of twelve street side bioretention gardens and connected to storm drain catch basins closest to each site. Underdrains are designed to allow water to percolate through the bioretention gardens prior to arriving in the storm drain (lowimpactdevelopment.org, 2014). Catch basins are central areas within the storm drain system that are designed to catch runoff and sediment from the street. The two remaining street side bioretention sites not connected by underdrains were distal from any catch basins, and an underdrain could

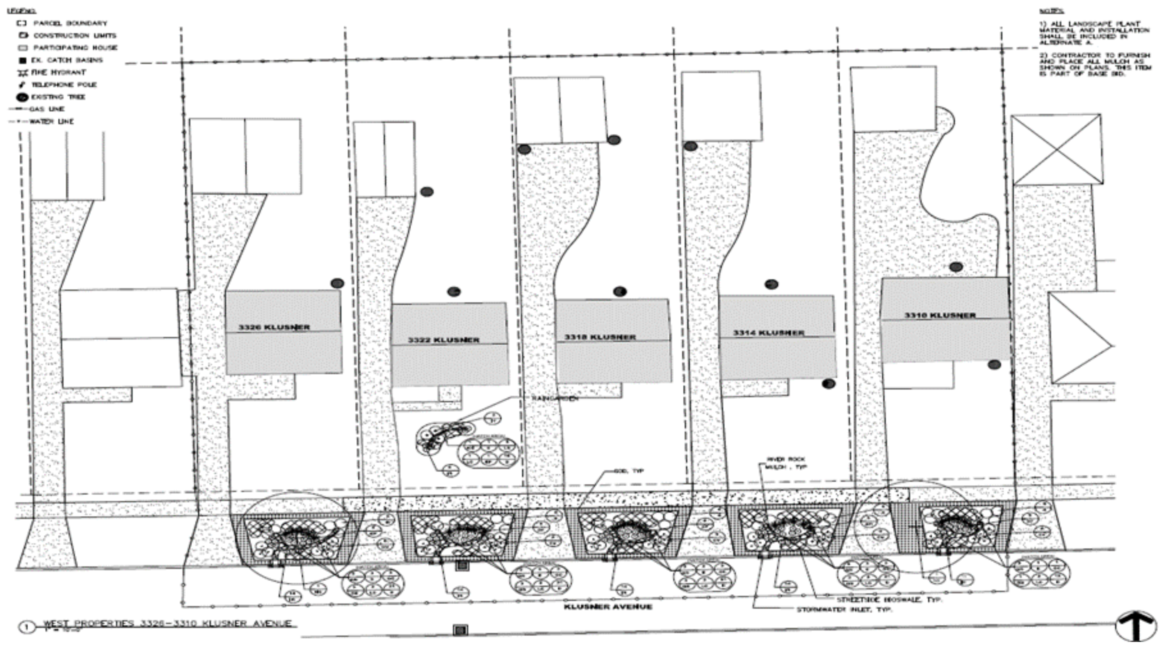



Figure 1-4. Typical site design for street side bioretention gardens and rain gardens at West Creek Watershed Parma, Ohio. Black dots represent the locations of rain barrels. (URS Design, 2013).

not easily be connected to the street side bioretention gardens. One of the bioretention gardens without an underdrain had augered shafts, backfilled with gravel, to allow for more storage capacity, while no special treatment was done for the other unconnected street side bioretention garden. Initial performance of the street side bioretention gardens without underdrains appeared successful based on the visual observations of infiltration. As a result, underdrains and augered shafts were eliminated from the design of the street side bioretention gardens in Phase 2 of construction on both Klusner and Parkhaven, allowing for cost savings in Phase 2 construction. Properties with rain barrels connected to downspouts have flow from rooftops diverted from the storm sewer system. Additionally, select homes with front yard rain gardens also have rooftop downspouts disconnected from the storm sewer system.

Each of the study streets have standard curb and gutter stormwater collection practices. On all of the treatment and control streets roof runoff from downspouts is directed into the storm drain at each residence. Road and driveway runoff is carried along roadside curbs which lead directly into the storm drains. During the monitoring period, but before construction of green infrastructure treatments on Parkhaven, a new road surface, storm drains, curbs and gutters were installed. Also, at this time houses on Parkhaven were disconnected from septic and incorporated into municipal sewers. Previously, Parkhaven had curbs and gutters on the street, but large sections including the road surface were cracked and broken.

## Data Collection

Runoff data was measured using ISCO 2150 Area Velocity Flow Module and Sensors in the storm drains at the end of each street near the storm drain outfall. Data were collected in 15 minute intervals for total volume ($m^3$), flow rate ($m^3/s$), velocity (m/s), water level (m), and input voltage (volts), using storm drain dimensions to convert from velocity and level to total flow volume and flow rate. Flow sensors were installed in April 2012 on Klusner and Hetzel and were added to Parkhaven and Mazepa in October 2012. Data were downloaded from the flow meters on a weekly basis using Flow Link software and compiled into a master data set.

Individual storm events were defined as periods when recorded velocity and calculated discharge from flow meters in the storm outfall rose above zero flow and returned to zero flow. Events were only considered when there was flow on both treatment and control streets, and a nearby meteorological station recorded precipitation. Due to the flashy nature of the hydrograph (Figure 1-5), at least three storm flow data points (45 minutes) were required for a storm event and at least three data points of zero flow were needed to separate storm events. This separation was used because scattered thunderstorms often occur in this area and times of intermittent heavy precipitation could produce distinct responses. For this study, data analysis was focused on the warm season, which has been defined as April 1 – October 31. These time periods coincide with the normal growing season in the Northern Ohio Region (city-data.com, 2014). Figure 1-6 shows a typical storm event as it was coded in Excel. This shows the beginning (green), peak (yellow), and end of precipitation (red), and beginning (green),

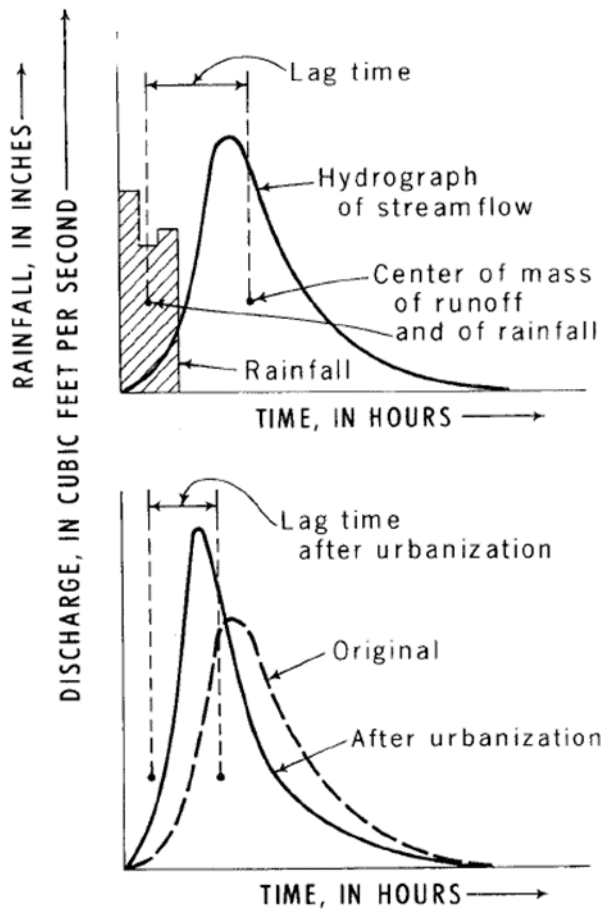



Figure 1-5. Hypothetical unit hydrographs relating runoff to rainfall, with definitions of significant parameters (Leopold, 1968). Lag time after urbanization emphasizes the flashy nature of urban hydrographs.

| Event Number | Event Time Stamp | Event Time ti | Date | Daily Rain Ridgewood (mm) | 15 min rain Wi (mm) | Daily Rain Wi*ti | Khusner Flow Rate Qi ($m^3/s$) | Khusner Qi * ti | Khusner Velocity (m/s) | Khusner Volume ($m^3$) | Hetzel Flow Rate Qi ($m^3/s$) | Hetzel Qi*ti | Hetzel Velocity (m/s) | Hetzel Volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0 | 9/3/12 19:30 | 1.52 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.472 | 0.390 |
| 2 | 2 | 15 | 9/3/12 19:45 | 8.13 | 6.60 | 99.06 | 0.179 | 2.688 | 2.523 | 161.289 | 0.048 | 0.717 | 1.693 | 43.039 |
| 2 | 3 | 30 | 9/3/12 20:00 | 10.67 | 2.54 | 76.20 | 0.287 | 8.612 | 3.149 | 258.360 | 0.247 | 7.402 | 2.492 | 222.054 |
| 2 | 4 | 45 | 9/3/12 20:15 | 12.19 | 1.52 | 68.58 | 0.160 | 7.208 | 2.754 | 144.156 | 0.100 | 4.505 | 2.511 | 90.096 |
| 2 | 5 | 60 | 9/3/12 20:30 | 12.19 | 0.00 | 0.00 | 0.060 | 3.601 | 1.852 | 54.018 | 0.053 | 3.203 | 2.132 | 48.052 |
| 2 | 6 | 75 | 9/3/12 20:45 | 12.45 | 0.25 | 19.05 | 0.025 | 1.861 | 1.292 | 22.331 | 0.022 | 1.687 | 1.627 | 20.241 |
| 2 | 7 | 90 | 9/3/12 21:00 | 12.45 | 0.00 | 0.00 | 0.015 | 1.337 | 1.061 | 13.371 | 0.015 | 1.348 | 1.426 | 13.476 |
| 2 | 8 | 105 | 9/3/12 21:15 | 12.45 | 0.00 | 0.00 | 0.005 | 0.493 | 0.698 | 4.229 | 0.011 | 1.121 | 1.324 | 9.609 |
| 2 | 9 | 120 | 9/3/12 21:30 | 12.45 | 0.00 | 0.00 | 0.003 | 0.414 | 0.661 | 3.105 | 0.007 | 0.840 | 1.131 | 6.298 |
| 2 | 10 | 135 | 9/3/12 21:45 | 12.45 | 0.00 | 0.00 | 0.003 | 0.426 | 0.576 | 2.838 | 0.006 | 0.751 | 1.034 | 5.005 |
| 2 | 11 | 150 | 9/3/12 22:00 | 12.45 | 0.00 | 0.00 |  | 0.000 |  | 0.000 | 0.004 | 0.624 | 0.947 | 3.741 |
| 2 | 12 | 165 | 9/3/12 22:15 | 12.45 | 0.00 | 0.00 | 0.002 | 0.389 | 0.489 | 2.120 | 0.003 | 0.567 | 0.891 | 3.093 |
| 2 | 13 | 180 | 9/3/12 22:30 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.543 | 0.842 | 2.717 |
| 2 | 14 | 195 | 9/3/12 22:45 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.471 | 0.791 | 2.174 |
| 2 | 15 | 210 | 9/3/12 23:00 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.563 | 0.817 | 2.413 |
| 2 | 16 | 225 | 9/3/12 23:15 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.605 | 0.817 | 2.421 |
| 2 | 17 | 240 | 9/3/12 23:30 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.642 | 0.817 | 2.408 |
| 2 | 18 | 255 | 9/3/12 23:45 | 12.45 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.615 | 0.791 | 2.169 |
| 2 | 19 | 270 | 9/4/12 0:00 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.590 | 0.765 | 1.966 |
| 2 | 20 | 285 | 9/4/12 0:15 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.610 | 0.765 | 1.926 |
| 2 | 21 | 300 | 9/4/12 0:30 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.531 | 0.711 | 1.593 |
| 2 | 22 | 315 | 9/4/12 0:45 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.480 | 0.683 | 1.371 |
| 2 | 23 | 330 | 9/4/12 1:00 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.433 | 0.655 | 1.182 |

Figure 1-6. Example of a coded storm event using Excel. Green cells indicate the beginning of precipitation or stormflow, yellow indicates the peak of precipitation or stormflow, and red indicates the end of precipitation or stormflow.

peak (yellow), and end (red) of storm flow. Times for event variables were counted between green and red cells for consistency.

### Precipitation Data

Precipitation data have been collected from Metroparks meteorological stations located at Ridgewood Road near the entrance of the West Creek Reservation and Abram Creek near the Big Creek Reservation. The Vaisala WXT520 meteorological stations use Vaisala RAINCAP® Sensor 2-technology. The measured parameters are accumulated rainfall, peak intensity, and the duration of a rain event. Precipitation data was collected in 15 minute intervals and downloaded to the Metroparks server via remote download. The Ridgewood Road data was the primary precipitation data used for this study. From April 2, 2013 at 08:00:00 to September 13, 2013 at 13:30:00, the Abram Creek rain gauge was used because the Ridgewood Road gauge was not functioning. The Ridgewood rain gauge is located approximately 1.6 km from the downslope end of each pair of streets, near the entrance of the Cleveland Metroparks West Creek Reservation. The Abram Creek rain gauge is located approximately 10 km from the downslope end of each pair of streets, inside the Cleveland Metroparks Big Creek Reservation (Figure 1-7).

### Analysis Methods

The effect of street-scale BMP retrofits on storm hydrograph characteristics was analyzed by quantifying the effects on peak discharge, total runoff volume, and lag time for storm events between April 1 and October 31 for each phase of monitoring. Peak discharge was identified for each storm as the highest point on the hydrograph, when the

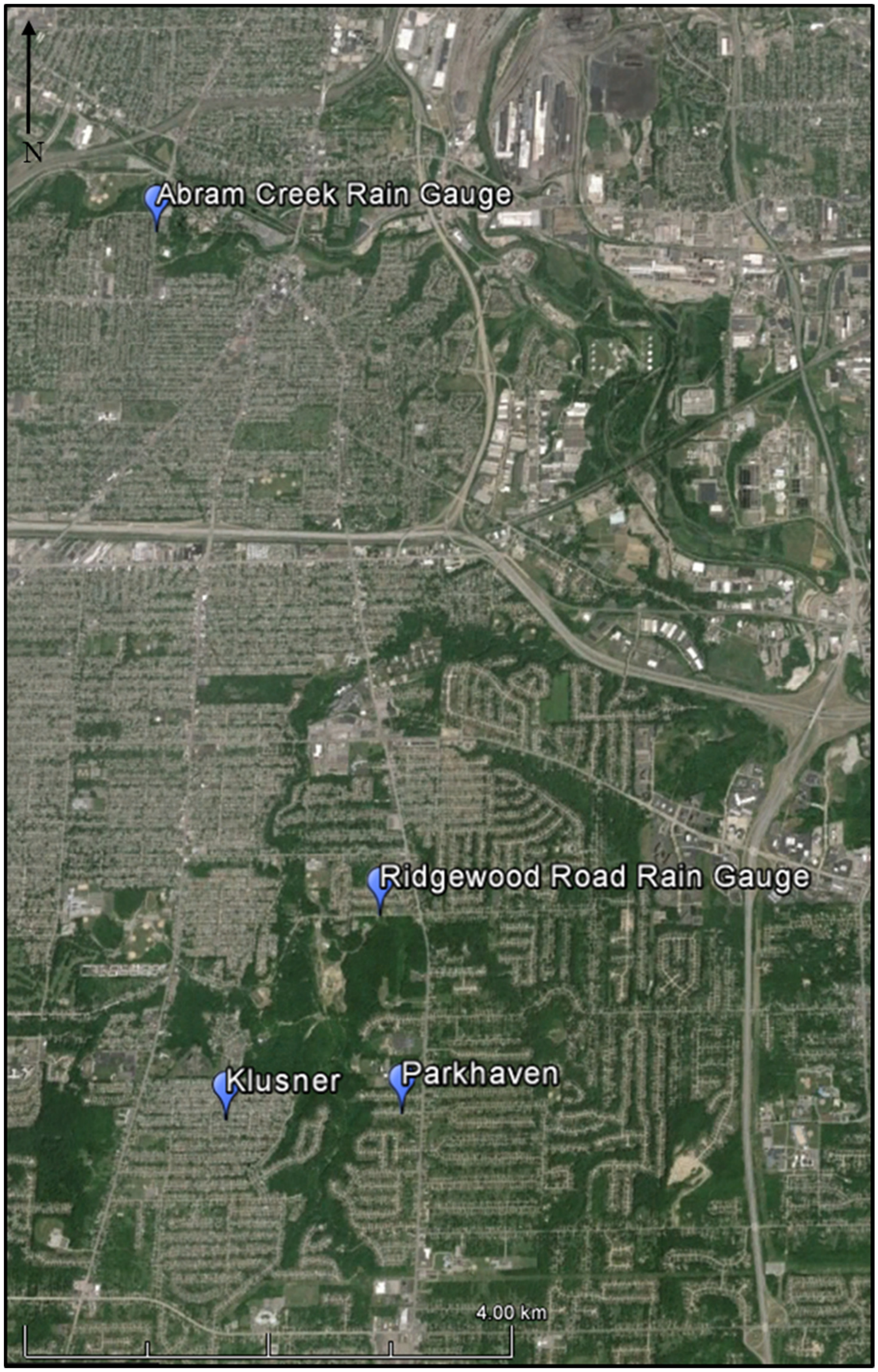



Figure 1-7. Locations of Ridgewood and Abram Creek rain gauges in proximity to monitoring and treatment sites.

rate of discharge is greatest. Total runoff volume was compared for each storm event. Statistical differences between linear trend lines on Klusner/Hetzel and Parkhaven/ Mazepa for peak and total discharge were calculated using Student's t-test least squares method (Zar, 1984) in JMP version 11 software.

Lag time analysis was conducted to analyze the difference in lag time between the treatment street and the adjacent control street discharge for all storm events. Four measures of lag time were calculated for each set of treatment streets; centroid lag-to-peak (time from the centroid of precipitation to the peak discharge), centroid lag (time from the centroid of precipitation to the centroid of discharge), lag-to-peak (time from the beginning of precipitation to the peak discharge), and peak lag-to-peak (time from the peak rainfall intensity to the peak discharge) (Dingman, 2002) (Figure 1-8). The centroid of precipitation was calculated as

$$t_{\mathrm{wc}} \equiv \frac{\sum_{i=1}^{n} W_i \times t_i}{\sum_{i=1}^{n} W_i},$$

where $t_{wc}$ = centroid of precipitation, $W_i$ = precipitation for period i, and $t_i$ = time for period I (Dingman, 2002). The centroid of runoff was calculated from as

$$t_{\mathrm{qc}} \equiv \frac{\sum_{i=1}^{n} Q_i \times t_i}{\sum_{i=1}^{n} Q_i},$$

where $t_{qc}$ = centroid of runoff, $Q_i$ = runoff for period i, and $t_i$ = time for period I (Dingman, 2002).

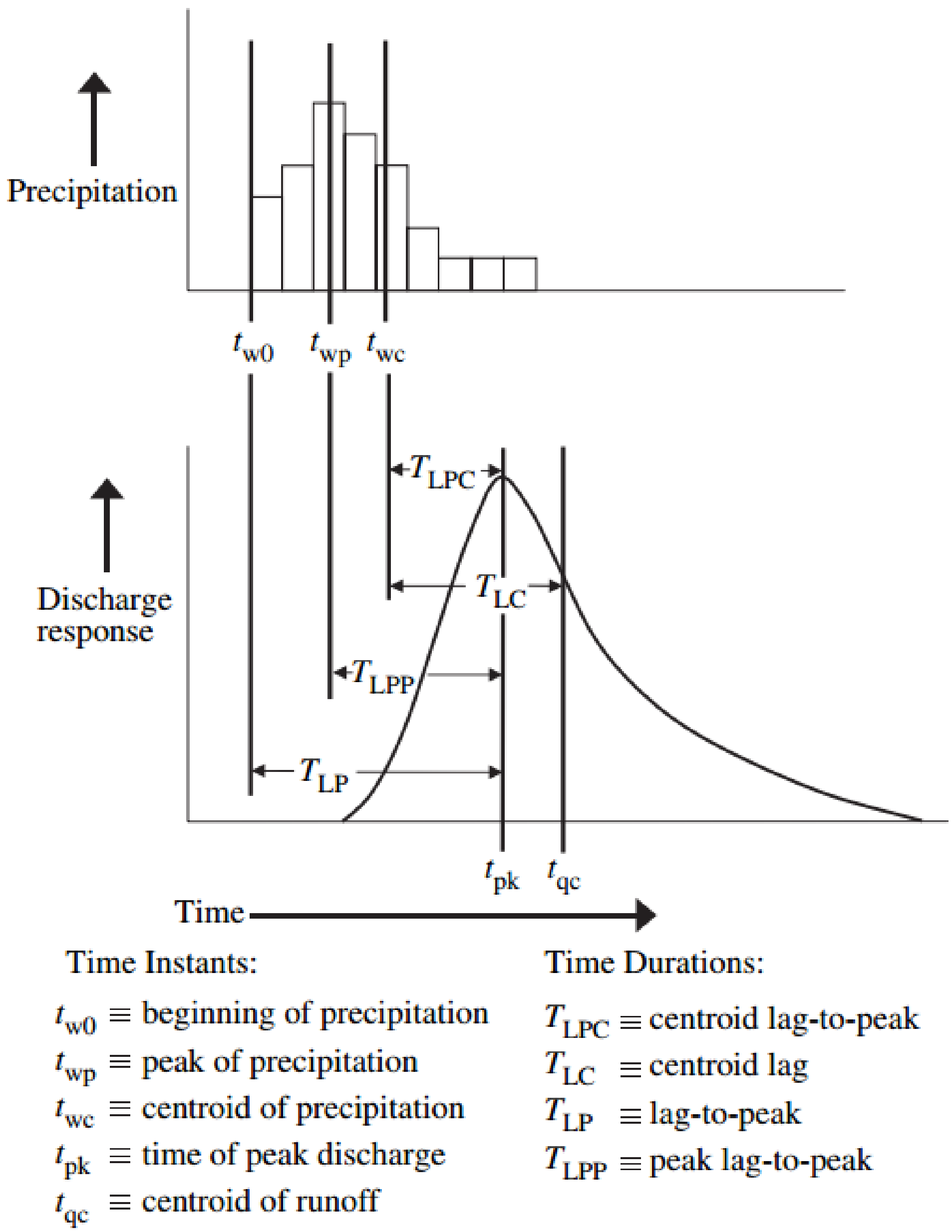



Figure 1-8. Definitions of terms used to describe hyetographs and hydrographs based on Dingman (2002).

Lag time calculations were done using relationships between precipitation and runoff data for each set of control and treatment streets. For an example storm, the peak lag-to-peak might have been 30 minutes for Hetzel (control) and 45 minutes for Klusner (treatment), and the peak lag-to-peak time difference is therefore 15 minutes. If the treatment street had a shorter lag time than the control street, the lag time difference is negative. Any effect in lag times due to the difference in distances between the Ridgewood Road and Abram Creek rain gauges and the study site is not considered to have an effect of overall lag time analysis because of this differencing. The mean difference was calculated using the geometric mean in lag time variables.

Non-parametric Wilcoxon each pair comparisons were used to test the statistical significance of lag time differences for each pair of treatment and control streets during each phase of observation and treatment, using JMP version 11. Box and whisker plots were used to show changes in lag time variables during each phase of monitoring and construction (Figure 1-9).

Multiple regression analysis was conducted using JMP version 11 software to predict peak and total discharge on the treatment street for total precipitation, peak precipitation, and antecedent moisture conditions (AMC). AMC was based on total accumulated precipitation in the 12 hours, 24 hours, 48 hours, and 7 days prior to each event. Using the Fit Model function in JMP, multiple regression parameters for peak discharge and total discharge were analyzed by phase of treatment (Klusner: Pre-Treatment, Phase 1, and Phase 2; Parkhaven: Pre-Treatment 1, Pre-Treatment 2, Phase 2) and model effects for peak precipitation, total precipitation, AMC 12 hours, AMC, 24

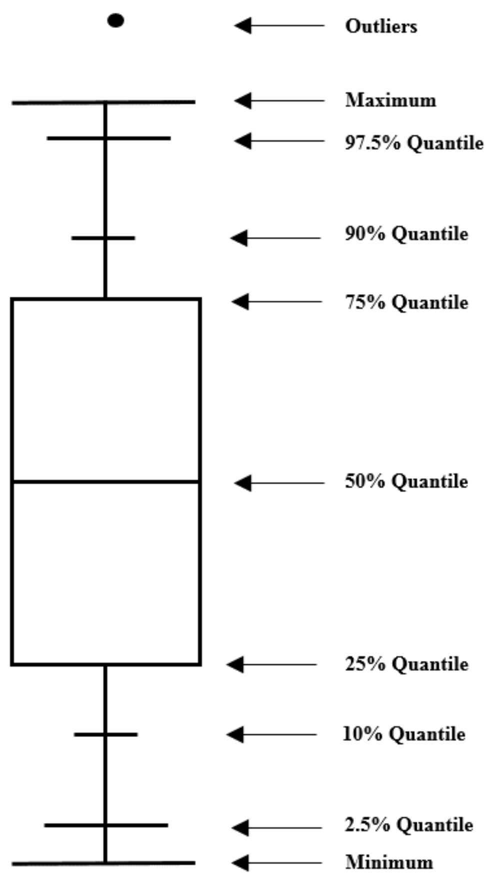



Figure 1-9. Explanation of box and whisker plot.

hours, AMC 48 hours, and AMC 7 days. The model was run stepwise in the forward direction with a p-value threshold of 0.1.

## 1.3 – Results

### Monitoring Data

Data for both sets of streets during all three phases of monitoring can be seen in Table 1-3. This data covers the runoff and precipitation variables for all of the analyzed storm events. Data gaps on Parkhaven were during a time when the data logger became disconnected in the storm drain and no data was collected.

### Peak Storm Flow – Klusner/Hetzel

Comparisons of peak stormflows were made for Klusner (treatment) and Hetzel (control). When comparing all storm flows for all three observation periods, a general trend in decreasing peak storm flows is seen for the treatment street (Figure 1-10). Linear trend lines for the Phase 1 and Phase 2 observation periods show that the hydrologic response is being skewed by a greater reduction in peak stormflows from larger events during these two periods. Using the Student's t-test for least square means, linear trend lines in Figure 1-10 are statistically significantly different ($p = 0.050$) between Phase 1 and Phase 2 (least sq mean = 0.129, Phase 1; 0.095, Phase 2). No statistically significant difference was seen between Pre-Treatment and either Phase 1 or Phase 2.

Removing the largest peak stormflow events from Phase 1 and Phase 2 and only comparing peak stormflow events from within the range of Pre-Treatment events shows that there was a significant difference ($p = 0.050$) between Phase 1 (least sq mean =

Table 1-3. Descriptive data for Klusner/Hetzel and Parkhaven/Mazepa storm events for all three monitoring phases.

| Monitoring Phase | Street | Number of Storm Events (n) | Range of Total Precipitation (mm) | Range of Peak Discharge ($m^3/s$) | Range of Total Discharge ($m^3$) | Range of Storm Duration (min) | Range of AMC 12 hours (mm) | Range of AMC 24 hours (mm) | Range of AMC 48 hours (mm) | Range of AMC 7 days (mm) | Data Gaps (m/d/y - m/d/y) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-Treatment | Klusner | 40 | 0.51 - 42.93 | 0.005 - 0.413 | 21.18 - 1752.23 | 15 - 585 | 0 - 42.67 | 0 - 52.83 | 0 - 129.79 | 0 - 162.31 | - |
| | Hetzel | | | 0.002- 0.247 | 8.91 - 1846.02 | | | | | | - |
| Phase 1 | Klusner | 56 | 0.51 - 89.15 | 0.007 - 0.503 | 31.87 - 3152.58 | 15 - 1125 | 0 - 39.37 | 0 - 42.67 | 0 - 99.57 | 0 - 125.22 | - |
| | Hetzel | | | 0.001 - 0.769 | 1.86 - 1625.99 | | | | | | - |
| Phase 2 | Klusner | 66 | 0.25 - 81.28 | 0.002 - 0.386 | 8.54 - 3793.20 | 15 - 1395 | 0 - 45.72 | 0 - 45.72 | 0 - 64.52 | 0 - 121.92 | - |
| | Hetzel | | | 0.001 - 0.926 | 1.05 - 3631.39 | | | | | | - |
| Pre-Treatment 1 | Parkhaven | 27 | 1.02 - 42.93 | 0.002 - 0.081 | 5.11 - 1154.01 | 15 - 915 | 0 - 6.35 | 0 - 26.92 | 0 - 42.93 | 0.76 - 88.65 | - |
| | Mazepa | | | 0.05 - 0.189 | 10.99 - 1360.63 | | | | | | - |
| Pre-Treatment 2 | Parkhaven | 24 | 0.51 - 35.31 | 0.002 - 0.069 | 6.65 - 521.66 | 30 - 1230 | 0 - 42.67 | 0 - 52.83 | 0 - 129.79 | 1.52 - 162.32 | 5/29/2013 - 9/1/2013 |
| | Mazepa | | | 0.003 - 0.056 | 12.84 - 645.25 | | | | | | - |
| Phase 2 | Parkhaven | 55 | 0.51 - 81.28 | 0.001 - 0.170 | 0.74 - 1306.22 | 30 - 1035 | 0 - 45.72 | 0 - 45.72 | 0 - 64.52 | 0 - 121.92 | - |
| | Mazepa | | | 0.002 - 0.653 | 2.66 - 2703.48 | | | | | | - |

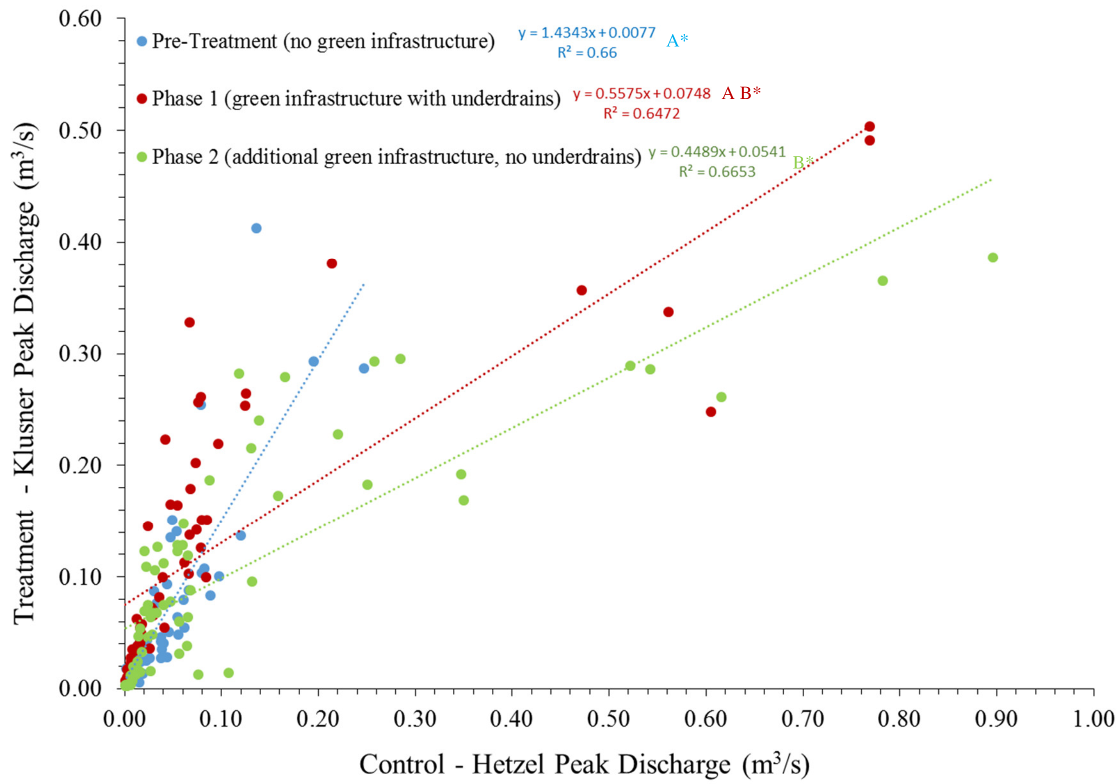



Figure 1-10. Comparison of peak stormflow for all storm events from Pre-Treatment, Phase 1, and Phase 2 on Klusner and Hetzel (n = 40, 56, 66). The difference between the regression lines for Phase 1 and Phase 2 is statically significant (p = 0.05).

0.114) and the Pre-Treatment phase and Phase 2 (least sq mean = 0.082, Pre-Treatment; 0.076, Phase 2). There was no significant difference ($p = 0.050$) between Phase 2 and Pre-Treatment. The significant difference between Phase 1 and Phase 2 indicates that there was a substantial reduction in peak stormflow, for smaller events, once the additional green infrastructure was added to the treatment street in Phase 2 (Figure 1-11). The comparison of smaller events is made showing the trend lines with an intercept of zero because when there is no stormflow on the street, any data point would be plotted as (0, 0).

The largest peak stormflow events from Phase 1 and Phase 2, which fall outside of any comparable peak discharge values for the Pre-Treatment period, indicate a reduction in peak stormflow on the treatment street with the addition of increased green infrastructure on the street. Using Student's t-test, there was a statistical difference ($p = 0.050$) between the larger events on Klusner and Hetzel in Phase1 and Phase 2 (least sq means = 0.384, Phase 1; 0.286, Phase 2). A comparison of the linear trend lines of the larger peak stormflows shows that a peak discharge on Hetzel of 0.35 $m^3/s$ resulted in a 5% reduction of peak storm flow on Klusner, whereas a peak storm flow of 1.0 $m^3/s$ on Hetzel resulted in a 35% reduction on Klusner between Phase 1 and Phase 2.

When plotting all data for Phase 1 and Phase 2 logarithmic relationships are observed (Figure 1-12). These relationships help illustrate the greater peak stormflow reductions for larger events. Where smaller events produce similar peak stormflows, the larger storms show greater reductions in peak stormflow with the addition of Phase 2 green infrastructure.

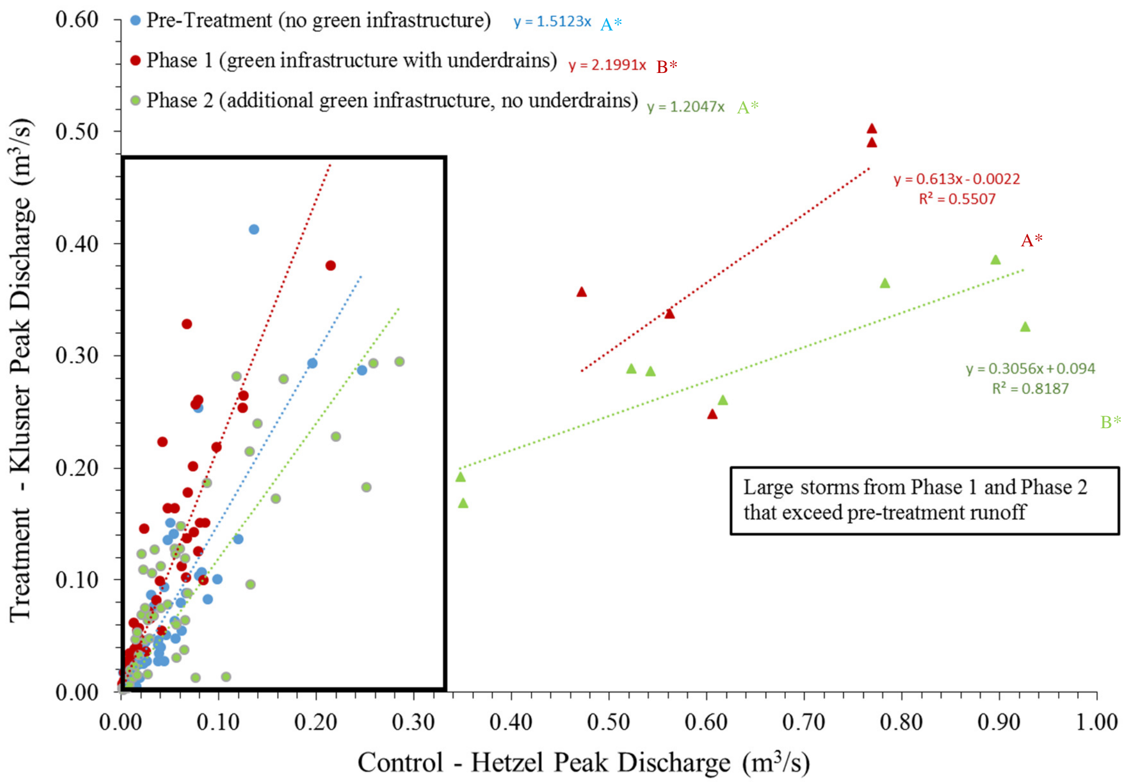



Figure 1-11. Comparison of peak stormflow for all storm events from Pre-Treatment, Phase 1, and Phase 2 on Klusner and Hetzel (n = 40,56,66). Values inside the box show storms for all three phases, only in the range of Pre-Treatment values (n = 40, 51, 58). Statistical differences (p=0.05) using Student's t-test were seen between Phase 1 (least sq mean = 0.114) and the Pre-Treatment phase and Phase 2 (least sq mean = 0.082, Pre-Treatment; 0.076, Phase 2). The larger peak discharge values for Phase 1 and Phase 2 are analyzed separately due to lack of Pre-Treatment comparison (n = 5, 8). Statistical differences (p=0.05) using Student's t-test were seen between Phase1 and Phase 2 (least sq means = 0.384, Phase 1; 0.286, Phase 2).

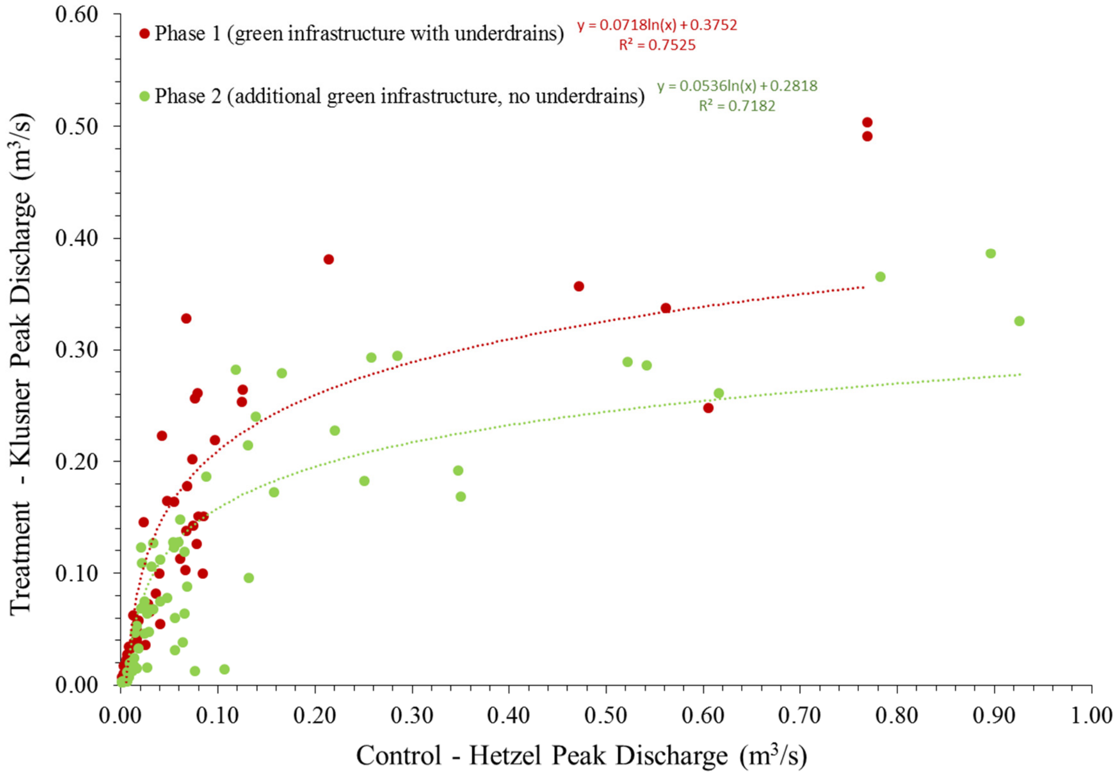



Figure 1-12. Comparison of peak stormflows for all storm events from Phase 1 and Phase 2 on Klusner and Hetzel (n = 56, 66).

## Peak Stormflow – Parkhaven/Mazepa

Similarly to Klusner and Hetzel, comparisons of peak stormflows were made on Parkhaven (treatment) and Mazepa (control) (Figure 1-13). The comparison of peak stormflow between Pre-Treatment 1 and Pre-Treatment 2 shows an increase in overall peak stormflow on the treatment street. During the Pre-Treatment 2 observation period, the treatment street was repaved, including fixing the road surface, curbs, and storm drains. No green infrastructure was installed during the Pre-Treatment 2 observation period. In the Phase 2 observation period, when the green infrastructure had been added to the street, an overall reduction in peak stormflow is observed relative to Pre-Treatment 2. This reduction brought the peak stormflows back to values seen prior to the improvement of the road, as in Pre-Treatment 1. While the general trend of peak stormflows shows a decrease in Phase 2 with the addition of green infrastructure, there is still a large amount of scatter among all of the peak stormflow data. Using the Student's t-test no significant differences were found for any of the phases. Combining the Pre-Treatment phases into a single dataset and comparing the peak stormflows to Phase 2 also did not result in any significant differences using Student's t-test.

The Phase 2 observation period for Parkhaven and Mazepa had peak stormflows that were outside of the range of peak stormflows for the Pre-Treatment 1 and Pre-Treatment 2 observation period.  Comparing peak stormflows between the treatment and control streets for only Phase 2, a logarithmic relationship is observed (Figure 1-14). This relationship is similar to the relationship seen on Klusner and Hetzel, where larger peak stormflows have a greater reduction in peak stormflows on the treatment street, relative to the control street, than smaller peak stormflow events. However, for both sets of

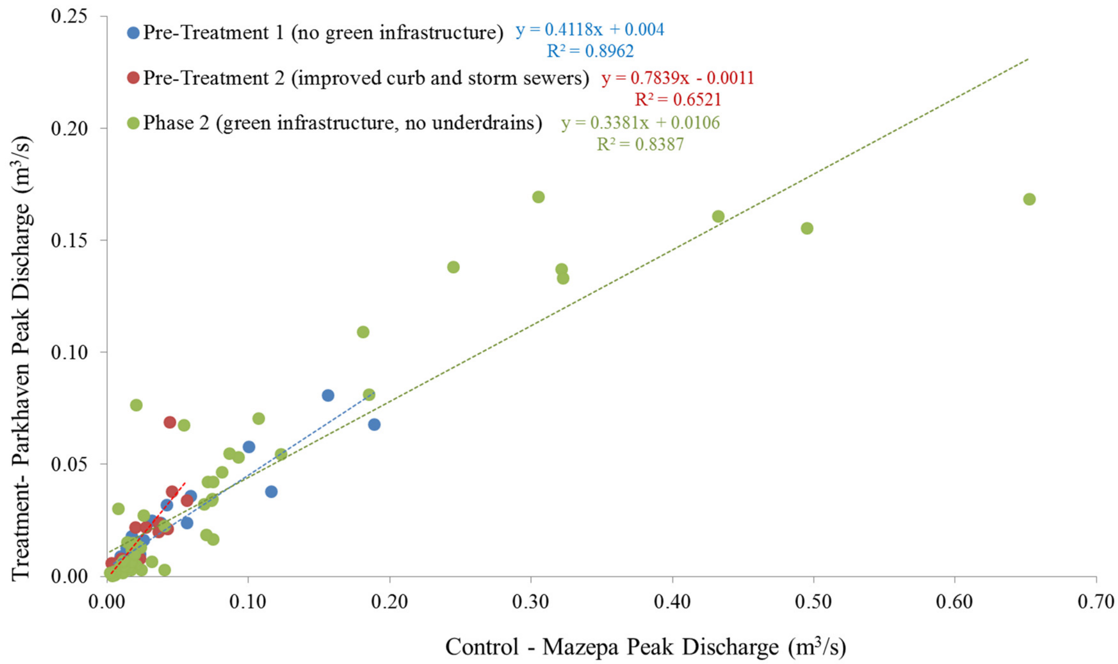



Figure 1-13. Comparison of peak stormflow for all storm events from Pre-Treatment 1, Pre-Treatment 2, and Phase 2 on Parkhaven and Mazepa (n = 27, 24, 55). Using Student's t-test (p=0.05), regression lines are not statistically significantly different between phases.

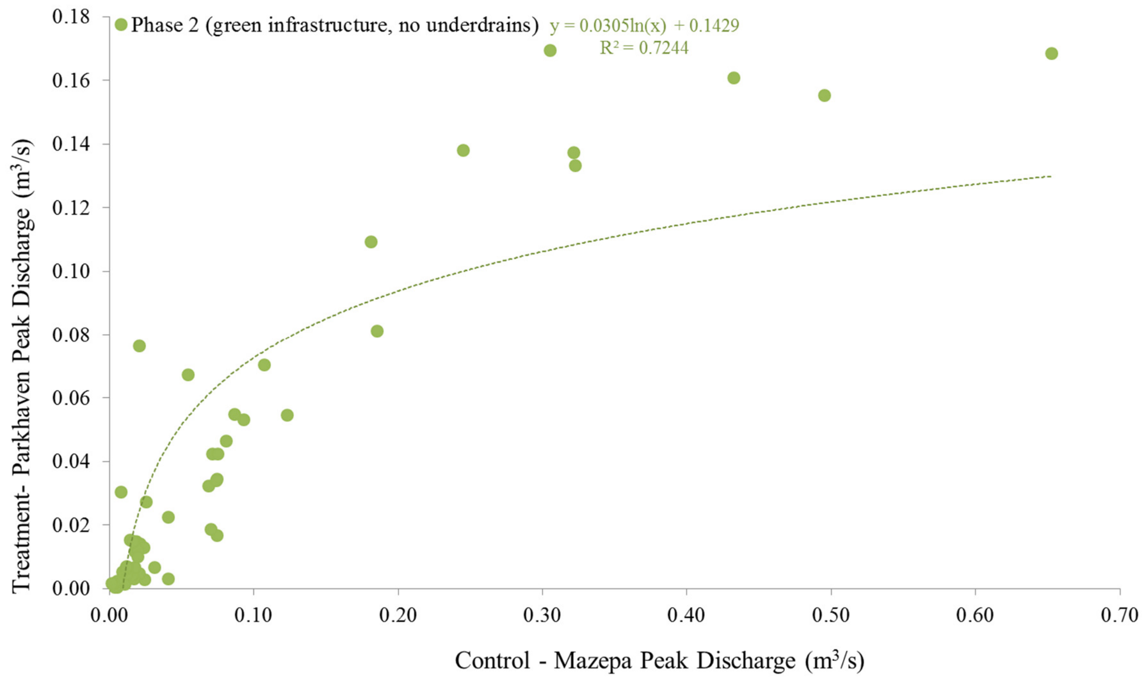



Figure 1-14. Peak stormflows for all storm events from Phase 2 on Parkhaven and Mazepa (n = 55).

treatment and control streets, large storms were not observed in the Pre-Treatment phase, so it is possible that the logarithmic relationship observed with large peak stormflow in Phase 1 and Phase 2 can be attributed to the general nature of runoff on the streets during large storm events and not the addition of green infrastructure.

### Total Storm Volume – Klusner/Hetzel

Comparison of total storm volume was made for all three observation periods on Klusner and Hetzel (Figure 1-15). An increase in total storm volume was seen on the treatment street from the Pre-Treatment to the Phase 1 observation period. During the Phase 1 to Phase 2 observation period, an overall decrease in total storm volume was observed. Underdrains in the green infrastructure in Phase 1 did not lead to a substantial reduction in total storm volume because the water was only being slowed by the street side bioretention gardens and was still connected to the storm sewers. In Phase 2, the removal of underdrains from the street side bioretention gardens and additional front and back yard rain gardens, allowed for the water captured in the gardens to be completely removed from the stormwater system. Using Student's t-test for least square means, linear trend lines in Figure 1-15 are significantly different between Phase 1 and Pre-Treatment, and Phase 1 and Phase 2 (least sq means = 550.74, Pre-Treatment; 764.64, Phase 1; 591.32, Phase 2). No statistical differences were found between Pre-Treatment and Phase 2 linear trend lines. Comparison of the linear trend lines for total storm volume from Phase 1 to Phase 2 shows that a total discharge on Hetzel of 100 $m^3$ resulted in a 20% reduction of total storm flow on Klusner, whereas a total storm flow of 2000 $m^3$ on Hetzel resulted in a 30% reduction on Klusner.

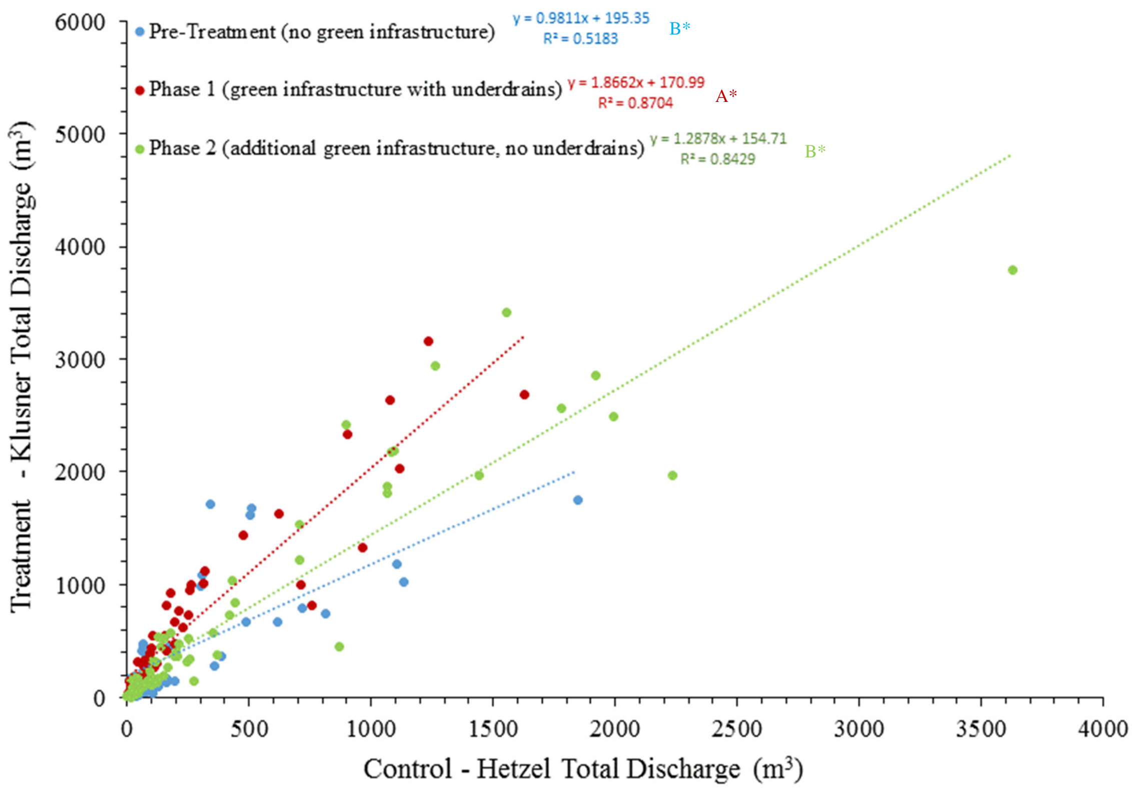



Figure 1-15. Comparison of total stormflow for all storm events from Pre-Treatment, Phase 1, and Phase 2 on Klusner and Hetzel (n = 40, 56, 66). Regression lines between Phase 1 and Pre-Treatment, and Phase 1 and Phase 2 are statistically significantly different ($p = 0.05$) (least sq means = 550.74, Pre-Treatment; 764.64, Phase 1; 591.32, Phase 2). Regressions lines between Phase 2 and Pre-Treatment are not statistically significantly different.

## Total Storm Volume – Parkhaven/Mazepa

Comparison of total storm volume was made for all three observation periods on Parkhaven and Mazepa (Figure 1-16). Total storm volume did not show any change from Pre-Treatment 1 to Pre-Treatment 2. From Pre-Treatment 2 to Phase 2, a decrease in total storm volume was observed. It could be expected that total storm volume would remain the same or increase when the road was repaved and new curbs were installed because the flow path to the storm drains would be improved. The reduction in storm volume during the Phase 2 observation period can be attributed to not having underdrains in the street side bioretention gardens where, similar to Klusner, water entering the gardens would be completely removed from the stormwater system. Comparison of the linear trend lines for total storm volume from Pre-Treatment 2 to Phase 2 shows that a total discharge on Mazepa of 200 $m^3$ resulted in a 6.7% reduction of peak storm flow on Parkhaven, whereas a total storm flow of 2000 $m^3$ on Mazepa resulted in a 35% reduction on Parkhaven. Using the Student's t-test no significant differences were found for any of the phases.

## Lag Time Analysis – Klusner/Hetzel

Lag time analysis was conducted on Klusner and Hetzel to compare the centroid lag-to-peak, centroid lag, lag-to-peak, and peak lag-to-peak (Figure 1-17). Significant differences in all measures were seen between Pre-Treatment vs Phase 1 and Pre-Treatment vs Phase 2 (Table 1-4). Significant differences were only observed in the centroid lag variable between Phase 1 vs Phase 2. The addition of green infrastructure to the treatment street increased lag times, but the additional green infrastructure added in Phase 2 did not add significantly to the lag time on the treatment street. Pre-Treatment

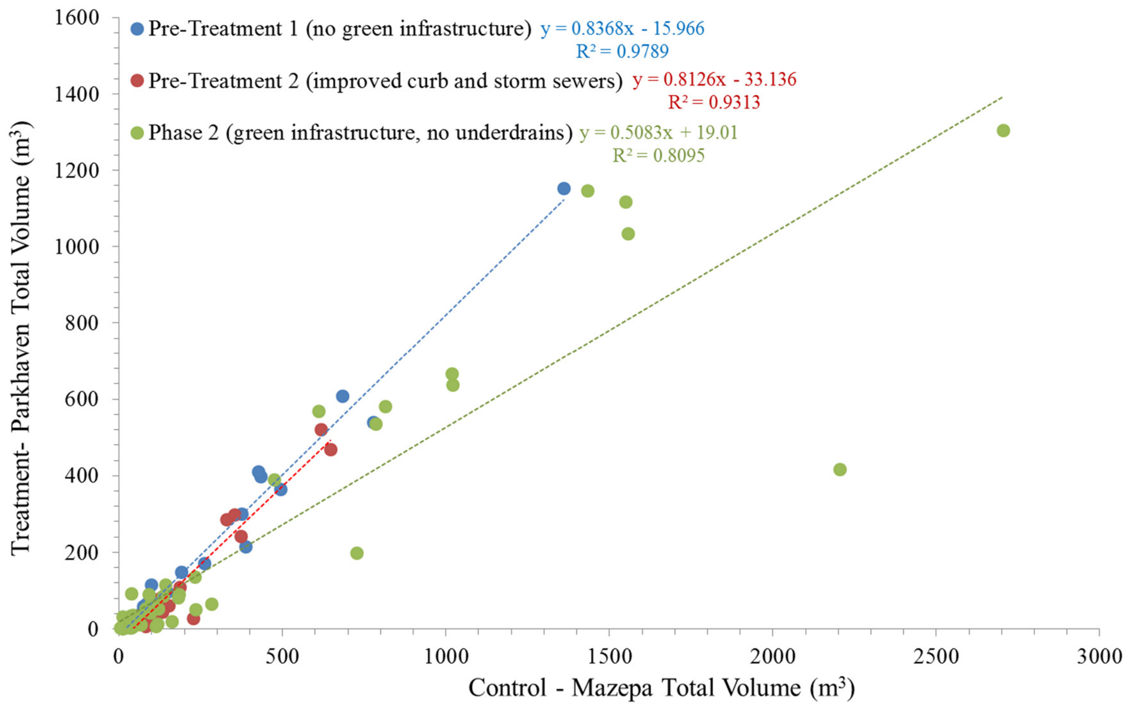



Figure 1-16. Comparison of total stormflow for all storm events from Pre-Treatment 1, Pre-Treatment 2, and Phase 2 on Parkhaven and Mazepa (n = 27, 24, 55). Regression lines are not statistically significantly different between phases.

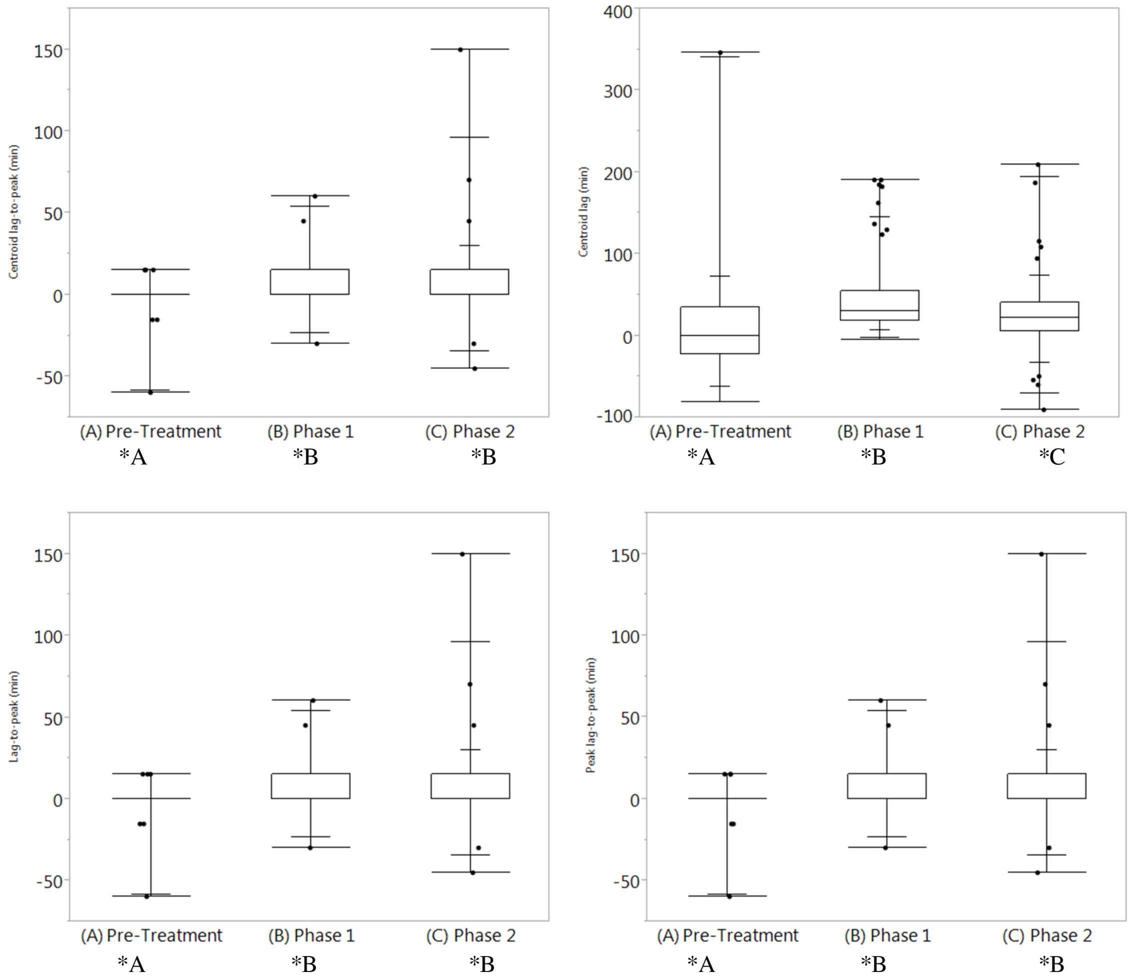



Figure 1-17. Box plots of (a) Centroid lag-to-peak, (b) Centroid lag, (c) Lag-to-peak, and (d) Peak lag-to-peak for Klusner (treatment) as compared to Hetzel (control) for all storm events.

Table 1-4. Nonparametric comparisons for each pair of observation periods comparing Klusner lag times to Hetzel lag times using Wilcoxon Method. Values with (*) indicate significant differences ($p < 0.05$) in lag time variables.

| Observation Period Comparison | Centroid lag-to-peak p-value | Centroid Lag p-value | Lag-to-peak p-value | Peak lag-to-peak p-value |
|---|---|---|---|---|
| Phase 1 - Pre-Treatment | 0.0453* | 0.0001* | 0.0453* | 0.0453* |
| Phase 2 - Pre-Treatment | 0.0006* | 0.0058* | 0.0003* | 0.0003* |
| Phase 2 - Phase 1 | 0.0647 | 0.0148* | 0.0538 | 0.0538 |

Table 1-5. Geometric means of lag time variables for Klusner (treatment) as compared to Hetzel (control). Positive values indicate longer lag time on the treatment street.

| Lag Time Variable | Pre-Treatment Mean Difference (min) | Phase 1 Mean Difference (min) | Phase 2 Mean Difference (min) |
|---|---|---|---|
| Centroid lag-to-peak | -1.1 | 5.4 | 9.4 |
| Centroid Lag | 8.8 | 48.6 | 28.1 |
| Lag-to-peak | -1.1 | 4.3 | 10.0 |
| Peak lag-to-peak | -0.9 | 4.1 | 9.4 |

observations showed that Klusner often had slightly shorter lag times than Hetzel (Table 1-4). During Phase 1 and Phase 2, lag times on Klusner increased over Hetzel, indicating that it was taking longer for the stormflow to reach the end of the street on Klusner.

### Lag Time Analysis – Parkhaven/Mazepa

Lag time analysis was conducted on Parkhaven and Mazepa to compare the centroid lag-to-peak, centroid lag, lag-to-peak and peak lag-to-peak (Figure 1-18). Statistically significant differences were only seen between Pre-Treatment 2 and Phase 2 for all lag time variables except centroid lag (Table 1-5). Between Pre-Treatment 2 and Phase 2 centroid lag-to-peak, lag-to-peak and peak lag-to-peak lag times decreased on the treatment street, with runoff reaching the end of the street more quickly after the addition of green infrastructure. Conversely, the centroid lag time variable showed a statistically significant increased lag time on the treatment street over all three observation periods (Table 1-6).

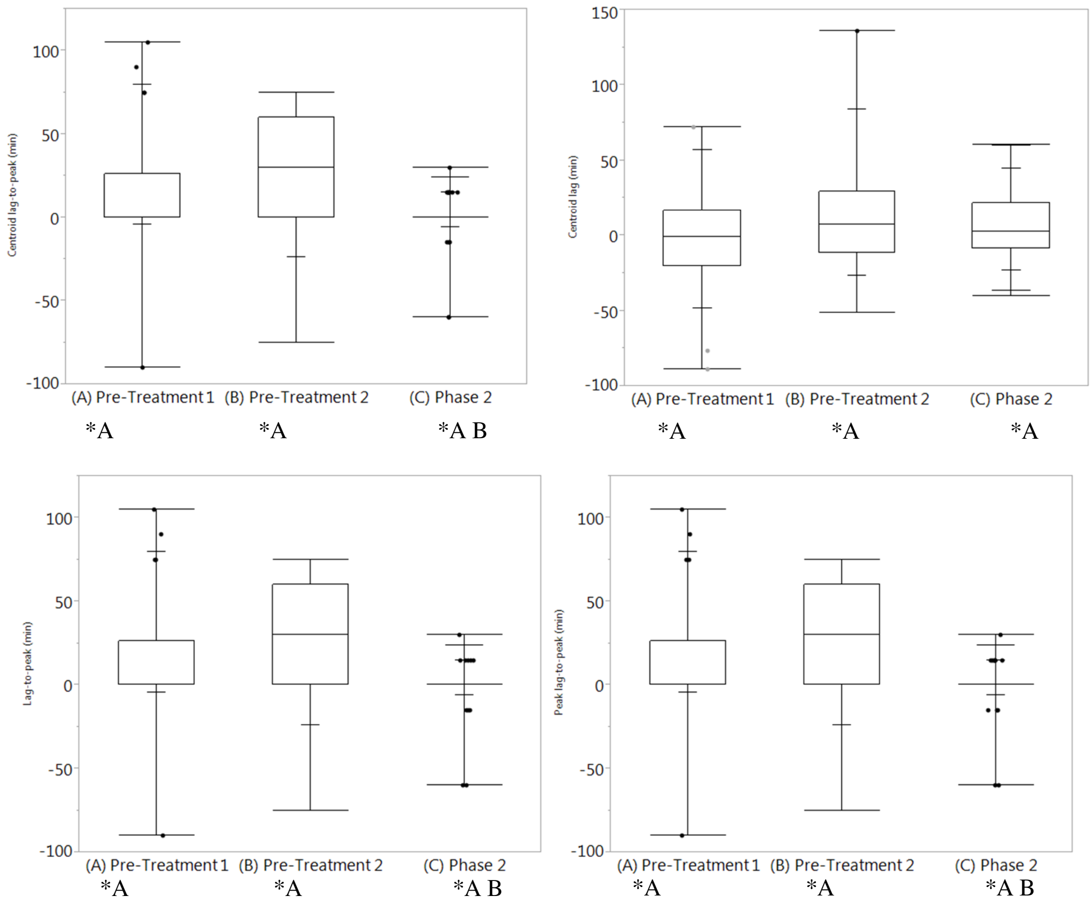



Figure 1-18. Box plots of (a) Centroid lag-to-peak, (b) Centroid lag, (c) Lag-to-peak, and (d) Peak lag-to-peak for Parkhaven (treatment) as compared to Mazepa (control) for all storm events.

Table 1-6. Nonparametric comparisons for each pair of observation periods comparing Parkhaven lag times to Mazepa lag times using Wilcoxon Method. Values with (*) indicate significant differences ($p < 0.05$) in lag time variables.

| Observation Period Comparison | Centroid lag-to-peak p-value | Centroid Lag p-value | Lag-to-peak p-value | Peak lag-to-peak p-value |
|---|---|---|---|---|
| Pre-Treatment 2 - Pre-Treatment 1 | 0.213 | 0.2027 | 0.1892 | 0.1892 |
| Phase 2 - Pre-Treatment 1 | 0.0576 | 0.2066 | 0.096 | 0.096 |
| Phase 2 - Pre-Treatment 2 | 0.0001* | 0.6737 | 0.0001* | 0.0001* |

Table 1-7. Geometric means of lag time variables for Parkhaven (treatment) as compared to Mazepa (control). Positive values indicate longer lag time on the treatment street.

| Lag Time Variable | Pre-Treatment 1 Mean Difference (min) | Pre-Treatment 2 Mean Difference (min) | Phase 2 Mean Difference (min) |
|---|---|---|---|
| Centroid lag-to-peak | 15.2 | 27.2 | -0.1 |
| Centroid Lag | -29.5 | -11.4 | 6.0 |
| Lag-to-peak | 15.4 | 29.0 | -0.1 |
| Peak lag-to-peak | 15.5 | 27.7 | -0.4 |

## Multiple Regression Analysis – Klusner/Hetzel

Multiple regression analysis was conducted for peak and total discharge on Klusner for all three separate monitoring phases and on Hetzel for all phases combined, since no construction occurred on the control street (Table 1-8). Each regression was run in a forward stepwise fashion using a p-value threshold of 0.1 until all significant variables were included in the final model. The first variable to enter the model is the most strongly correlated with the variable being predicted.

The multiple linear regression equations developed for peak and total discharge (Q) take the following forms:

Peak Q = A ± (B*Peak Precip) ± (C*Total Precip) ± (D*AMC 12hr) ± (E*AMC 24 hr) ± (F*AMC 24 hr) ± (G*AMC 7 day)

Total Q = A ± (B*Peak Precip) ± (C*Total Precip) ± (D*AMC 12hr) ± (E*AMC 24 hr) ± (F*AMC 24 hr) ± (G*AMC 7 day)

where, A is the intercept, B, C, D, E, F, and G are the coefficients in Table 1-8 and peak precipitation, total precipitation, AMC 12hr, AMC 24hr, AMC48hr, and AMC 7day are the input variables. Using the multiple linear regression equations, peak discharge can be calculated in $m^3/s$ and total discharge can be calculated in $m^3$.

For peak discharge on Klusner, strong regression models were developed for the Pre-Treatment phase ($r^2$=0.74) and Phase 2 ($r^2$=0.68) (Table 1-8). Peak precipitation was the first variable to enter each of the models, and was followed by total precipitation and one or more AMC variables. For the Phase 1 data, peak precipitation was the only variable to enter the regression model, which had less explanatory power ($r^2$=0.32). The

Table 1-8. Multiple Regression Analysis of precipitation variables for determining peak and total discharge on Klusner and Hetzel (Stepwise Fit, Forward Direction).

| Street | Period of Interest | Phase | p-value | $R^2$ | Intercept | Peak Precipitation (mm) | Total Precipitation (mm) | AMC 12 Hours (mm) | AMC 24 Hours (mm) | AMC 48 Hours (mm) | AMC 7 Days (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klusner | Peak Q | Pre-Treatment | 0.1 | 0.74 | 0.011 | 0.032 | -0.002 | 0.004 | 0 | 0 | 0 |
| Klusner | Peak Q | Phase 1 | 0.1 | 0.32 | 0.055 | 0.024 | 0 | 0 | 0 | 0 | 0 |
| Klusner | Peak Q | Phase 2 | 0.1 | 0.68 | 0.007 | 0.012 | 0.003 | 0 | 0 | 0.002 | 0.001 |
| Klusner | Total Q | Pre-Treatment | 0.1 | 0.75 | 10.534 | 0 | 34.923 | 29.443 | 0 | 4.943 | 0 |
| Klusner | Total Q | Phase 1 | 0.1 | 0.46 | 161.473 | 0 | 36.631 | 0 | 0 | 0 | 4.737 |
| Klusner | Total Q | Phase 2 | 0.1 | 0.78 | 13.628 | -119.709 | 88.195 | 0 | 14.540 | 0 | 4.776 |
| Klusner | Total Q | Phase 2* | 0.1 | 0.72 | 28.346 | 0 | 56.809 | 0 | 0 | 14.796 | 0 |
| | | | | | | | | | | | |
| Hetzel | Peak Q | All Phases | 0.1 | 0.48 | -0.015 | 0.037 | 0 | 0 | 0 | 0 | 0 |
| Hetzel | Total Q | All Phases | 0.1 | 0.62 | 2.781 | 0 | 32.679 | 0 | 5.272 | 0 | 0 |
| Hetzel | Peak Q | Pre-Treatment | 0.1 | 0.61 | 0.015 | 0.016 | 0 | 0 | 0.000 | 0 | 0 |
| Hetzel | Total Q | Pre-Treatment | 0.1 | 0.87 | -13.686 | -29.227 | 41.524 | 0 | 3.415 | 0 | 0 |

*Phase 2 multiple regression model excluding peak precipitation as a predictor variable.

coefficients for peak precipitation decrease from Pre-treatment through Phase 2, suggesting a slight decoupling between peak precipitation rate and peak discharge as green infrastructure was added to the street. The regression model developed for peak discharge on Hetzel includes only peak precipitation ($r^2$=0.48), and the coefficient on peak precipitation is similar in magnitude to that of the pre-treatment data on Klusner.

For total discharge on Klusner, strong regression models were developed for the Pre-Treatment phase ($r^2$=0.75) and Phase 2 ($r^2$=0.72) (Table 1-8). Total precipitation was the first variable to enter each of the models. Peak precipitation was the next variable to enter the model only for Phase 2, followed the AMC variables. However, the model was rerun to exclude peak precipitation in Phase 2, because the peak precipitation variable was much smaller (estimate = -119.7) than the other two phases that did not include peak precipitation in the model. Peak precipitation did not enter the model in the Pre-Treatment phase or Phase 1, only AMC variables were added. Phase 1 had the least explanatory power of all three phases ($r^2$=0.46). The coefficients for total discharge increase from Pre-Treatment through Phase 2, suggesting a slightly stronger relationship between total precipitation and total discharge as green infrastructure was added to the street. The regression model for peak discharge, using data from all phases on Hetzel includes total precipitation and AMC 24 hours ($r^2$ = 0.62), and the coefficient on total precipitation is similar in magnitude to that of the Pre-Treatment phase and Phase 1.

Comparisons between actual and predicted peak discharge (Figure 1-19) and actual and predicted total discharge (Figure 1-20) show how well the model was able to predict each outcome on Klusner. The Pre-Treatment phase and Phase 2 models were able to better predict peak discharge than the Phase 1 model, which under-predicts the

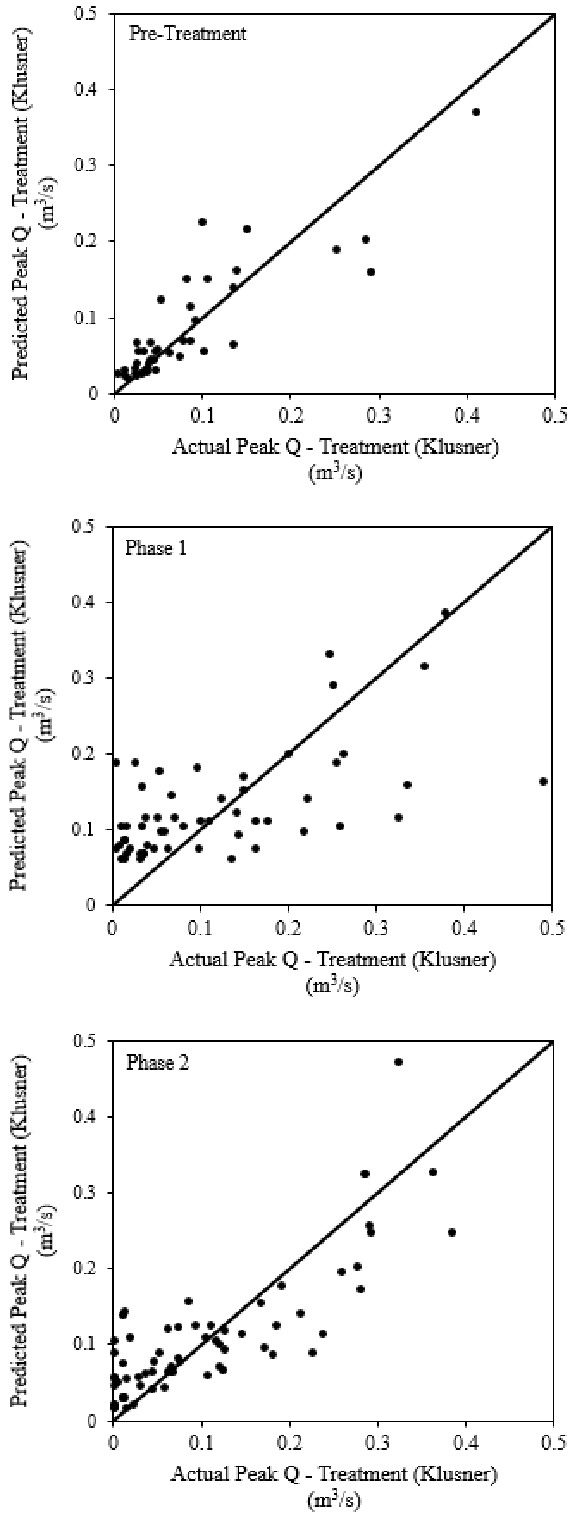



Figure 1-19. Actual and predicted peak discharge for Klusner using multiple regression analysis. The diagonal line indicates a 1:1 relationship between actual and predicted data.

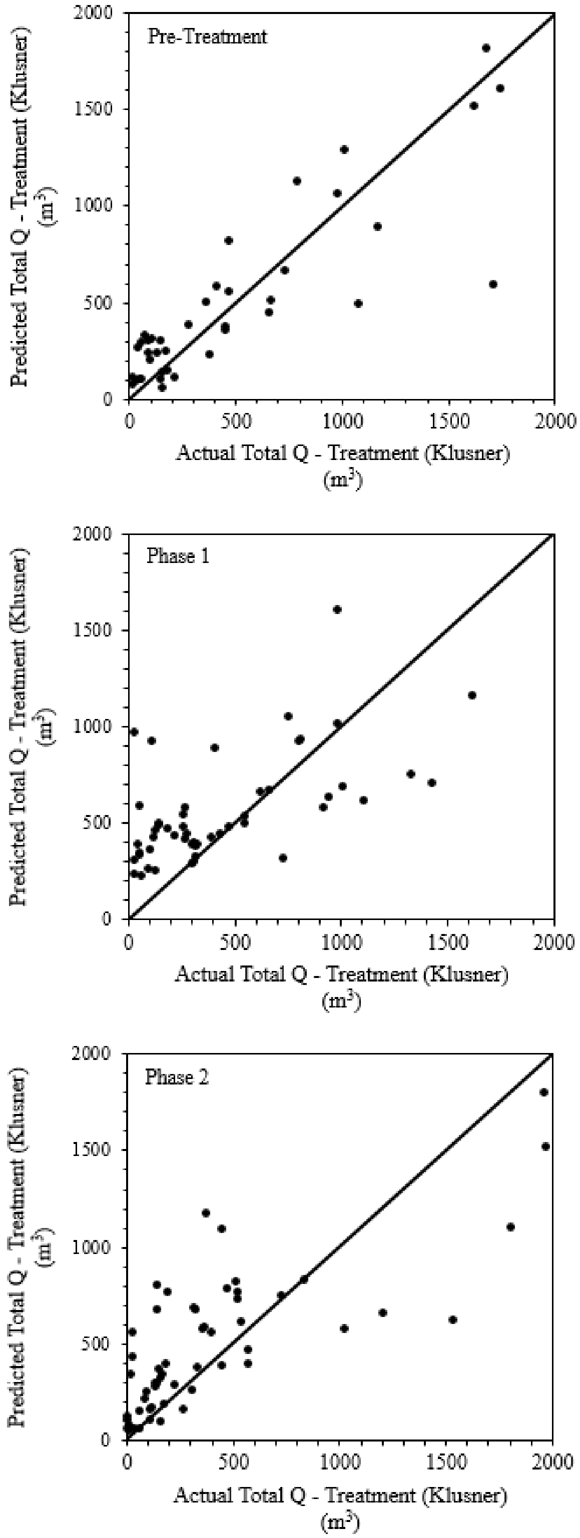


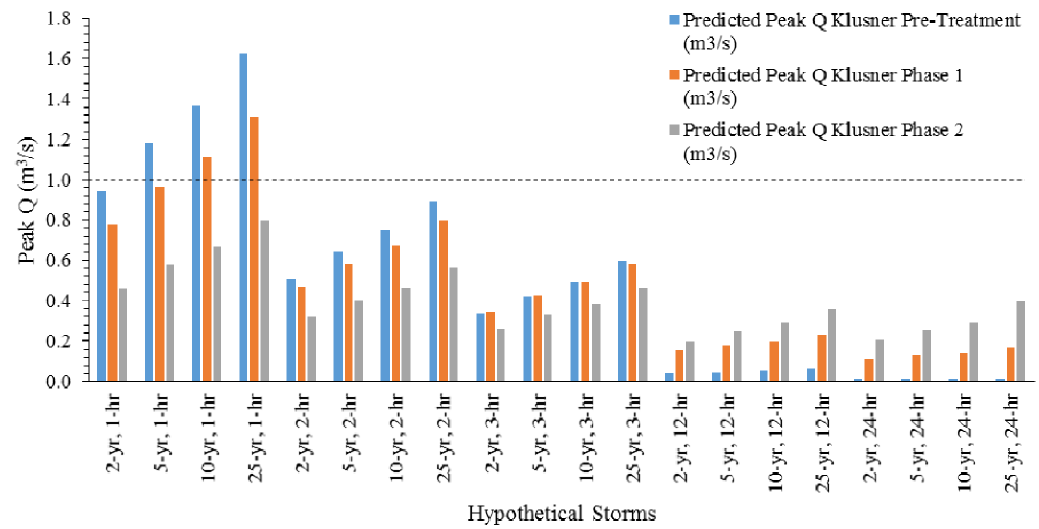

Figure 1-20. Actual and predicted total discharge for Klusner using multiple regression analysis. (Phase 2 predicted total discharge excludes peak precipitation from the model). The diagonal line indicates a 1:1 relationship between actual and predicted data.

larger storms. For total discharge, while the Phase 1 model has the lowest explanatory power ($r^2$), examination of the actual versus predicted graphs indicates that scatter across a range of storm sizes explains the poor model performance. In contrast, the Phase 2 model has greater explanatory power but under-predicts many of the larger storms while over-predicting many storms in the 200-500 $m^3$ range.

The regression models for peak and total discharge were used along with hypothetical storms from NOAA's precipitation frequency data server (PFDS) (NOAA, 2015). Total precipitation values were obtained from the PFDS using the Cleveland WSFO AP station located at the Cleveland Hopkins International Airport (Table 1-9). Peak precipitation was calculated assuming a constant rain fall over the duration of the storm and AMC were assumed to be zero for consistency in modeling and because they were not as strongly correlated to peak and total discharge. On Klusner 1, 2, 3, 12, and 24 hour storms were used with recurrence intervals of 2, 5, 10, and 25 years (Figure 1-21). For the shorter duration, higher intensity storms (1, 2, and 3 hours) peak discharge was predicted to decrease with the addition of green infrastructure, whereas the longer duration, less intense storms (12 and 24 hours) predicted an increase in peak discharge with the addition of green infrastructure. Only Phase 1 and Phase 2 had actual storms long enough to be included in the range of the 12 and 24 hour hypothetical storms (Table 1-3). For all hypothetical storms, total discharge was predicted to be higher with the addition of green infrastructure, contrary to the pattern observed in the analysis of data from Klusner versus Hetzel. Several predicted storms were outside of the range of actual observed storms.

Table 1-9. Precipitation variables used in hypothetical storm events for predicted peak discharge and total discharge on all streets.

| Hypothetical Storm Event | Peak Precipitation (mm/hour) | Total Precipitation (mm) |
|---|---|---|
| 2-yr, 1-hr | 30.73 | 30.73 |
| 5-yr, 1-hr | 38.61 | 38.61 |
| 10-yr, 1-hr | 44.70 | 44.70 |
| 25-yr, 1-hr | 53.34 | 53.34 |
| 50-yr, 1-hr | 59.94 | 59.94 |
| 100-yr, 1-hr | 67.06 | 67.06 |
| 2-yr, 2-hr | 17.65 | 35.31 |
| 5-yr, 2-hr | 22.48 | 44.96 |
| 10-yr, 2-hr | 26.16 | 52.32 |
| 25-yr, 2-hr | 31.50 | 62.99 |
| 50-yr, 2-hr | 35.94 | 71.88 |
| 100-yr, 2-hr | 40.51 | 81.03 |
| 2-yr, 3-hr | 12.45 | 37.34 |
| 5-yr, 3-hr | 15.83 | 47.50 |
| 10-yr, 3-hr | 18.54 | 55.63 |
| 25-yr, 3-hr | 22.52 | 67.56 |
| 50-yr, 3-hr | 25.65 | 76.96 |
| 100-yr, 3-hr | 29.13 | 87.38 |
| 2-yr, 12-hr | 4.21 | 50.55 |
| 5-yr, 12-hr | 5.29 | 63.50 |
| 10-yr, 12-hr | 6.20 | 74.42 |
| 25-yr, 12-hr | 7.58 | 90.93 |
| 50-yr, 12-hr | 8.74 | 104.90 |
| 100-yr, 12-hr | 10.03 | 120.40 |
| 2-yr, 24-hr | 2.46 | 58.93 |
| 5-yr, 24-hr | 3.07 | 73.66 |
| 10-yr, 24-hr | 3.58 | 85.85 |
| 25-yr, 24-hr | 4.85 | 116.33 |



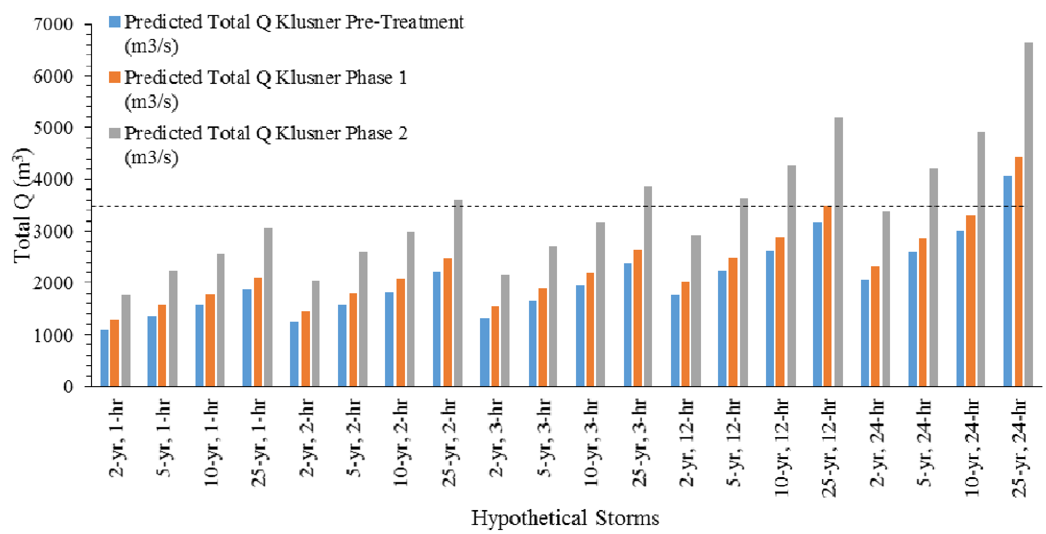




Figure 1-21. Predicted peak discharge and total discharge values for Klusner using hypothetical storms from the NOAA Precipitation Data Server based precipitation frequency estimates. Peak discharge and total discharge values above the dashed line are outside the scope of discgarge experienced during any phase of monitoring.

Predicting peak and total discharge above observed values should be done with caution because they are outside the realm of known data.

### Multiple Regression Analysis – Parkhaven/Mazepa

For peak discharge on Parkhaven, a strong regression model was developed for Phase 2 ($r^2$=0.76) and total precipitation was the first variable to enter the model, followed by AMC 48 hours (Table 1-10). Pre-Treatment 1 ($r^2$=0.56) and Pre-Treatment 2 ($r^2$=0.46) phases had less explanatory power. Peak precipitation was the first variable to enter the model in both pre-treatment phases and showed similar coefficients for peak precipitation. The coefficient for total precipitation in Phase 2 was an order of magnitude higher than the coefficients for peak precipitation in Pre-Treatment 1 and Pre-Treatment 2. The regression model developed for peak discharge on Mazepa had peak precipitation entering the model first, followed by AMC 48 hours. The coefficient for peak precipitation on Mazepa was similar in magnitude to the coefficients of peak precipitation in Pre-Treatment 1 and Pre-Treatment 2 on Parkhaven.

For total discharge on Parkhaven, strong regression models were developed for Pre-Treatment 1 ($r^2$=0.89), Pre-Treatment 2 ($r^2$=0.82), and Phase 2 ($r^2$=0.85) (Table 1-10). Peak precipitation was the first variable to enter each of the models, and was followed by one or more AMC variables. Total precipitation did not enter any of the models for total discharge in any of the phases. The coefficients for peak precipitation were within the same order of magnitude for all three phases. Suggesting that peak precipitation and total discharge are related regardless of the addition of green infrastructure to the street. The regression model developed for total discharge on Mazepa includes peak precipitation, followed by AMC 48 ($r^2$=0.66).

Table 1-10. Multiple Regression Analysis of precipitation variables for determining peak and total discharge on Parkhaven and Mazepa (Stepwise Fit, Forward Direction).

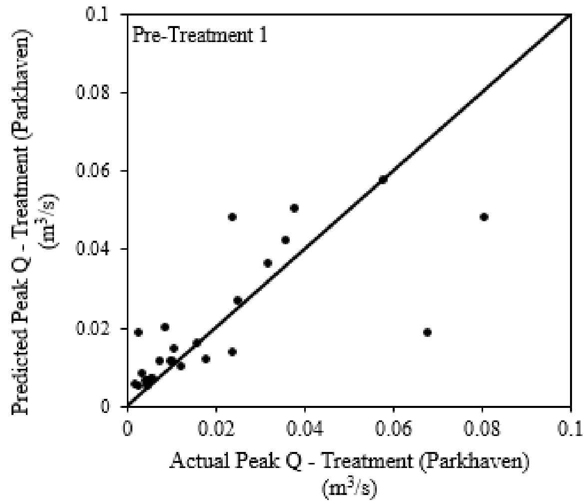
| Street | Period of Interest | Phase | p-value | $R^2$ | Intercept | Peak Precipitation (mm) | Total Precipitation (mm) | AMC 12 Hours (mm) | AMC 24 Hours (mm) | AMC 48 Hours (mm) | AMC 7 Days (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parkhaven | Peak Q | Pre-Treatment 1 | 0.1 | 0.5600 | 0.0035 | 0.0012 | 0 | 0 | 0.0013 | 0 | 0 |
| Parkhaven | Peak Q | Pre-Treatment 2 | 0.1 | 0.4563 | 0.0065 | 0.0012 | 0 | 0 | 0 | 0 | 0 |
| Parkhaven | Peak Q | Phase 2 | 0.1 | 0.7646 | -0.0082 | 0 | 0.0101 | 0 | 0 | 0.0013 | 0 |
| Parkhaven | Total Q | Pre-Treatment 1 | 0.1 | 0.8904 | -75.6141 | 19.4796 | 0 | 20.5048 | 5.4655 | 0 | 1.7511 |
| Parkhaven | Total Q | Pre-Treatment 2 | 0.1 | 0.8859 | -12.9036 | 17.9861 | -23.4582 | 4.3212 | 0 | 0.0000 | 0 |
| Parkhaven | Total Q | Pre-Treatment 2* | 0.1 | 0.8231 | -29.7982 | 14.6187 | 0 | 3.5607 | 0 | 0 | 0 |
| Parkhaven | Total Q | Phase 2 | 0.1 | 0.8518 | -117.8213 | 18.8429 | 0 | 0 | 0 | 6.8616 | 1.5378 |
| Mazepa | Peak Q | All Phases | 0.1 | 0.5529 | 0.0120 | 0.0062 | 0 | 0 | 0 | 0.0007 | 0 |
| Mazepa | Total Q | All Phases | 0.1 | 0.6621 | -62.0306 | 29.1983 | 0 | 0 | 0 | 3.7613 | 0 |
| Mazepa | Peak Q | Pre-Treatment 1 | 0.1 | 0.4163 | 0.0091 | 0.0020 | 0 | 0 | 0.0035 | 0 | 0 |
| Mazepa | Total Q | Pre-Treatment 1 | 0.1 | 0.8637 | -14.4975 | 23.3810 | 0 | 0 | 10.0881 | 0 | 0 |

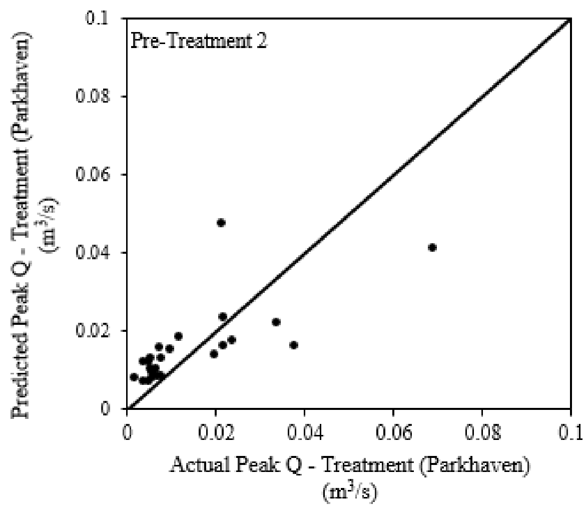
*Pre-Treatment 2 multiple regression model excluded total precipitation as a predictor variable.

The coefficient for peak precipitation is within the same order of magnitude as that of all three phases on Parkhaven.

Comparisons made between actual and predicted peak discharge (Figure 1-22) and actual and predicted total discharge (Figure 1-23) show how well the model was able to predict each outcome on Parkhaven. Peak discharge was best correlated in Phase 2 between actual and predicted storms. The Pre-Treatment 1 and Pre-Treatment 2 phases were more weakly correlated. This could be related to the lower number of storms included in the model for both pre-treatment phases. The model was able to better predict total discharge for all three phases on Parkhaven. This can be related to how strongly the peak precipitation was correlated to total discharge. When comparing all phases on Mazepa, the total discharge was also best predicted by the peak precipitation.

The models to calculate peak and total discharge on Parkhaven were calculated the same as for Klusner. For all hypothetical storm events and durations peak discharge was predicted to me much higher after the addition of green infrastructure on Parkhaven, but similarly predicted peak discharge for both pre-treatment phases (Figure 1-24). Predicted total discharge shows a reduction in total discharge on Parkhaven after the addition of green infrastructure for all hypothetical storm events and durations (Figure 1-25). The reduction in total discharge for the longer duration storm events is a function of the regressions' dependence on peak precipitation rates. The longest actual storms observed on Parkhaven were 20.5 hours in Pre-Treatment 2 and 17.25 hours in Phase 2. Not having as manly longer storms in all of the phases could also have some dependence on the outcome of the predicted total discharge. The analysis for Pre-Treatment 2 was



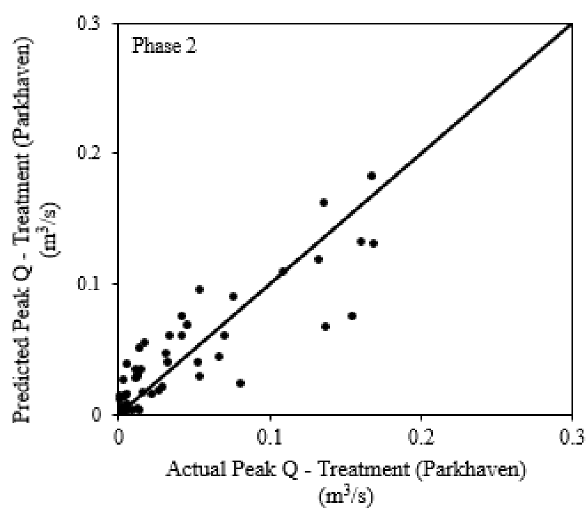




Figure 1-22. Actual and predicted peak discharge for Parkhaven using multiple regression analysis. The diagonal line indicates a 1:1 relationship between actual and predicted data.

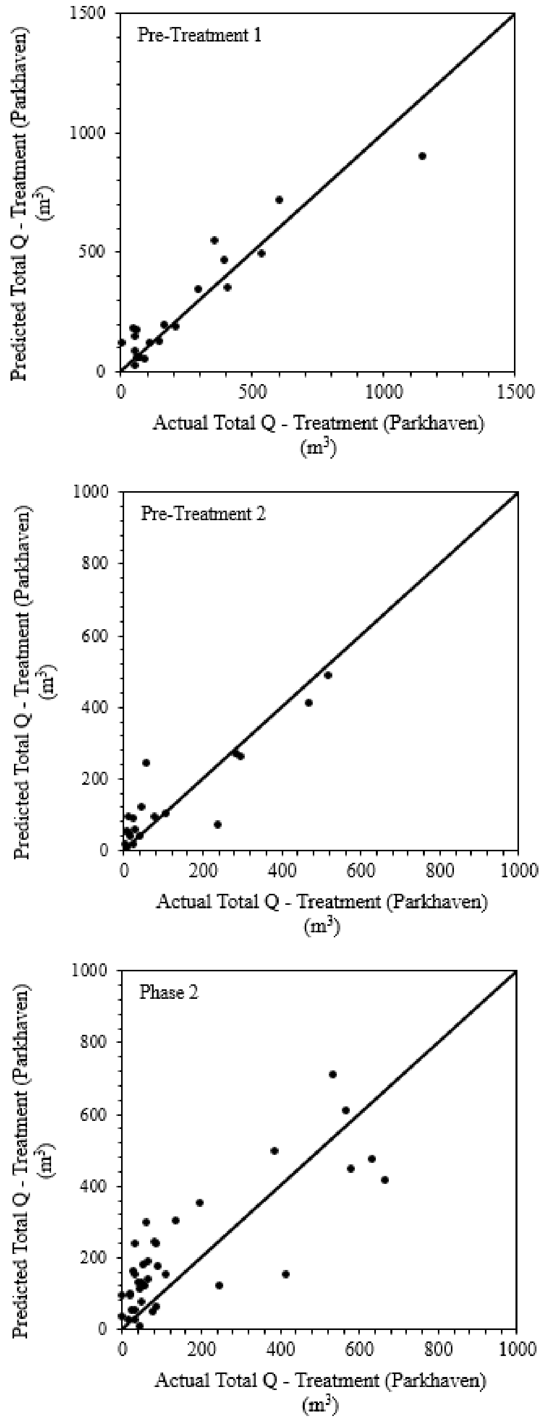
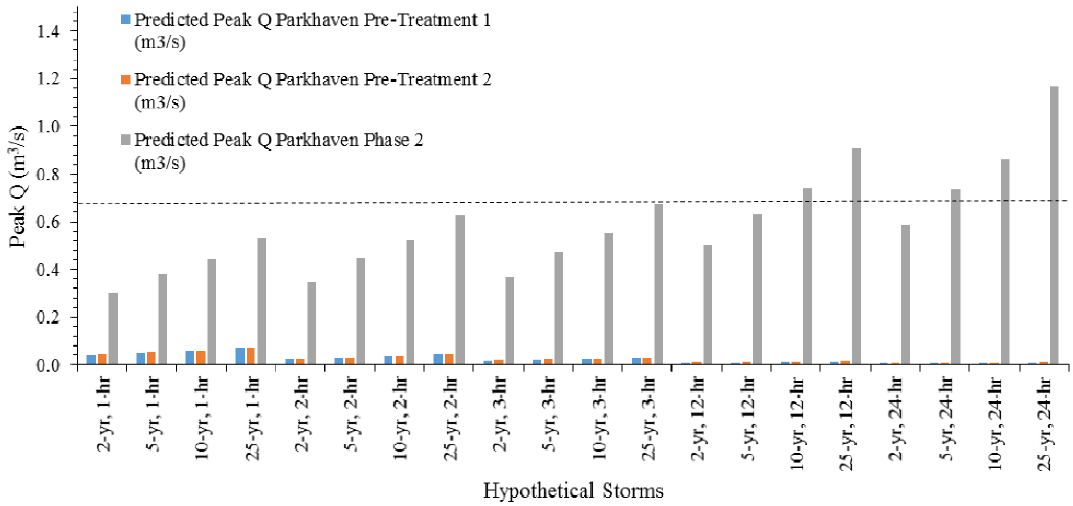



Figure 1-23. Actual and predicted total discharge for Parkhaven using multiple regression analysis. The diagonal line indicates a 1:1 relationship between actual and predicted data.



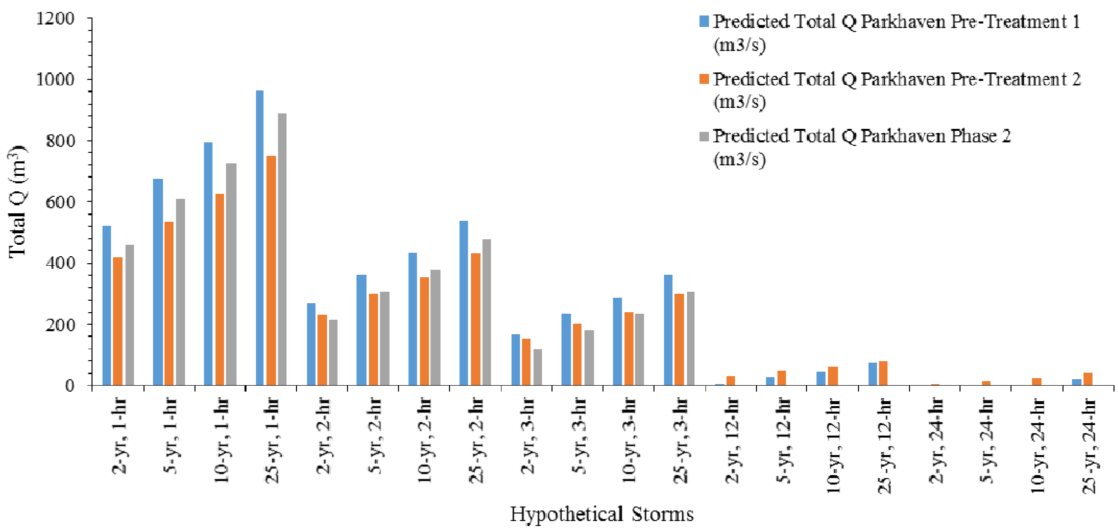




Figure 1-24. Predicted peak discharge and total discharge values for Parkhaven using hypothetical storms from the NOAA Precipitation Data Server based precipitation frequency estimates. Peak discharge values above the dashed line are outside the scope of discgarge experienced during any phase of monitoring.

predicted to have very large negative total discharge volumes (-181 $m^3$ to -3000$m^3$) and are reported as zero in the bar graphs.

## 1.4 - Discussion

### Hydrology

Green infrastructure retrofits have been shown to reduce peak stormflow as compared with traditional stormwater conveyance systems (Hood et al., 2007). Peak flow reductions from green infrastructure retrofits are highly dependent upon soil infiltration rate and the volume of water captured (Davis et al., 2009). Green infrastructure retrofits treat stormwater directly at the source, before it reaches the storm sewer, and help to improve infiltration and reduce total storm volume (Rushton, 2001). The peak storm flow, total storm flow, and lag time quantities measured in this study showed that the addition of green infrastructure to the treatment streets had a positive effect on reducing and slowing stormwater flow, even though not all differences were statistically significant.

### Peak Storm Flow

Reductions in peak stormflow observed on Klusner (treatment) from Pre-Treatment to Phase 1 and from Phase 1 to Phase 2 can be attributed to the addition of green infrastructure on the treatment street. A reduction in peak storm flow from Pre-Treatment to Phase 1 would be expected because green infrastructure retains water in the rain barrels, rain gardens, and street side bioretention gardens. The street side bioretention gardens would be expected to impact the largest amount of stormwater runoff because they are trapping street runoff, which accounts for the largest area of directly connected impervious surface to the storm sewers (Lee and Heaney, 2003, Mayer et al., 2012). The street side bioretention gardens with the underdrains in Phase 1 on Klusner should have contributed to the reduced peak stormflows by trapping stormwater runoff from the street and slowing down the flow of water as it moves from the bioretention gardens to the underdrain, then ultimately to the storm sewer. A further reduction of peak stormflow from Phase 1 to Phase 2 could be attributed to the additional green infrastructure on the street. The Phase 2 green infrastructure included additional front- and backyard rain gardens, as well as the street side bioretention gardens. In Phase 2 the street side bioretention gardens did not contain underdrains, so reduced peak stormflows observed in this phase could be attributed to the street side bioretention gardens and the front- and backyard rain gardens retaining stormwater runoff from the street and residents' properties, allowing the water to infiltrate into the ground. Overall, street side bioretention gardens with underdrains should help to slow stormwater before it reaches the storm sewer, whereas green infrastructure without underdrains should help to completely remove stormwater from the storm sewer system.

In this study, no significant differences in peak flows were seen between the pre-treatment phase and the two later phases on Klusner. However, the small range of storm sizes may have limited the power of this study, as significant differences between Phase 1 and Phase 2 were measured. Comparisons of storms on Klusner and Hetzel from Phase 1 and Phase 2, when larger peak flows were observed during monitoring, indicate a logarithmic relationship (Figure 1-3) and may be related to the way the street side bioretention gardens are able to trap stormwater runoff. The relationship can be correlated to the green infrastructure having greater impacts on stormwater runoff for larger storms. This phenomena was something that was visually observed during storm events on Klusner. During small storm events with low volumes of runoff, it was observed that stormwater would flow down the street, along the curbs and not always enter the street side bioretention gardens. However, during larger storm events, where runoff was much higher, it was observed that runoff would typically be diverted into the street side bioretention gardens. The field observations correlate well with the data collected on peak stormflows, where more water is diverted off the street in larger events than in smaller events. While, this may appear to be a good outcome for the larger storms, it is concerning that the green infrastructure treatments are not having as great of an effect on the smaller, more common storms. When assessing the downstream effects of storm size, smaller more frequent storms often can have more detrimental impacts to natural landscapes than larger, less frequent storms, due to the cumulative effects over long periods of time (Charlton, 2008).

Similar studies of subcatchment green infrastructure implementation have shown that small but significant treatment effects are possible with parcel-level implementation, even with no direct connection to street runoff (Shuster and Rhea, 2013). Shuster and Rhea (2013) suggest that green infrastructure retrofits may have greater reduction in peak and total stormflow volumes if they are connected to transportation surfaces. Comparisons of a traditionally built neighborhood versus a neighborhood built with green infrastructure practices from the start, utilizing green infrastructure connected to transportations surfaces, showed that peak discharge can be reduced by 11% over the traditional development (Hood et al., 2007). This study, in West Creek, took advantage of street side bioretention, connected to transportation surfaces, and realized effects of reduced peak stormflow.

The importance of transportation surfaces in affecting peak flows, and the potential for mitigating peak flows through green infrastructure, was also demonstrated by the Parkhaven (treatment) and Mazepa (control) results. Peak flow on Parkhaven appeared to increase from the Pre-Treatment 1 to the Pre-Treatment 2 period, though the differences were not statistically significant. Here increases in peak stormflow may be attributed to the road resurfacing and replacement of curbs and gutters. Prior to fixing the road, Parkhaven was an old road with areas of crumbling asphalt and broken and cracked curbs. After the road was repaved, flowpaths to the storm sewer were improved and stormwater runoff had an easier time reaching the storm drains. Once green infrastructure was added to Parkhaven in Phase 2, the peak storm flows returned to conditions similar to before the road was repaired. This reduction in peak stormflows indicates that the green infrastructure, particularly the street side bioretention gardens, is helping to reduce peak stormflows on the treatment street.

The peak stormflows for the Phase 2 period, in which storms producing higher peak flow occurred, show a logarithmic relationship similar to the relationship observed on Klusner and Hetzel. As at Klusner, it was observed that smaller amounts of runoff would travel down the curb and bypass the street side bioretention and larger amounts of runoff would be diverted into the curb-cuts of the bioretention gardens. It is difficult to quantify this relationship on either sets of streets due to the lack of larger storms in the Pre-Treatment observation periods. It is interesting to note however, that the same logarithmic relationship was observed on both sets of treatment and control streets. The fact that this phenomenon happened on both sets of streets, in data and observation, is suggestive that the relationship is due to the addition of green infrastructure and not the preexisting flow paths on either set of streets.

## Total Storm Volume

Total storm volumes on Klusner and Hetzel show a statistically significant increase from Pre-Treatment to Phase 1, then a significant reduction in volume from Phase 1 to Phase 2. The initial increase in total storm volume from Pre-Treatment to Phase 1 may be attributed to increasing flow paths to the storm sewers via the underdrains of the street side bioretention. Prior to constructing the bioretention gardens, the tree lawns could intercept runoff directly from precipitation as well as sidewalks and a small portion of driveways. Once the gardens were constructed with the underdrains, the amount of water the tree lawn would normally trap could now be infiltrated through the gardens and directed to the storm sewers through the underdrains. In Phase 2 of construction, the removal of underdrains from the design helped to remove street runoff without creating additional connection to the storm sewer system. The removal of the underdrains from the Phase 2 street side bioretention gardens and the addition of more front- and backyard rain gardens can account for the reduction in total storm volume from Phase 1 to Phase 2. The net result of the two phases of green infrastructure additions on Klusner Avenue was no statistically significant difference in total flows.

Total stormflow volume remained relatively constant on Parkhaven and Mazepa for the Pre-Treatment 1 and Pre-Treatment 2 phases. The similar total storm volume flows can be attributed to not having green infrastructure on the street in either phase. Fixing the street surface, curbs, and gutters helped to contribute to increased peak flows, but fixing the street did not have an effect of the total volume of stormflow reaching the end of the street. In Phase 2, when green infrastructure was added to the street, total stormflow volumes were significantly reduced relative to both Pre-Treatment periods. The reduction in total storm volume in Phase 2 indicates that the addition of green infrastructure to the street is helping to retain stormwater volume and remove stormwater from the storm sewer system.

**Lag Time Analysis**

Lag times were found to significantly increase with the addition of green infrastructure on Klusner. All four lag time variables between Phase 1 and Pre-Treatment, and Phase 2 and Pre-Treatment were statistically significantly longer. Increased lag times from Pre-Treatment to Phase 1 can be attributed to the underdrains in the street side bioretention. This occurs because the street side bioretention is able to slow down the flow of water to the storm drain. However, with the removal of underdrains from the design of the street side bioretention in Phase 2, the diverted stormflow is completely removed from the storm sewer system. If the green infrastructure is distributed relatively evenly along the street, as in this study, complete removal of water from the system will only have an effect on total volume, not the timing of stormflow to the end of the street. Thus, there were no further significant increases in lag time associated with Phase 2 green infrastructure.

Lag time analysis conducted for Parkhaven and Mazepa showed a significant decrease in the lag time variables for centroid lag-to-peak, lag-to-peak, and peak lag-to-peak from Pre-Treatment 2 to Phase 2. This significant decrease in lag time may be attributed to the improved road surface, thus improving flow paths to the storm sewer system. The lack of underdrains in the street side bioretention might be expected to show similar results to that of the Phase 2 implementation on Klusner, where no significant increases in lag times were associated with the addition of green infrastructure without underdrains. The results for lag times requires further investigation to the shorter lag times observed after the implementation of green infrastructure. However, due to the smaller number of storms in the Pre-Treatment observation periods and the lack of larger storms for comparison to the Phase 2 observation period, it may not be possible to make meaningful conclusions regarding lag times on Parkhaven and Mazepa.

## Multiple Regression Analysis

Strong regression models of peak and total discharge were developed based on peak precipitation, total precipitation, and AMC. For Klusner, peak discharge was strongly correlated with peak rainfall and total discharge was strongly correlated with total rainfall. Predicted peak discharge could be more accurately predicted for shorter, more intense storms than longer, steadier storms. This can be related to fewer actual larger storms in the data set and the fact that larger storms that were observed skewed the relationship of peak discharge when comparing the treatment and control streets (Figure 1-11 and Figure 1-12). The modeled reductions in peak discharge with the addition of green infrastructure in short, intense storms is in agreement with the relationship seen in the runoff data, where there was a greater reduction in storms with peak flows >0.3 $m^3/s$ than smaller storms. Field observations suggested that during less intense storms, runoff did not enter the bioretention gardens as easily as in more intense storms. Using an even distribution of precipitation, the shorter storms are more intense and the longer storms are less intense, leading to the reductions in peak discharge with the addition of green infrastructure in the modeled 1, 2, and 3 hour storms and increases in peak discharge in the modeled 12 and 24 hour storms. The models show increases for total discharge with the addition of green infrastructure for all storm durations and recurrence intervals. However, this result is contradicted by the observed discharge data, where no increase in total discharge was observed between Pre-Treatment and Phase 2.

Overall, the multiple regressions for Parkhaven were not able to replicate the observed changes in peak and total discharge across Pre-Treatment 1, Pre-Treatment 2, and Phase 2. Both peak and total discharge were strongly related to peak precipitation. The strong relationship of total discharge and peak precipitation could be related to the length of the road. Parkhaven is a relatively short road (~0.40 km), so runoff from any point on the street will reach the storm drain outfall quickly. The shorter more intense storms (1, 2, and 3 hours) showed much greater total storm discharge in the predicted model than the longer, less intense storms (12 and 24 hours) for both the Pre-Treatment 1 phase and Phase 2, but an overall decrease in total runoff with the addition of green infrastructure. This could be related to the lower amount of impervious cover on Parkhaven, where a longer, less intense storm would have a greater opportunity to infiltrate into lawns before creating runoff.

## Overall Hydrology Discussion

Both sets of control and treatment streets saw reductions in peak stormflow and total stormflow following the addition of green infrastructure. Including street runoff in the design of the green infrastructure retrofits could be an important factor in the overall performance of street-scale green infrastructure implementations. Imperviousness related to roadways can exert a greater hydrological impact than rooftop-related imperviousness, because roadways generally cover a larger, directly connected impervious surface (Lee and Heaney, 2003). The impacts of parcel-level green infrastructure can be limited when transportation surfaces are not included, because roadways can contribute to proportionally greater amounts of runoff as compared to runoff coming from driveways and rooftops (Mayer et al., 2012). Placement of the green infrastructure on properties and in relation to the road surface can also have a large impact on the performance of green infrastructure retrofits.

Having a higher density of implementation can result in greater quantity reductions of stormwater runoff (Mayer et al., 2012). However, the density distribution is important when considering the trapping of runoff from road surfaces. Having multiple street side bioretention gardens in a row could show diminished returns, because most of the street runoff could be captured in gardens directly upstream and not have enough volume left to divert by the time the runoff reaches the final garden in a row. Directly connected impervious area can be a major contributor for smaller, more frequent storms, while total impervious area can be more significant in larger, less frequent storm events (Lee and Heaney, 2003). Distributing the green infrastructure retrofits to capture rooftop, driveway, sidewalk, and roadway runoff from various LID applications can help to improve stormwater retention over a large range of storm event intensities and durations.

The goal of LID is to mimic predevelopment hydrology, reduce peak stormflows and total storm volume, and improve water quality (Hood et al., 2007). As with most studies of urban hydrology, this study is limited by having a lack of understanding of overall predevelopment hydrology in the watershed. Even the goal of fully understanding total hydrological improvements in the study is limited due to the lack of larger storms in the Pre-Treatment observation period. Being able to continue monitoring over a longer period of time would help to better quantify long term effects of the green infrastructure retrofits. Long term observations will also help to determine if the improvements to storm flow already quantified are repeatable.

Other limitations to this study can include the construction and maintenance of the green infrastructure retrofits. Water from smaller storms may have not been entering the street side bioretention gardens due to the placement and slope of the curb cuts and aprons. Making improvements to these features may help to improve runoff from smaller stormflows. The maintenance of rain gardens may have limited the effectiveness of the rain gardens due to excessive weeds growing around the entrance to the gardens and blocking flowpaths. Finally, if homeowners are not emptying their rain barrels, the barrels will not be effective in removing stormflow from the total runoff volumes.

Beyond long term monitoring for repeatability, continuous monitoring will help to better understand how maintenance of the green infrastructure affects performance over time. Being able to maintain the amount of green infrastructure implementations and the overall performance is important to obtaining consistent stormwater improvements. The Phase 1 and Phase 2 periods on Klusner and Hetzel showed results that indicate the addition or removal of underdrains from the design of the street side bioretention have an effect on peak storm flow and total storm volume. Further research is needed to fully understand the effects of underdrains and the applicability to the overall goals of a green infrastructure project. The use of rain gardens and rain barrels on homeowner’s properties versus the street side bioretention that traps road runoff should be investigated further. The distribution of green infrastructure is also important for the overall understanding of the improvements realized by green infrastructure retrofits. This study had several areas, particularly on Klusner, with a higher density of green infrastructure and also entire sections without any green infrastructure. Investigating a more even distribution of green infrastructure on the street is important to the overall understanding of the green infrastructure benefits. Finally, having a better understanding of how repaving old roads and fixing curbs and gutters impacts stormwater flow paths is needed to realize the overall benefits of adding green infrastructure.

## 1.5 - Conclusion

Green infrastructure retrofits added to suburban streets have produced reductions in peak storm flow and total storm flow, and have increased lag times. Connecting green infrastructure to transportation surfaces may have helped to gain more substantial results in the reductions of stormflow by affecting a greater surface area of directly connected imperviousness. The addition or removal of underdrains to street side bioretention gardens impacted peak storm flow, total flow volume, and lag time by either retaining and slowing the flow of stormwater or completely removing stormwater from the storm sewer system. Fixing degraded road surfaces can enhance flowpaths for stormwater, but adding green infrastructure can help to reduce the impacts of improved flowpaths. The effects of different distributions of green infrastructure retrofits along a street is still unknown, but such distributions may exert an important control on the improvements in peak stormflow and lag times. The site of this study is very typical of development in the northeastern Ohio area and may be easily replicated in other neighborhoods. Future projects should focus on investigating the importance of underdrains to overall performance, density distribution along the street of implementation, and connection to transportation surfaces.

## 2.1 - Introduction

### Water Quality and Magnetics

The accumulation of atmospheric pollution from vehicle exhaust, industrial emissions, and dust (Davis et al., 2003, Wong et al., 2012) on impervious surfaces makes them available for stormwater runoff (Rushton, 2001). Collection of these materials on impervious surfaces is then directed into storm drains. Storm drains can greatly increase the hydrologic connectivity at the watershed scale and in turn increase heavy metal and other constituent loads to streams (Kaushal and Belt, 2012). Stormwater runoff contributes to non-point source pollution when rainfall and snowmelt runs over land, picks up pollutants and deposits them into rivers, lakes and other receiving bodies of water (EPA.gov, 2014a). In urban areas non-point source pollution is conveyed through pipes and storm water control measures (SCMs) prior to reaching receiving bodies of water.

Traditional SCMs, such as retention ponds, wetlands, swales, infiltration systems and catch basins, often have high concentrations of suspended sediment, nutrients, bacteria, metals, pesticides, and herbicides and can degrade the quality of ground and surface water (Stanley, 1996, Wong et al., 2012). Suspended sediments in stormwater runoff often settle out within the SCM, retain pollutants with in the sediment, and slowly drain stormwater, yielding lower turbidity (Stanley, 1996). Metals are of particular concern because they cannot biodegrade and can accumulate in nature, where prolonged deposition can lead to contamination of soils and waterways (Wong et al., 2006, Davis et al., 2003). Metals are contributed to urban runoff by automobile exhaust, wearing of brakes and tires, degradation of siding and roofs of buildings, and atmospheric deposition (Davis et al., 2001b). The concentration of all metals in urban runoff typically ranges from 10 – 100 μg/L (Hunt et al., 2011). Trace metals of particular concern from urban stormwater runoff include Cd, Cu, Pb, and Zn with typical concentrations generally increasing from Cd (< 12ug/L), Cu and Pb (5-200 ug/L), and Zn (200-500 ug/L) (Davis et al., 2001b). Other trace metals of concern include Fe, Mn, and Ni because of their toxicity and impact on taste and color of water (Wong et al., 2006 and Feng et al., 2012). Direct human health impacts on trace metal contamination can be difficult to assess, however Pb can be toxic at trace levels (5-200 μg/L) whereas Cu and Zn are only toxic in elevated concentrations (Wong et al., 2006).

The use of low impact development (LID) bioretention gardens and rain gardens can help to improve water quality through evapotranspiration, soil filtering, and adsorption (Davis et al., 2003). Metal removal occurs as the stormwater runoff infiltrates through the bioretention garden and adsorbs to the surface of the mulch layer and soil media (Davis et al., 2001a). Field and lab studies have shown that metals are usually captured in the top 5 – 10 cm of filter media (Feng et al., 2012) and top 20 cm of filter media, respectively (Davis et al., 2003). While plants can aid in pollutant removal from bioretention gardens, a field study conducted in Connecticut concluded that plants only removed 0.1, 0.0 and 0.2% of Cu, Pb, and Zn respectively (Dietz and Clausen, 2006). In order for plants to substantially aid in pollutant removal, a very thick growth of grasses would be necessary (Hunt et al., 2012).

The rate and intensity of stormwater infiltration through a bioretention garden or rain garden can have significant effects on the pollution reduction potential, especially in the upper portions of the garden (Davis et al., 2003). In experimental lab studies, it was discovered that low flow rates (< 4.1cm/h) were better at removing metal pollutants than high flow rates (~8.1 cm/h) (Davis et al., 2003). In lab experiments conducted by Davis et al. (2003), the systems became overwhelmed at the high flow rates and could not infiltrate the stormwater quickly enough, causing the systems to overflow. If the bioretention garden is only designed to treat first flush pollutant removal, having the system reach capacity may not be of high concern, but if constant removal of pollutants throughout the duration of a storm is important, then a larger system may need to be designed (Davis et al., 2003). Therefore, there is a strong link between the amount of runoff captured by the bioretention garden and the pollutant reduction potential (Davis et al., 2009).

Lab studies of pollutant removal from runoff have shown that greater than 90% removal of Cu, Pb, and Zn is possible with LID (Davis et al, 2001a), with an average range of removal of Cu, Pb, and Zn of 43 – 99% from selected lab studies conducted on bioretention systems (Ahiablame et al., 2012). Lab studies conducted by Davis et al. (2001a, 2003) consisted of prototype boxes 61 – 91 cm deep with PVC pipes installed at 2 or 3 depths depending on the box size. Boxes were filled with sandy loam soil, topped with mulch and planted with creeping juniper plants. Synthetic stormwater runoff was created using dechlorinated tap water and predetermined concentrations of pollutants (Cu, Pb, and Zn). Water samples were collected from the runoff of the PVC tubes and analyzed for effluent concentrations of the pollutants. Another study conducted by Feng et al. (2012) utilized a total of 120 biofilter columns to test for the removal of Fe, Cu, Cr, Zn, Pb, and Al. The columns were constructed from PVC pipe with a diameter of 35.7 cm, a sandy loam filter media depth of 30 – 70 cm, a sand and gravel drainage layer depth of 21 cm, and a 40 cm transparent top section to allow for plant growth. Semisynthetic stormwater made from dechlorinated tap water and sediment collected from a stormwater pond was used to maintain consistency in experiments. In this study, Feng et al. (2012) found that biofilter columns matured over time to eventually reach a steady state of pollutant removal and indicated that metal removal occurred in the upper few centimeters of the filter.

Field studies of pollutant removal from runoff have shown that 95% removal of Cu, Pb, and Zn is possible (Davis et al., 2003, Davis et al., 2009), with an average range of removal of Cu, Pb, and Zn from 30 – 99% from selected field studied on bioretention systems (Ahiablame et al., 2012). Field experiments conducted by Davis et al., (2003) utilized the application of synthetic stormwater onto an existing bioretention cell and collected the runoff from underdrain pipes. Pollutant removals ranged from 43 – 97% Cu, Pb, and Zn. In both the lab and field studies mentioned, no distinct pattern was observed where certain metals showed a more preferential removal than others through the use of green infrastructure.

Watershed-scale studies of metals removal by LID have reported conflicting results. One paired watershed study compared a traditional residential development to a LID design and found that concentration of Pb and Zn in stormwater runoff was significantly lower in the LID design (Bedan and Clausen, 2009). Another paired watershed study with partial retrofit stormwater management conducted by Roy et al.

(2014) did not see any significant reductions in pollutants such as dissolved metals (Al, Fe, Mn, Cu, Zn) between their control and retrofit watersheds. However, in the latter study, water samples were taken from nearby streams, not storm sewers. The LID design used in the Bedan and Clausen (2009) study could be considered a best case scenario for LID stormwater management because the entire development was designed with LID control measures, many of which were directly connected to transportation surfaces. In contrast, the study conducted by Roy et al. (2014) only utilized front yard rain gardens and rain barrels in an existing neighborhood as a stormwater retrofit design. There is still a greater need for research at the street scale to determine the overall effectiveness of LID at removing trace metal pollutants from stormwater runoff. The retrofits added in the West Creek study can help add to existing research because they are using a more established neighborhood with LID retrofits on individual properties and LID directly connected to transportation surfaces.

Once water is filtered through the bioretention garden, the metals can accumulate in the gardens until later mobilization or removal (Davis et al., 2003). Metal accumulation in near-surface bioretention soils presents both a potential method for analyzing the efficacy of removal from stormwater (Davis et al., 2003) and a potential concern due to toxicity (Charlesworth et al., 2011). If maintenance is regularly conducted on the bioretention gardens, by removing the top few centimeters of material, the metal-removal ability may be extended indefinitely (Hunt et al., 2011). However, Hunt et al, (2011) suggest that if maintenance is neglected, the removal and proper disposal of metal-laden material may be necessary, along with testing for toxicity.

Lab testing of soils for accumulated metals can be both time consuming and expensive, so utilizing magnetics analysis of topsoil samples could allow for a proxy of metal accumulation in street side bioretention gardens as compared to the adjacent tree lawns (Zhang et al., 2012). All substances, particularly metals, exhibit some sort of magnetism, therefore environmental magnetism could be a simple and inexpensive way to experimentally detect and assess metals in materials such as soils and sediments (Evans and Heller, 2003).

Using the topsoil to measure magnetic susceptibility can help to determine the pollution effects on local areas. Particles emitted from pollution will give off a different magnetic signal than particles formed from normal soil forming processes (Evans and Heller, 2003). Increased population and road density in urban areas can lead to higher emissions from roadway pollution. Many industrial processes, such as production of steel and other industrial products also generate airborne magnetic minerals (Evans and Heller, 2003). The concentration of these processes in urbanized city centers can lead to higher levels of magnetic minerals being deposited onto the topsoil, roadways, parking areas, and rooftops (Wang et al., 2012). The amount of magnetic material deposited on trees, soils, and buildings varies inversely with distance from its source. Over time, equilibrium is achieved between new particles being deposited and old particles being washed away (Evans and Heller, 2003).

Many studies have been conducted on atmospheric contaminants and roadside pollution using topsoil samples for magnetic analysis (Evans and Heller, 2003). There have also been a variety of studies conducted that highly correlate magnetic concentration parameters with the concentration of heavy metals (Zhang et al., 2012). It can be inferred that magnetic particles and heavy metal concentrations with strong correlations can be coming from the same anthropogenic sources (Zhang et al., 2012). Another study comparing magnetic particles to heavy metal contamination showed strong links between the two resulting from combustion processes (Wang et al., 2012). Other studies have shown that magnetic susceptibility in urbanized industrial areas is significantly higher than the susceptibility of rural non-industrial areas. A study conducted in the Katowice Province of Poland showed that samples taken near a coal burning power plant had susceptibility values greater than 600 x $10^{-8}$ $m^3$ $kg^{-1}$ as compared to the top soils of the Slowinski National Park near that Baltic Sea that reported susceptibilities of approximately 20 x $10^{-8}$ $m^3$ $kg^{-1}$ (Evans and Heller, 2003). The samples from these studies demonstrate the range of susceptibility from various locations.

By combining water quality analysis and magnetics analysis, a better understanding of how street side bioretention gardens function for pollution removal could be achieved. Both heavy metal contamination and magnetic particles are the result of anthropogenic activities. Having a better understanding of how these pollutants accumulate and at what concentrations is important to long term functioning of green infrastructure practices. **The goal of this research is to assess the ability of street side bioretention gardens to remove heavy metals from stormwater runoff and to correlate magnetic properties of topsoil samples to pollution inputs.**

## 2.2 - Methods

### Metals Analysis

Stormwater samples were collected from Klusner and Hetzel during the summer 2014 sampling period. ISCO Autosamplers were installed at the end of each street to collect runoff during storm events at predetermined intervals. Intervals were based on the forecasted duration of the storm in order to maximize sample collection. Collection intervals ranged from 5 to 15 minutes. The ISCO sampler on Klusner collected samples from more events than the sampler on Hetzel, because the manhole opening on Hetzel did not allow for the ISCO sampler to be placed in the manhole. Storm samples on Hetzel could only be taken when someone was present to place the sampler outside of the manhole and monitor it throughout the duration of the storm. This was necessary because the manhole on Hetzel was in the center of the street. The sampler on Klusner fit properly in the manhole and could be triggered by the onset of flow in the storm drain and begin sampling manually, without anyone present.

For all stormwater collection, ISCO ProPak sample bags were used. These sample bags are designed for one time use and eliminated the need for bottle washing or acid washing. The ProPak bags are made of EPA-approved low-density polyethylene (LDPE). Using new bags for each sampling event helped to minimize sample contamination. Within 24 hours of each storm event, samples were collected from the ISCO samplers and placed on ice until filtration and acidification. Filtration and acidification was completed within 24 hours of sample collection from the field. Each sample was filtered through a 0.4 μm Millipore Isopore™ Membrane Filter. Samples were measured out to 10 mL each in clean, acid washed plastic vials and acidified with 15 μL trace metal grade nitric acid.

Inductively-coupled plasma optical emission spectroscopy (ICP/OES) was conducted at the Kent State University on a PerkinElmer Optima 8000 ICP-OES Spectrometer. Heavy metal analysis was conducted to determine dissolved concentrations of Cu, Fe, Mn, Ni, Pb and Zn in the stormwater runoff. Analysis with the ICP/OES was performed using standard lab procedures and equipment guidelines. US EPA Method 200.7 was followed for the determination of all trace metals in water (US EPA, 2001).

Calculations were conducted to determine mass load and event mean concentration (EMC). EMC is a flow-weighted average of constituent concentration and is useful because concentrations of pollutants can vary by orders of magnitude during a storm event (Lee and Bang, 2000). Calculations for total mass load were conducted using the following equation;

$$M = \sum_{i=1}^{n} ViCi$$

where M = total mass of pollutant, Vi = discharge amount corresponding to sample i, Ci = pollutant concentration in sample i, i = sample number, n = total number of samples collected (Gulliver, 2010). Calculations for EMC were conducted using the following equation;

$$EMC = \frac{\sum_{1=i}^{n} ViCi}{\sum_{1=i}^{n} Vi}$$

where EMC = event mean concentration, Vi = discharge amount corresponding to sample i, Ci = pollutant concentration in sample i, i = sample number, n = total number of samples collected (Gulliver, 2010).

## Magnetics Data

Soil samples were taken from six bioretention gardens and four of the adjacent tree lawns, at an equal distance from the road. This was done to account for general roadside pollutant deposition from cars, as captured by the soils of the tree lawns and assuming the magnetic pollution signal from cars decreased with distance from the road (Evans and Heller, 2003). In total 19 top soil samples were gathered. There were 10 samples collected in October 2013. Of these 10 samples, six topsoil samples were taken from within the bioretention gardens and four topsoil samples were taken from the lawn adjacent to the bioretention gardens. During the summer of 2014 four samples were collected from bioretention gardens when regular maintenance was performed and sediment was removed from the bioretention garden. In November 2014, five top soil samples were collected from the same bioretention gardens that were sampled in October 2013. One bioretention garden was not resampled in 2014 due to limited access to the bioretention garden. This collection method was used to help obtain a year-over-year analysis of the magnetic properties of the bioretention gardens and adjacent lawns. The tree lawns were not resampled in 2014 because it was assumed that soils only receiving atmospheric deposition will not experience a noticeable addition of magnetic particles in one year’s time (Evans and Heller, 2003). Samples were taken from soils that did not visually appear to have poor drainage conditions due to over saturation. Having well drained soils is important to ensure that excess water would not lead to the depletion of magnetic minerals during soil forming processes (Evans and Heller, 2003). Waterlogged soils can often lead to the leaching to naturally formed magnetic particles and produce a reduced magnetic signal (Evans and Heller, 2003).

Samples were air dried at room temperature prior to disaggregating using a wooden pestle and mortar and then sifted through a 1 mm sieve to remove larger aggregates. Then the samples were packed into 5.28 $cm^3$ plastic sampling boxes. Using the remaining portion of the topsoil samples, organic matter content was determined by loss-on-ignition (LOI).

$$LOI = \frac{\text{Dried Sediment Weight} - \text{Ignited Sediment Weight}}{\text{Dried Sediment Weight}} * 100$$

To determine organic content samples were dried at 100°C for a minimum of 48 hours. Then the samples were ignited in a 550°C oven for 2 hours (Heiri et al., 2001). Sample weights were taken before and after ignition. The LOI value is expressed as the percentage weight loss.

Magnetic analysis was conducted at the University of Akron Magnetics Lab. Magnetic susceptibility was measured at dual frequencies on a Barrington Instruments meter and MSB2 sensor. Magnetic susceptibility is a measure of how magnetizable a substance can become in the presence of a magnetic field and can be used in a general way to describe the various classes of magnetic materials (Appendix A). Anhysteretic remanent magnetization (ARM) alternating field (AF) demagnetization was done on an ASC D-2000 AF Demagnetizer/Magnetizer Machine. ARM is magnetization acquired by the combined effects of a large alternating field and a small DC field, therefore the larger the value, the more ferrimagnetic material present (Appendix A). Isothermal remanent magnetization (IRM) and direct current (DC) demagnetization was imparted on an ASC IM-10 Impulse Magnetizer. IRM is the magnetization acquired by a sample after exposure to (and subsequent removal from) a preset magnetizing field, all at fixed temperature (usually, but not necessarily, room temperature). IRM was imparted at room temperature for this analysis (Appendix A). IRM is a useful way to determine the magnetic mineralogy of a sample. A Molspin Spinner Magnetometer was used to measure the magnetic moments of ARM and IRM between each acquisition and demagnetization step. Measurements were converted from the meter reading on the magnetometer to account for the sample weight minus the weight of the plastic containers (3.099g) (Evans and Heller, 2003).

## 2.3 - Results

### Water Quality

Stormwater samples were collected from the end of the street on Klusner and Hetzel during the Phase 2 observation period (summer 2014). A total of five events were collected on Klusner and three events on Hetzel (Table 2-1). During each event, 3 - 19 samples were collected from each street. Direct comparisons of heavy metal concentrations in the stormwater could only be made on the events where samples were collected from both streets.

The two events where comparisons could be made between streets had dry antecedent moisture conditions (AMC). AMC for the two comparison events were similar, with zero precipitation in the preceding 12 hours, and only 0.51 mm of precipitation in the preceding 24 hours for event #34. The total runoff for the two comparison events ranged from ~150 – 2000 $m^3$ on Klusner and ~175 – 1500 $m^3$ on Hetzel. The range of total runoff helps to provide a comparison for the metal loads for various sized events.

The samples collected during the comparison events (#34 and #64) were collected during the initial runoff of the storm and essentially captured the first flush of stormwater from the event. Each of these events had an initial first flush followed by a period of low runoff and then a larger total and peak discharge. Figure 2-1 shows an example of how the hydrograph and timing of sample collection occurred for each event.

Table 2-1. Water quality sampling of storm events on Klusner and Hetzel during the sampling period, Phase 2.

| Event No. (#) | Street | Sample Date (M/D/Y) | Time of First Sample Collected (24 hr) | No. of Samples (#) | Peak Q ($m^3/s$) | Total Q ($m^3$) | Total Precip (mm) | Peak Precip (mm) | AMC 12 Hours (mm) | AMC 24 Hours (mm) | AMC 48 Hours (mm) | AMC 7 days (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Klusner | 7/7/2014 | 21:51 | 3 | 0.02 | 40.67 | 0.51 | 0.51 | 0.00 | 0.00 | 0.00 | 1.27 |
| 33 | Hetzel | - | - | 0 | - | - | - | - | - | - | - | - |
| 34 | Klusner | 7/8/2014 | 10:19 | 11 | 0.26 | 1965.29 | 30.99 | 8.13 | 0.00 | 0.51 | 0.51 | 1.52 |
| 34 | Hetzel | 7/8/2014 | 11:12 | 4 | 0.62 | 1443.64 | 30.99 | 8.13 | 0.00 | 0.51 | 0.51 | 1.52 |
| 51 | Klusner | 8/12/2014 | 21:30 | 2 | 0.01 | 32.48 | 3.05 | 2.03 | 1.78 | 8.13 | 14.99 | 14.99 |
| 51 | Hetzel | - | - | 0 | - | - | - | - | - | - | - | - |
| 63 | Klusner | 9/30/2014 | 7:35 | 19 | 0.01 | 151.33 | 13.46 | 8.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| 63 | Hetzel | 9/30/2014 | 7:37 | 11 | 0.11 | 275.30 | 13.46 | 8.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| 64 | Klusner | 10/3/2014 | 12:16 | 10 | 0.04 | 573.83 | 6.35 | 2.03 | 0.00 | 0.00 | 0.00 | 13.46 |
| 64 | Hetzel | 10/3/2014 | 12:12 | 8 | 0.06 | 175.76 | 6.35 | 2.03 | 0.00 | 0.00 | 0.00 | 13.46 |

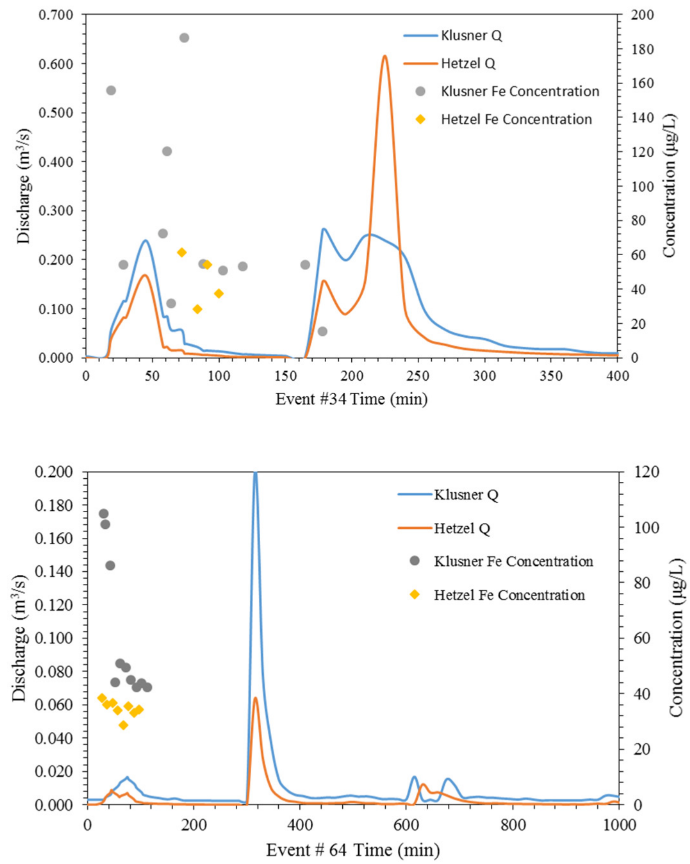



Figure 2-1. Hydrographs of events #34 and #64 on Klusner and Hetzel show the initial first flush of runoff when the sampling took place. Followed by a larger volume of storm runoff.

Total mass load and event mean concentration (EMC) were calculated for both Klusner and Hetzel (Table 2-2). The highest mass loads were from Fe, Zn, Mn, and Cu. Ni and Pb had the highest number of non-detects. Based on the small number of events sampled, the EMC of the metals collected generally increased with increased total discharge, except for Mn which decreased with increased runoff (Figure 2-2). However, for event #33 only three samples were collected on Klusner, but this event had the lowest total runoff and highest EMC out of all of the storms sampled.

Due to the limited number of storms sampled on both streets, and the lack of data collected prior to green infrastructure installation, it is difficult to quantify any pollutant retention by the green infrastructure on Klusner. Comparisons between total discharge and EMC show that the metal loads vary between streets, but that higher runoff is associated with higher EMCs in both cases (Figure 2-2). Klusner and Hetzel consistently have different storm volumes and peak flows, where flows on Klusner are often higher than Hetzel.

Table 2-2. Water quality results for sampling events on Klusner and Hetzel. Calculations for total load, event mean concentration (EMC). Total and EMC Load values with N/A were below detection limits.

| Event No. (#) | Street | Sample Date (M/D/Y) | Time of First Sample Collected (24 hr) | No. of Samples Collected (#) | Total Mass Load Fe (µg) | Total Mass Load Cu (µg) | Total Mass Load Mn (µg) | Total Mass Load Ni (µg) | Total Mass Load Pb (µg) | Total Mass Load Zn (µg) | EMC Fe (µg/L) | EMC Cu (µg/L) | EMC Mn (µg/L) | EMC Ni (µg/L) | EMC Pb (µg/L) | EMC Zn (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Klusner | 7/7/2014 | 21:51 | 3 | 1,865,229 | 613,447 | 351,876 | 28,571 | 39,620 | 600,112 | 111.95 | 36.82 | 21.12 | 1.71 | 2.38 | 36.02 |
| 33 | Hetzel | - | - | 0 | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 | Klusner | 7/8/2014 | 10:19 | 11 | 40,586,523 | 3,882,490 | 4,014,829 | 116,135 | 1,337,560 | 20,416,203 | 61.83 | 5.91 | 6.12 | 0.18 | 2.04 | 31.10 |
| 34 | Hetzel | 7/8/2014 | 11:12 | 4 | 1,488,356 | 208,069 | 65,067 | 4,622 | 111,482 | 375,340 | 49.80 | 6.96 | 2.18 | 0.15 | 3.73 | 12.56 |
| 51 | Klusner | 8/12/2014 | 21:30 | 2 | 86,757 | 66 | 2,906 | N/A | N/A | 81,023 | 16.62 | 0.01 | 0.56 | N/A | N/A | 15.52 |
| 51 | Hetzel | - | - | 0 | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 | Klusner | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 | Hetzel | 9/30/2014 | 7:37 | 11 | 12,017,009 | N/A | 2,141,800 | N/A | N/A | 5,446,783 | 24.97 | N/A | 4.45 | N/A | N/A | 11.32 |
| 64 | Klusner | 10/3/2014 | 12:16 | 10 | 4,243,921 | 256,561 | 1,130,598 | N/A | N/A | 941,850 | 53.30 | 3.22 | 14.20 | N/A | N/A | 11.83 |
| 64 | Hetzel | 10/3/2014 | 12:12 | 8 | 1,132,592 | 154,147 | 145,930 | N/A | N/A | 269,682 | 34.38 | 4.68 | 4.43 | N/A | N/A | 8.19 |

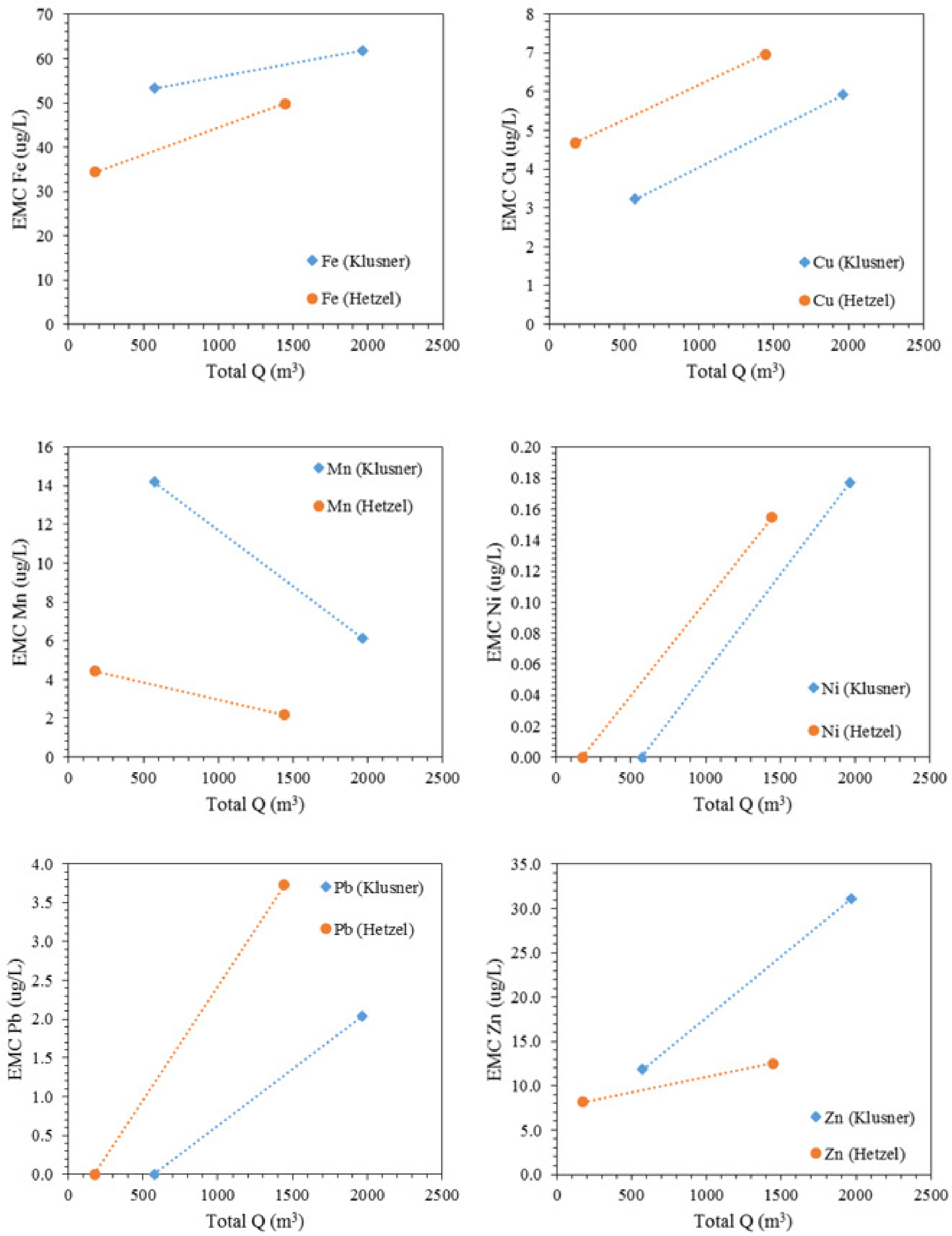



Figure 2-2. Relationships between EMC and total event runoff for trace metals Fe, Cu, Mn, Ni, Pb, and Zn on Klusner and Hetzel for events #34 and #64.

## Magnetics

The magnetic properties for all 19 tree lawn and bioretention samples are summarized in Table 2-3. This table also includes the calculations needed to determine all of the concentration, grain size and mineralogy results for each of the samples. All of the concentration-related parameters, such as $\chi$ (susceptibility), $\chi$ARM, and SIRM (Figure 2-3) show relatively similar results for both the tree lawn samples and the bioretention samples. The $\chi$ values for all of the samples were under 100 x $10^{-8}$ $m^3$ $kg^{-1}$, which indicates the presence of ferrimagnetic material but not at very high levels (Evans and Heller, 2003). The average $\chi$ for the tree lawn samples was 62.6 while the average of the bioretention samples was 78.5, which can indicate the presence of slightly more magnetic minerals in the bioretention gardens (Evans and Heller, 2003). The $\chi$ARM and SIRM preferentially respond to stable single domain (SSD) particles, which are small particle sizes that acquire more remanence than particles containing domain walls and allow for lower magnetostatic energy configurations to be achieved (Appendix A). The values for $\chi$ARM and SIRM are generally low for both the tree lawn samples and the bioretention samples that indicate low concentrations of SSD particles (Evans and Heller, 2003).

Grain size parameters show the variation of magnetic grain sizes and can help to identify the source of the magnetic particles (Figure 2-4). The $\chi$fd% (frequency dependence), which is sensitive to the super paramagnetic (SPM) particle component, is generally low throughout all of the samples, with an average value of 1.3% in the tree lawn and bioretention. This indicates the presence of SSD and multi domain (MD) particles in nearly all of the samples (Evans and Heller, 2003). The $\chi$ARM/SIRM plots

Table 2-3. Magnetic parameters for bioretention cells and adjacent tree lawns on Klusner Ave, Parma, Ohio.

| Sample ID | Date Collected | | Sed + Box wt. (g) | Sediment wt. (kg) | Organic Content (%) | $\chi$lf ($10^{-8}m^3kg^{-1}$) | $\chi$hf ($10^{-8}m^3kg^{-1}$) | $\chi$FD (%) | ARM Meter ($10^{-8}$ Am) | $\chi$ARM ($10^{-6}m^3kg^{-1}$) | IRM Meter ($10^{-8}$ Am) | SIRM ($10^{-6}Am^2kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L1A | Oct-13 | Round 1 | 9.72 | 0.0066 | 10.3 | 43.2 | 42.9 | 0.7 | 45.7 | 0.9 | 1761.8 | 4850.7 |
| L2A | Oct-13 | Round 1 | 9.04 | 0.0059 | 10.7 | 63.2 | 62.3 | 1.4 | 55.6 | 1.2 | 1270.8 | 9626.7 |
| L3A | Oct-13 | Round 1 | 9.09 | 0.0060 | 9.4 | 88.2 | 86.9 | 1.5 | 86.4 | 1.8 | 2260.9 | 11751.0 |
| L4A | Oct-13 | Round 1 | 9.54 | 0.0064 | 10.1 | 55.7 | 54.7 | 1.8 | 75.6 | 1.5 | 2108.6 | 9532.3 |
| B1A | Oct-13 | Round 1 | 11.05 | 0.0080 | 10.2 | 81.2 | 80.3 | 1.1 | 110.7 | 1.7 | 3816.2 | 10026.3 |
| B1B | Nov-14 | Round 2 | 10.40 | 0.0073 | 11.8 | 74.9 | 74.1 | 1.1 | 119.8 | 2.1 | 2202.9 | 10300.0 |
| B2A | Oct-13 | Round 1 | 11.82 | 0.0087 | 12.0 | 70.0 | 69.2 | 1.1 | 105.4 | 1.5 | 3595.7 | 8594.1 |
| B2B | Nov-14 | Round 2 | 10.16 | 0.0071 | 11.3 | 72.1 | 71.1 | 1.4 | 117.7 | 2.1 | 1940.3 | 9966.3 |
| B3A | Oct-13 | Round 1 | 12.58 | 0.0095 | 11.7 | 67.8 | 67.0 | 1.2 | 121.1 | 1.6 | 3826.3 | 8209.7 |
| B3B | Nov-14 | Round 2 | 11.66 | 0.0086 | 12.4 | 47.5 | 47.0 | 1.1 | 48.0 | 0.7 | 1009.1 | 4389.4 |
| B4A | Oct-13 | Round 1 | 11.21 | 0.0081 | 11.8 | 87.6 | 86.7 | 1.0 | 154.5 | 2.4 | 4646.1 | 12251.3 |
| B4B | Nov-14 | Round 2 | 7.71 | 0.0046 | 7.9 | 77.9 | 76.9 | 1.3 | 80.4 | 2.2 | 1316.8 | 10879.1 |
| B5A | Oct-13 | Round 1 | 8.88 | 0.0058 | 9.6 | 85.0 | 83.2 | 2.1 | 77.5 | 1.7 | 2756.1 | 12001.7 |
| B5B1 | Jul-14 | Maintenance | 11.66 | 0.0086 | 11.0 | 68.5 | 68.0 | 0.7 | 89.8 | 1.3 | 2224.5 | 9801.5 |
| B5B2 | Jul-14 | Maintenance | 10.69 | 0.0076 | 7.5 | 86.5 | 85.5 | 1.2 | 127.5 | 2.1 | 2374.5 | 12800.9 |
| B5B3 | Jul-14 | Maintenance | 8.19 | 0.0051 | 6.7 | 89.3 | 88.3 | 1.1 | 82.9 | 2.0 | 1321.2 | 13232.1 |
| B5B3-1 | Jul-14 | Maintenance | 11.49 | 0.0084 | 11.6 | 93.8 | 90.3 | 3.7 | 119.7 | 1.8 | 3079.8 | 10973.9 |
| B5C3 | Nov-14 | Round 2 | 10.66 | 0.0076 | 10.9 | 91.7 | 90.6 | 1.2 | 121.6 | 2.0 | 2453.4 | 12933.2 |
| B6A | Oct-13 | Round 1 | 7.37 | 0.0043 | 5.8 | 83.4 | 82.8 | 0.7 | 54.5 | 1.6 | 2098.3 | 11489.8 |

Table 2-3 (Continued). Magnetic parameters for bioretention cells and adjacent tree lawns on Klusner Ave, Parma, Ohio.

| Sample ID | χARM/SIRM ($10^3$) | χARM/χ ($10^{-2}$) | SIRM/χ ($10^{-2}$) | S-Ratio (%) | IRM$_{-300mT}$ Meter ($10^{-8}$ Am) | IRM$_{-300mT}$ ($10^{-6}Am^2kg^{-1}$) | HIRM ($10^{-6}Am^2kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| L1A | 0.179 | 2.006 | 0.011 | 0.91 | -2929 | -4421.8 | 214.4 |
| L2A | 0.122 | 1.862 | 0.015 | 0.95 | -5425.6 | -9138.6 | 244.1 |
| L3A | 0.154 | 2.054 | 0.013 | 1.00 | -7049.7 | -11765.2 | -7.1 |
| L4A | 0.155 | 2.649 | 0.017 | 0.99 | -6085.3 | -9455.1 | 38.6 |
| B1A | 0.174 | 2.153 | 0.012 | 1.00 | -7988.4 | -10042.0 | -7.9 |
| B1B | 0.200 | 2.752 | 0.014 | 0.91 | -681.74 | -9338.9 | 480.5 |
| B2A | 0.177 | 2.170 | 0.012 | 0.97 | -7292.8 | -8364.3 | 114.9 |
| B2B | 0.210 | 2.906 | 0.014 | 0.95 | -667.26 | -9455.3 | 255.5 |
| B3A | 0.195 | 2.367 | 0.012 | 1.03 | -8016.9 | -8460.2 | -125.3 |
| B3B | 0.160 | 1.483 | 0.009 | 0.94 | -353.78 | -4132.9 | 128.2 |
| B4A | 0.195 | 2.731 | 0.014 | 0.96 | -9532.4 | -11749.5 | 250.9 |
| B4B | 0.201 | 2.813 | 0.014 | 0.96 | -479.12 | -10395.3 | 241.9 |
| B5A | 0.140 | 1.980 | 0.014 | 0.95 | -6618.4 | -11440.6 | 280.6 |
| B5B1 | 0.134 | 1.923 | 0.014 | 0.97 | -812.92 | -9492.3 | 154.6 |
| B5B2 | 0.165 | 2.438 | 0.015 | 0.93 | -906.19 | -11933.0 | 434.0 |
| B5B3 | 0.155 | 2.292 | 0.015 | 0.93 | -632.9 | -12259.8 | 486.1 |
| B5B3-1 | 0.163 | 1.912 | 0.012 | 0.95 | -876.42 | -10449.7 | 262.1 |
| B5C3 | 0.156 | 2.202 | 0.014 | 0.95 | -927.91 | -12267.5 | 332.9 |
| B6A | 0.140 | 1.922 | 0.014 | 0.97 | -4736.7 | -11100.8 | 194.5 |

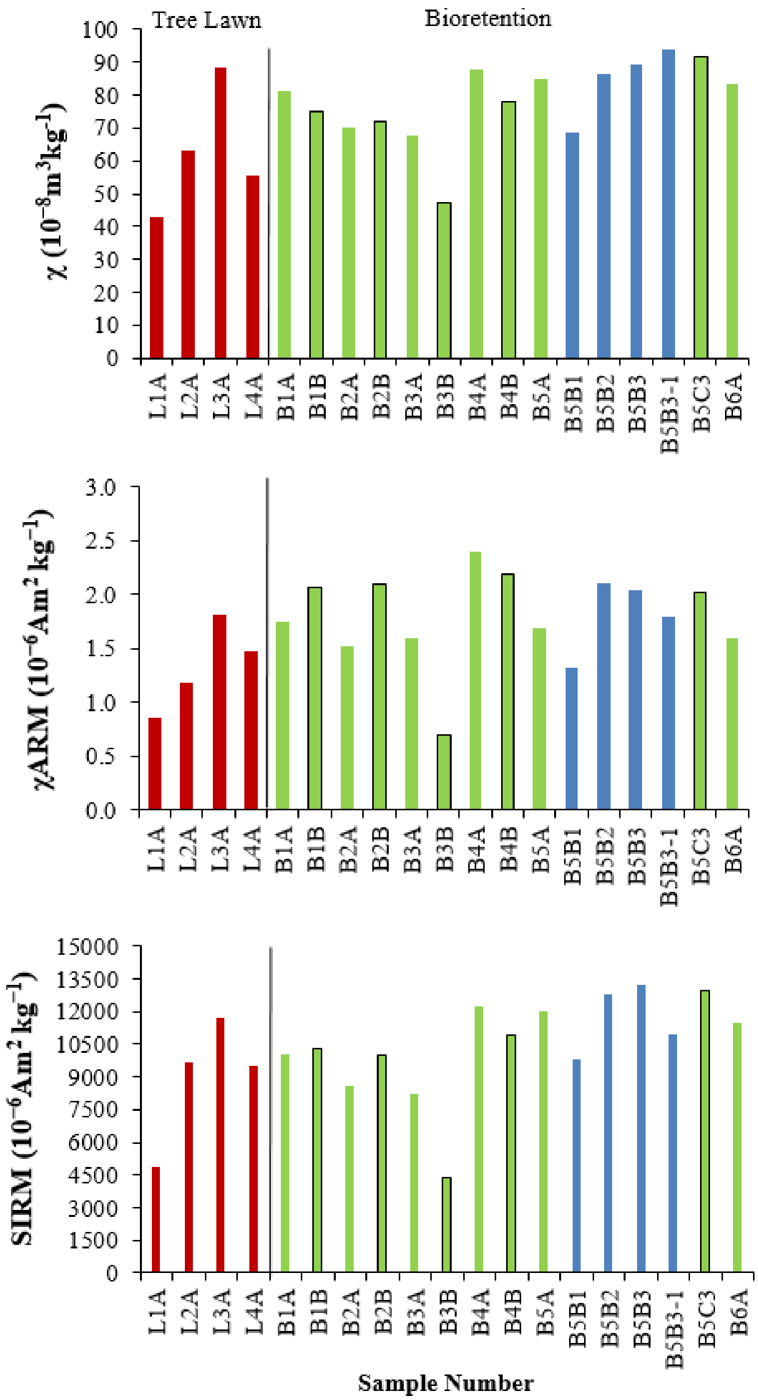



Figure 2-3. Magnetic concentration parameters for all tree lawn and bioretention samples. Red bars indicate samples taken from tree lawns next to the bioretention cells. Green and blue bars indicate samples that were taken from within the bioretention cells. Green cells with black borders were taken in the second round of sampling and blue bars indicate samples that were taken during bioretention maintenance.

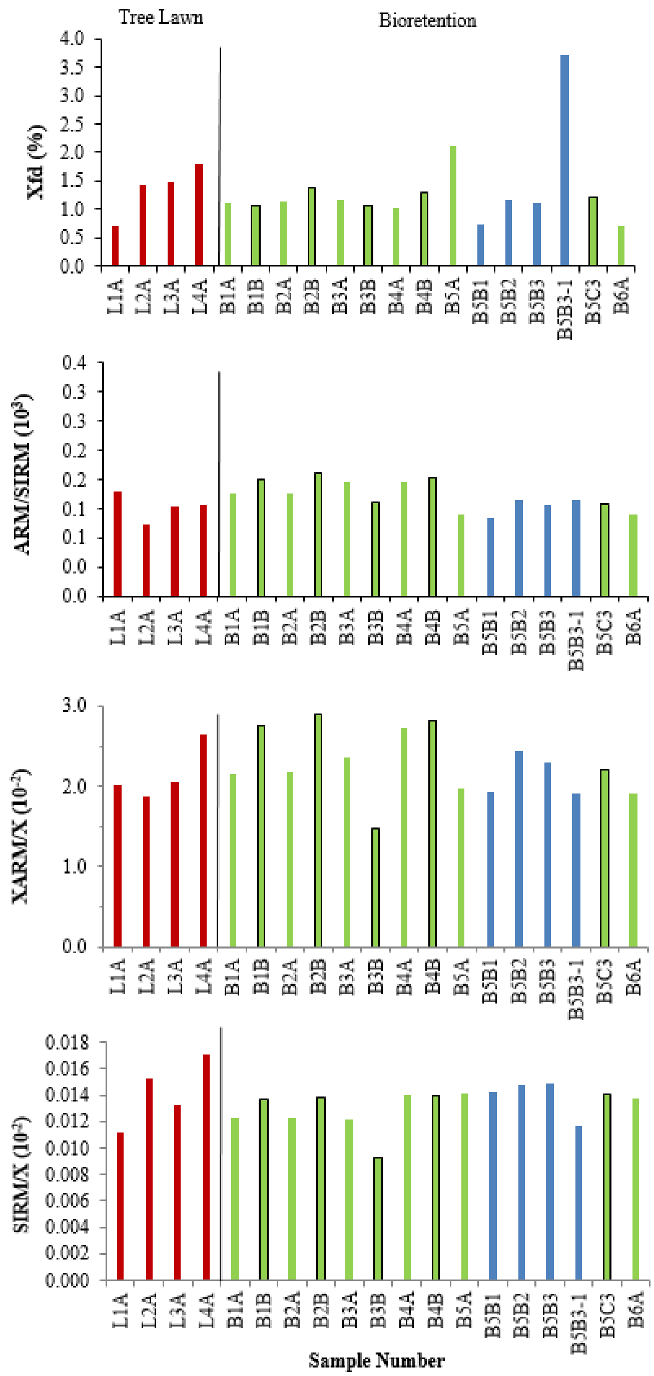



Figure 2-4. Grain size parameters for all tree lawn and bioretention samples. Red bars indicate samples taken from tree lawns next to the bioretention cells. Green and blue bars indicate samples that were taken from within the bioretention cells. Green cells with black borders were taken in the second round of sampling and blue bars indicate samples that were taken during bioretention maintenance.

show that small particles yield higher values because they are more efficient at acquiring remanence, particularly ARM. The low values for $\chi$ARM/SIRM would indicate the presence of more coarse grained particles, again SSD and MD (Evans and Heller, 2003). Larger ratios of $\chi$ARM/$\chi$ indicate finer modal grain sizes, and the data show that the values for $\chi$ARM/$\chi$ are generally low, indicating the presence of more coarse grained particles (Evans and Heller, 2003). However, a limitation of this ratio is if SPM particles are present, then $\chi$ will be increased and no $\chi$ARM will be present (Appendix A). Larger ratios of SIRM/$\chi$ ratio indicate finer grain sizes. If a high SIRM and low $\chi$ were present, then there would be more SSD particles which are related to natural soil forming magnetic signals rather than pollution signals (Evans and Heller, 2003). Also, higher values for SIRM and $\chi$ indicate the presence of more ferrimagnetic particles. However the samples for the tree lawns and bioretention gardens had generally low values for SIRM and slightly elevated $\chi$ values leading to a low SIRM/$\chi$ ratio. The smaller the values present in the SIRM/$\chi$ ratio indicates the presence of more multi-domain particles, which can be related to pollution (Evans and Heller, 2003).

Another technique for visualizing the presence of various particle domains and sources is the $\chi$fd% vs. $\chi$lf plot (Figure 2-5) (Evans and Heller, 2003). This plot shows that particles with a $\chi$fd% lower than two percent and a $\chi$lf value between ~100-1000 ($10^{-8}$ $m^3$ $kg^{-1}$) contain fossil fuel combustion particles, which is representative of all of the samples collected. None of the samples collected from the tree lawn or bioretention gardens plot closer to the area of enhanced soil forming processes and finer SP grains.

The S-Ratio is used as a mineralogy parameter (Figure 2-6). In general if the S-ratio is 1.0 then the sample will be all magnetite (Evans and Heller, 2003). As the S-ratio

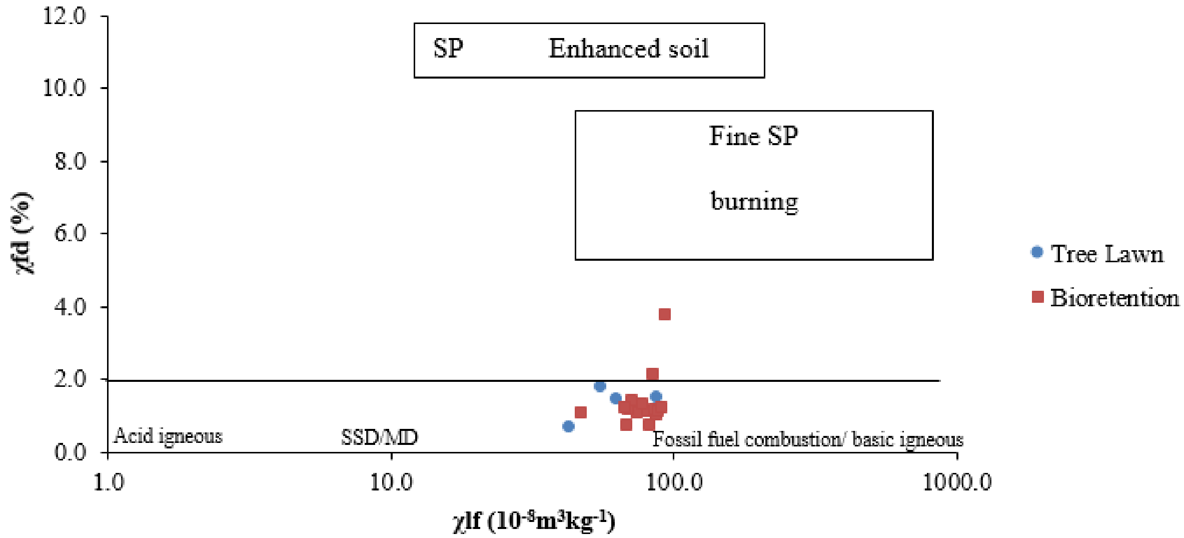



Figure 2-5. χfd/ χlf scatter graph showing where samples are dominated by various domains and sources for tree lawn and bioretention samples.

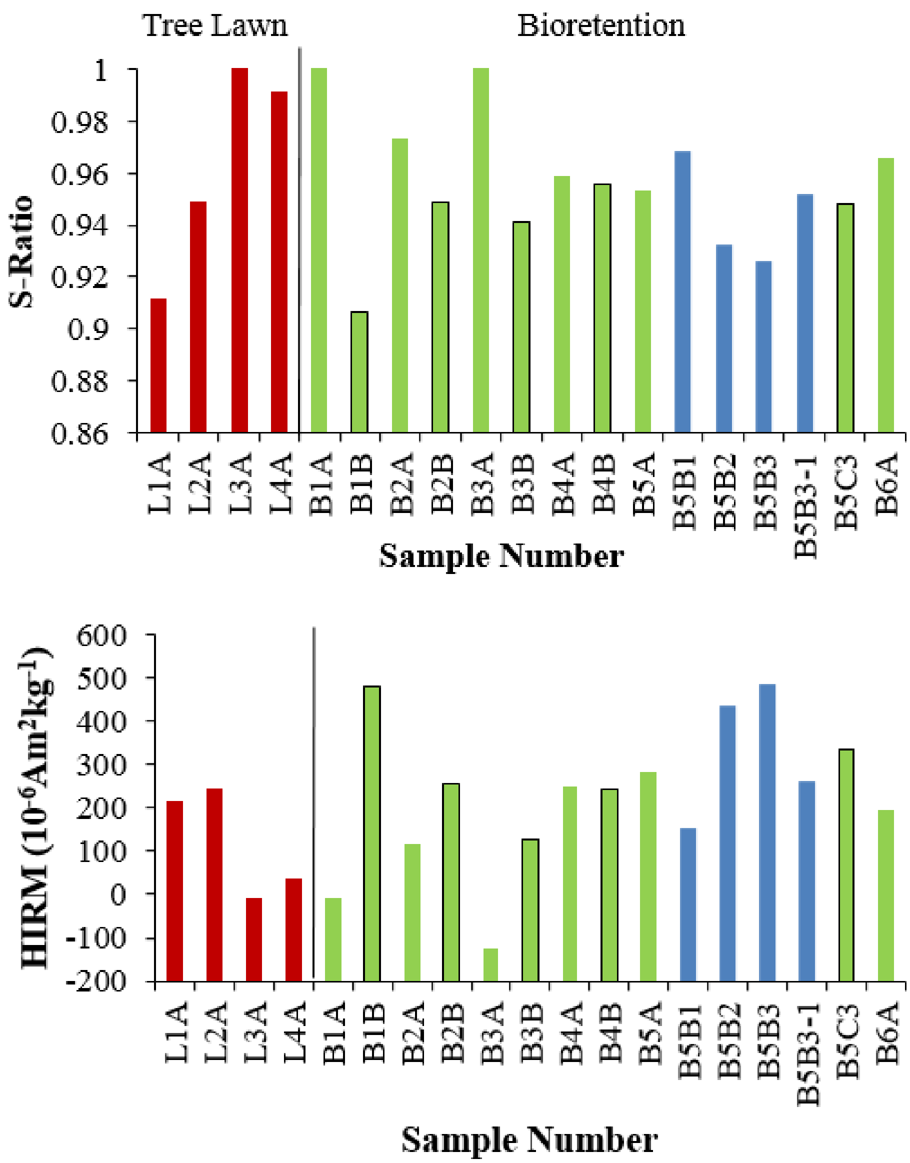



Figure 2-6. Mineralogy parameters for all tree lawn and bioretention samples. Red bars indicate samples taken from tree lawns next to the bioretention cells. Green and blue bars indicate samples that were taken from within the bioretention cells. Green cells with black borders were taken in the second round of sampling and blue bars indicate samples that were taken during bioretention maintenance.

decreases, the level of hematite in the samples will increase (Appendix A).The graph shows that samples L3A, L4A, and B3A are at or close to 1.0 indicating the presence of magnetite. All of the other samples are below 1.0 which indicates the presence of both magnetite and hematite. HIRM is another method used to measure mineralogy (Figure 2-6). The values for HIRM are not consistent throughout any of the tree lawn or bioretention samples. Positive values of HIRM indicate the presence of hematite and magnetite while values near zero indicate the presence of all magnetite (Evans and Heller, 2003). However, HIRM can be problematic when the remanence carried by hematite/goethite is completely masked by a strongly magnetic background signal because the HIRM can have similar magnitude to the measurement errors, which can account for the higher HIRM levels in many of the bioretention samples (Appendix A). The Maher and Thompson graph is a biplot if magnetic stability versus squareness (Figure 2-7) (Evans and Heller, 2003). This is used to show a relationship of the different magnetic minerals, grain sizes and morphologies. In general all of the samples plotted to the left side of the graph, this indicates the presence of both hard (high coercivity) and soft (low coercivity) minerals. Most of the samples have plotted in the goethite and gregite zone of the graph indicating intermediate stability minerals (Maher and Thompson, 1999).

Organic content was determined by loss on ignition (Table 2-2, Figure 2-8). Having a greater amount of organic content present in the sample can offset the magnetic susceptibility. Organic material is considered to be diamagnetic, meaning it does not have a magnetic charge (Evans and Heller, 2003). If samples measured have a high amount of organic content in them, then the magnetic measurements may be lower than expected

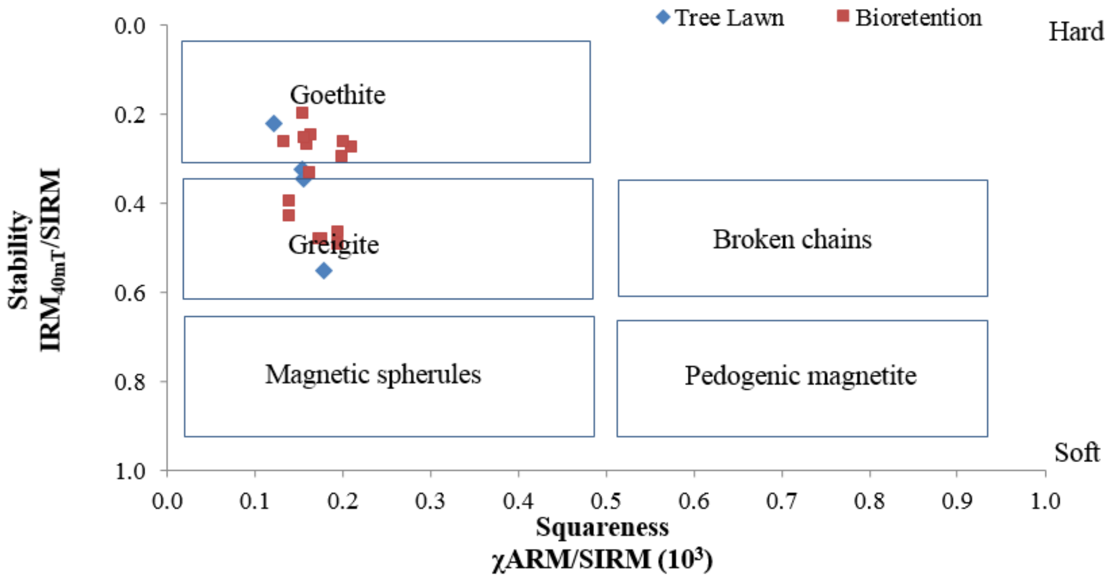



Figure 2-7. The distribution of all tree lawn and bioretention samples showing the different magnetic minerals, grain sizes and morphologies on a biplot of magnetic stability versus squareness.

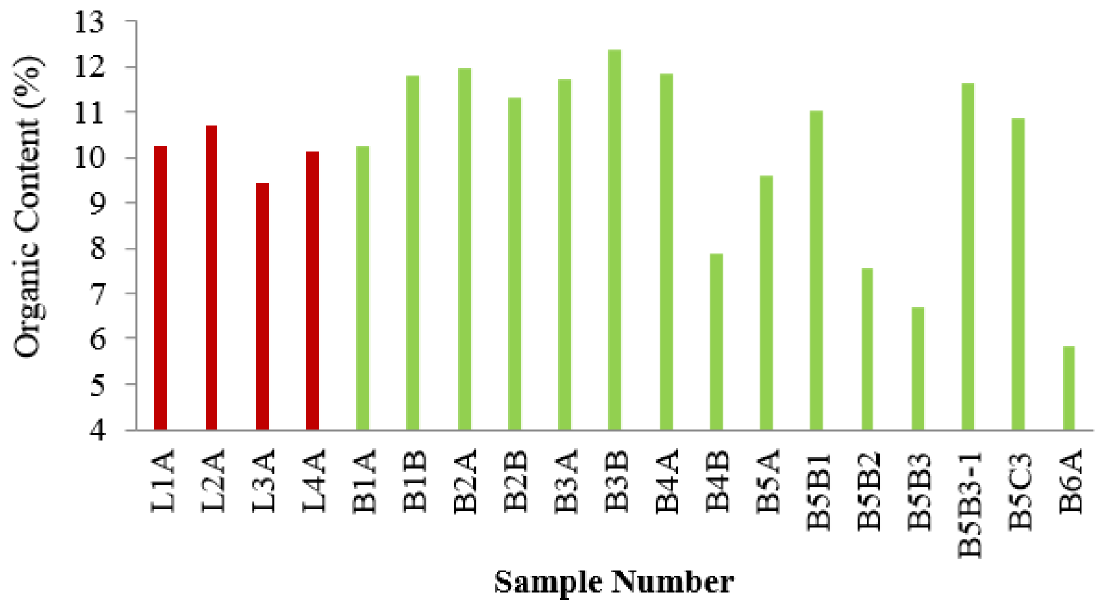



Figure 2-8. Organic content for all topsoil samples, tree lawn samples are denoted in red, bioretention samples are denoted in green.

because the diamagnetic organic content was off-setting the reading. In general all of the samples had relatively high amounts of organic material. However, the organic content was consistent, within an order of magnitude, throughout all of the samples so the offset created by the diamagnetic organic particles can be considered uniform throughout as well (Evans and Heller, 2003). The dilution of magnetic signal due to the presence of organic material is difficult to quantify, however comparing samples with in a study to one another can help show the offset due to organic matter. If more of the organics had been removed prior to taking the magnetic measurement, then the magnetic concentration may have been higher.

## 2.4 - Discussion

### Water Quality

The stormwater samples taken on Klusner and Hetzel show that the trace metal concentrations are in line with concentrations typical to urban runoff (Davis et al., 2001b, Hunt et al., 2012, Wong et al., 2006, and Feng et al., 2012). Many of the samples collected were on the low end of typical ranges. This can be attributed to the site being a low-traffic residential setting, as opposed to a more traffic dense urban thoroughfare. Fossil fuel combustion can account for Fe and Mn in stormwater runoff, which originates from street dust and resuspension of soils (Charlesworth et al., 2011). Concentrations of Mn have been on the rise in urban environments because it has replaced Pb in gasoline as an anti-knock agent (Wong et al., 2006). Levels of Pb on Klusner and Hetzel were very low or non-detectable, which can be related to the removal of lead from gasoline and paint starting in the 1970's. The concentrations of Fe and Mn found in the stormwater samples collected on Klusner and Hetzel were relatively low. Samples collected only on Klusner, from event #33, had the highest Fe and Mn concentrations (112 µg/L, 21 µg/L). Concentrations of Cu can be related to brake wear particles. Brake wear particles can account for up to 47% of the annual load of Cu (Davis et al., 2001b). The two storms compared on Klusner and Hetzel have Cu concentrations below 10 µg/L. Ni was also non-detectable in most of the samples collected and not of great concern in the stormwater runoff for these streets.

The concentrations for event #33 were much higher than any of the other sampled storm events. This storm also had the lowest total runoff of any of the sampled storms. Generally the first flush is attributed to having higher concentrations of pollutants than the subsequent runoff (Deletic, 1998). However, Deletic (1998) found that there is generally enough pollution in a given area for the concentrations to be seen throughout an entire event. The high concentration in event #33 may either be related to the first flush phenomenon, or the short storm duration and small number of samples taken. AMC for event #33 on Klusner was similar to the comparison events on Klusner and Hetzel (#34 and #64). Therefore with AMC being relatively the same, any effects from pollutant build-up or wash-off should be relatively similar for all events (#33, #34, and #64).

The lab study conducted by Davis et al. (2003) showed that concentrations of Cu, Pb, and Zn could be reduced from 47, 91, 580 μg/L to ~ <4, <2, and <25 μg/L respectively, when stormwater was filtered through bioretention cells. When comparing the concentrations of trace metals after going through the bioretention cells in the lab experiment, the final values are comparable to the values seen on both Klusner and Hetzel at the collection point at the end of the street. This shows that whether or not the bioretention gardens are able to remove trace metals on the street, the levels currently present are very low to begin with. If the bioretention gardens are as efficient at removing metals from stormwater runoff as they were in the lab and field studies, the metal concentrations on Klusner could be below detectable limits and even further below any levels of concern for trace metal pollution.

This study illustrates the importance of needing before-after-control-impact (BACI) monitoring. Much like the flow monitoring on Klusner and Hetzel, where pre-treatment flow data was collected, the water quality sampling could have benefited from the same design of experiment. Even though the streets are similar, the BACI flow monitoring showed that Klusner generally has higher amounts of runoff than Hetzel. By not having pre-treatment water quality samples to compare to, it is not possible to determine a street scale reduction in pollutant concentrations.

## Magnetics

Magnetic particles in top soils and heavy metal contaminants in water samples cannot be directly related in this study because the samples being compared were not taken from the same sources. However, there is a positive correlation between magnetic mineral concentration and that of heavy metals (Zhang et al., 2012). Magnetic particles can act as pollutant carriers through structural incorporation of heavy metals, therefore it is possible to quantify the degree of pollution to magnetic parameters at a small scale, such as with in a region or single location (Liu et al., 2012). Identifying specific sources of magnetic particles is also possible at a small scale, especially if anthropogenic inputs are known. Magnetic particles found on Klusner not related to soil forming processes could be attributed from road side pollution such as fossil fuel burning, vehicle exhaust, brake wear particles, and atmospheric deposition (Wang et al., 2012).

Using magnetics as a pollution proxy is effective when several parameters are taken into account. These parameters are highlighted in Evans and Heller (2003). The first parameter to look at is to see if particles are magnetically enhanced. Particles from pollution will have a greater magnetic enhancement than the natural background material. Second, would be to look at individual particles in a sample. If the particles are coarse grained spheres as opposed to angular opaque grains the sample will be considered to have been affected by pollution. Third, by establishing a direct link between magnetic properties and contamination, conclusions can be made to support the hypotheses of having greater amounts of pollution in certain areas. However, it is also important to take into account any other parameters that may have affected the outcome of the results that are magnetically enhanced and not formed by pollution.

The results for susceptibility showed slightly higher levels in the bioretention gardens versus the tree lawns. When comparing this study to others, the average susceptibility of 75.1 in this study shows that the magnetic concentrations are elevated above the signal from a rural area, but not nearly as high as that of a heavily industrialized area where coal burning is taking place (Evans and Heller, 2003). The $\chi$ARM and SIRM were relatively low from the samples collected from both the tree lawn and bioretention gardens which is also related to other studies that link high SIRM values to more polluted areas (Zhang et al., 2011).

More information on magnetic grain size can be obtained using frequency dependence. The $\chi$fd% of the tree lawn and bioretention samples is on average 1.3%, indicating larger grain sizes produced from combustion processes. Normal soil forming processes will have a $\chi$fd% of approximately 10% and will form more SPM particles (Evans and Heller, 2003). Lower levels on the SIRM/$\chi$ graph can indicate either coarse grains or fine SPM grains. Correlating this graph with the $\chi$fd%, I can infer that there is not a presence of SPM grains in any of the samples due to soil forming processes. The low numbers in the $\chi$ARM/SIRM graph also indicate coarse particles present in all of the samples. This too leads to the inference that the magnetic signal is not from soil forming processes and that the samples are dominated by a pollution signal.

The $\chi$fd% versus $\chi$lf graph helps to show how particles are dominated by various domains and sources. The $\chi$fd% helps to differentiate particles with high susceptibility from those formed in natural processes and those formed from combustion and fossil fuels. It is clear from the graph that all of the samples plot in the area denoted to be fossil fuel combustion particles. These fossil fuel combustion products are generally composed of iron oxide particulates that can pose a health risk, especially the smaller particles (Evan and Heller, 2003). The presence of magnetite and hematite, as indicated by the S-Ratio in Figure 2-6 and correlated to coarse grain sizes in the ARM/SIRM and $\chi$ARM/$\chi$ ratios indicates inputs from anthropogenic activities and not soil forming magnetite or hematite (Wang et al., 2012).

Equilibrium will often be reached in the environment with new particles being deposited and older ones being washed away (Evans and Heller, 2003). Since the homes in this neighborhood were built almost 60 years ago, there has been a long time for accumulation of anthropogenic magnetic particles and for equilibrium concentrations to be established. However, equilibrium may not be reached for the bioretention gardens, which have only been in place <2 years.

The fact that bioretention gardens have a similar magnetic concentration as the tree lawns could indicate that there is an increased buildup of magnetic particles in the short amount of time (<2 years) the bioretention gardens have been in place. Such buildup could be due to the concentration of particles delivered by runoff entering the gardens. However, this interpretation should be taken with caution because the exact source of the soils and gravel in the gardens is unknown and some magnetic particles may have been present prior to installation. However, the samples taken from garden B5 show increasing concentrations of magnetic susceptibility over time, including maintenance cleanouts. This increase in susceptibility helps to illustrate that previous magnetic concentrations in the bioretention soils and gravels should not be a factor in this study. This study shows that the tree lawns and the bioretention gardens have similar magnetic concentrations and the presence of coarse grained particles. Where the tree lawns have had over 60 years to accumulate the concentration of magnetism present, the bioretention gardens have accumulated almost the same concentration, if not greater in a shorter amount of time.

In this study, no direct comparisons can be made between the stormwater samples analyzed for trace metals and the magnetic concentrations of the top soil samples. However, other studies have found positive correlations between magnetic susceptibility and the concentration of Cu, Fe, Pb, Zn, and Ni (Zhang et al., 2012). The study conducted by Zhang et al. (2012) found that Fe strongly correlated with $\chi$ and SIRM and Ni and Cu were more weakly correlated. Zhang et al., (2012) also determined that Fe, Pb and Zn, and Ni and Cu were most likely related to different anthropogenic inputs, with Fe originating from coal burning and Pb, Zn, and Cu originating from heavy traffic. Wang et al. (2012) also found strong correlations between heavy metals produced by anthropogenic activities and magnetic concentrations.

## 2.5 – Conclusion

This study found that concentrations for trace metals on Klusner and Hetzel are within the range of typical urban stormwater runoff concentrations. The direct pollution reduction benefits could not be evaluated due to the lack of pre-treatment stormwater data. However, the results in this study do allow for a basis of stormwater quality for long term observations. Magnetics analysis indicated that there were coarse grained magnetic particles present in the top soils of both the tree lawns and bioretention gardens. Coarse grained particles can be related to particles formed from anthropogenic activities such as fossil fuel burning from vehicle exhaust. While magnetic concentrations of bioretention and tree lawn soils on Klusner were lower than heavily polluted urban centers, the buildup of magnetic concentrations in the bioretention cells was similar to those of the tree lawns, even though the tree lawns have been established for a long period of time. It can be inferred that by capturing street runoff, the bioretention cells have been able to acquire the same magnetic concentration as the tree lawns in just a fraction of the time. While direct correlation could not be made between heavy metal concentration and magnetic parameters, it is possible to relate the generally low concentrations of heavy metals in the water to the generally low magnetic susceptibility values from the tree lawns and bioretention gardens.

## 3.1 - Introduction

### Homeowner Survey

Population driven urban expansion increases impervious land cover, which creates excess stormwater runoff and water quality degradation. To combat this problem, green infrastructure such as, green roofs, porous pavements, rain gardens, and rain barrels are increasingly used as an alternative to conventional gray infrastructure in urban centers across the United States and around the world (Davis et al., 2009). The primary benefit of green infrastructure is to reduce stormwater runoff and increase water quality, however, potential co-benefits include increased urban green space, neighborhood involvement leading to increased quality of life, and aesthetics (Baptiste et al., 2015). In order to successfully implement a widespread green infrastructure plan, municipalities or sewer districts need to collaborate across multiple stakeholder groups, including private property landowners in residential neighborhoods, as part of their plan for achieving stormwater reduction goals (Keeley et al., 2013). It is still unclear, however, if residents are willing to install and manage green infrastructure on their property. The lack of understanding and knowledge of what green infrastructure really is and how it can benefit a homeowner are often cited barriers (Baptiste et al., 2015). Research suggests that it is difficult to convey the importance of managing diffuse stormwater problems to the public and their role in participating in stormwater management (Keeley et al., 2013). While education and outreach may increase the adoption of green infrastructure, social scientists have suggested that an individual's underlying environmental values, attitudes, and perceptions play a role in mediating behavior (Blaine et al., 2012, Keeley et al, 2013). This study investigates the relationships between these variables among homeowners with and without green infrastructure installed on their property.

By first understanding the factors that influence homeowners to participate in a green infrastructure project, municipalities and other driving organizations can begin to develop a plan to alleviate problems associated with stormwater and urban development. (Keeley, 2007). Bringing all of the key parties together to successfully implement a green infrastructure project on the scale necessary for watershed benefit can be very difficult (Keeley et al., 2013). Municipalities may begin their efforts by educating homeowners about their role in stormwater management (Baptiste et al., 2015). Educating homeowners about the benefits of green infrastructure as a solution to the complex problem of stormwater management may seem straightforward. If the gap between the possession of environmental knowledge and actually displaying pro-environmental behavior, known as the 'knowledge-to-action gap', is too large, then the level of participation from all involved will be lacking and the green infrastructure project may never realize its full beneficial outcomes (Kollmuss and Agyeman, 2002). This study addresses the drivers of homeowner participation in a green infrastructure project through a case study of the West Creek project. Specifically, the research questions are:

- **How do homeowner's environmental values, attitudes, perceptions, and behaviors correlate to participating in a green infrastructure project?**
- **What are the barriers to participation in GI projects?**

To examine these questions, all homeowners on both treatments streets, Klusner and Parkhaven, were surveyed to assess how their attitudes, perceptions, behaviors and environmental values lead them to participate in the green infrastructure project on their street. This insight should help future projects, of similar scope, realize the benefits of understanding these drivers for increased participation.

## Literature Review

The likelihood of a homeowner to participate in a green infrastructure project may be related to their environmental knowledge; however, individual environmental values, perceptions, and attitudes also play a strong role in influencing behavior. Kollmuss and Aqyeman (2002) state that the possession of environmental knowledge without displaying pro-environmental behavior is called the knowledge-to-action gap. Pro-environmental behavior is behavior that consciously seeks to minimize the negative impact of one's actions on the natural and built world (e.g. minimize resource and energy consumption, use of non-toxic substances, reduce waste production) (Kollmuss and Agyeman, 2002). Currently there is a gap between the level of environmental knowledge people possess and their actual actions surrounding pro-environmental behavior.

Emerging findings suggest that individuals that possess high levels of environmental awareness and concern do not necessarily display corresponding pro-environmental behavior. A study conducted in central Ohio found that homeowners with greater knowledge about the negative effects of applying chemical fertilizers to their yard were more likely to actually apply fertilizers (Robbins et al., 2001). This finding is contrary to the belief that low environmental education and awareness of the negative effects of chemical fertilizers would lead to more fertilizer application. Another study found that environmental action from environmentally aware individuals may not happen until the environmental actions become socially accepted, convenient, and inexpensive, such as household recycling (Barr, 2004). A study conducted in New York found that there is no correlation between demographic variables and environmental knowledge (Baptiste et al., 2015). Therefore environmental knowledge and social acceptance can be considered drivers for making pro-environmental decisions, regardless of a person's demographics. Finger (1994) suggests that pushing individuals for more information, more knowledge, and more awareness will not make people more socially active in environmental management because individual environmental behavior is linked to past environmental experience. He suggests that if pro-environmental behavior is not something someone exhibits early on in life then it may be difficult to inspire him or her to act on environmental initiatives later in life.

Many people living in urban areas are disconnected from nature because their livelihoods or lifestyle are not directly tied to local environmental systems. Kollmuss and Agyeman (2002) suggest that direct experiences have a stronger impact on people's behavior and normative influences such as social norms, cultural traditions, and family customs, which influence and shape people's attitudes. When living in an urban environment people are lacking a direct connection with nature, as are all of the people around them. This disconnect and a "keeping up with the Joneses" desire to fit in can affect larger environmental issues, such as water quality in an entire watershed. One study in Ohio found that homeowners did not believe that the addition of lawn chemicals was having a negative impact on water quality, however homeowners did agree that applying lawn chemicals helped to increase the value of their homes (Blaine et al., 2012). This highlights the fact that having a well-maintained lawn could help people fit in with their neighbors regardless of the impact to the environment. Residents in a community will also tend to help each other out, which can include landscaping activities. Robbins et al. (2001) found that neighbors can often show a "volunteerist" sense of lawn care, where one neighbors will help to take care or another's yard. One neighbor may try to "help" another neighbor by applying fertilizer or watering their yard, regardless of the other person's attitudes, behaviors, and values. In order to find a high correlation between attitude and behavior researchers have to measure the attitude toward that particular behavior (Kollmuss and Agyeman, 2002). By using this approach planners can determine if people's attitudes toward sustainable development and green infrastructure are in line with their behavior. Also, urban dwellers may have little interaction with nature and a strong desire to fit in with their neighbors, leading to barriers for becoming more environmentally active and bridging the knowledge-to-action gap.

Having a better understanding about what drives people to participate in a green infrastructure project can help promote its widespread success. Participation needs to be a two-way process in which a municipality helps in oversight of selecting appropriate green infrastructure projects and one in which the individual community members become involved (Shuster et al., 2008). Participatory approaches to environmental management engage social and cultural capital and substitute part of the technological and infrastructure-heavy capital that we currently have practiced with centralized stormwater quantity management (Keeley et al., 2013). An additional benefit of widespread public engagement is a shift in perception that embraces stormwater as a resource, rather than a potentially hazardous waste product to be diverted to streams or wastewater treatment plants (Shuster et. al, 2008, Walsh et al, 2012). Beginning with a bottom-up approach of community participation can help bring about a certain level of ownership to a project that creates a greater sense of involvement for community members. However, utilizing a bottom-up approach can be difficult to get up and running because there are so many participants that need to be organized. This could ultimately turn into a situation where projects are started but never completed (Fraser et al., 2006).

The implementation phase of green infrastructure generally focuses on the stormwater runoff reduction potential and water quality improvements to a watershed, leaving out any consideration for public preferences (Kaplowitz and Lupi, 2012). More recently there has been a greater understanding for the need of public involvement in the early stages of a green infrastructure project, however the process for doing so is not as clearly understood (Baptiste et al., 2015). Involving the community, including property owners, early in the design process can help to eliminate resistance to change and gain stronger participation from people who truly want to become involved (Kaplowitz and Lupi, 2012). Roy et al. (2008) outline the ways in which resistance to change can be a strong barrier to implementation of a green infrastructure system across scales due to actual risk and risk adverse perceptions. At the community or property owner level, resistance often involves concerns regarding poorly maintained green infrastructure having a ‘‘messy’’ appearance that is not appreciated by the community, therefore it can be difficult to counteract common perceptions that it is unattractive or ineffective. Roy et al. (2008) also highlight that the public understanding of the role of green infrastructure systems is often limited or inaccurate. Beyond any perceived risk or resistance, the public may simply not believe that stormwater is a problem or that stormwater management and any associated problems should be handled by the government and existing stormwater infrastructure (Baptiste et al., 2015).

One way that researchers have involved the public in the planning and design process is through the administration of surveys. Conducting surveys prior to implementation can be a way to understand incentives and barriers that will lead property owners to participate, which can help lead to more successful participation (Baptiste et al., 2015). Baptiste et al. (2015) found that socio-economic status could influence the willingness to implement green infrastructure if a savings is accrued, where survey respondents from a working-class ethnically diverse neighborhood were more likely to want to implement green infrastructure on their property if a savings was accrued than survey respondents from a more affluent, less diverse neighborhood. Another study found that young, well-educated, and politically liberal adults and people from urban areas tend to be more pro-environmental than older, less educated, and conservative adults (Dunlap et al., 2000). Both of those studies could help to ensure the correct groups are being selected. Surveys can also be conducted at the end of a study in order to gauge the success of a project and gain insight for necessary changes for future projects. One study showed that administering a survey before and after a class about rain barrel implementation was useful to assess the level of environmental awareness and knowledge homeowners gained from their class (Bakacs et al., 2013). This sort of process can help to not only gain more insight for developers and planners, but to also help design educational materials necessary for homeowners to successfully participate in green infrastructure implementation.

## Study Background

A double paired watershed study, with before-after-control-impact design was implemented by the Cleveland Metroparks as a demonstration project to evaluate the effectiveness of street-scale green infrastructure retrofits. Two treatment streets were selected for the green infrastructure implementation, with the adjacent streets used as the controls (Figure 1-2 and 1-3). Site selection was conducted by soliciting homeowners and installing green infrastructure treatments on their property at no cost to them. The green infrastructure treatments used in this study included rain gardens, bioretention gardens, and rain barrels. Rain gardens and bioretention gardens are depressed areas in the landscape that are designed to catch stormwater runoff, which helps to reduce runoff, increase ground water recharge and aid in pollution treatment (Dietz, 2007). A total of 91 rain gardens, bioretention gardens, and rain barrels have been installed on the two treatment streets. All of the homeowners on each of the treatment streets were contacted to participate and have green infrastructure installed on their property at no cost to them, but only 12% of homeowners on Klusner and 30% of homeowners on Parkhaven signed up to participate.

The main goal of this project was to assess the potential for mitigation of stormwater runoff. Flow meters were installed at the end of each treatment and control street to monitor stormwater runoff. Runoff was analyzed for reductions in peak stormflow, reductions in total stormflow, and increased lag time. Analysis was also conducted to determine the pollution reduction potential of trace metals by the green infrastructure implementations. It was concluded that on both treatment streets, peak stormwater flow and total stormwater flow were reduced with the addition of green infrastructure. Green infrastructure needs to be implemented at a large scale, such as in the case of the West Creek project, to ultimately realize effects at the street scale. Homeowner participation at this scale is necessary for realizing large scale benefits. Utilizing a survey of all homeowners on the treatment streets will help to gain insight into what lead homeowners to participate or not in this project. If greater participation rates can be achieved, then even greater reductions in stormwater runoff may be attained.

## 3.2 - Methods

### Survey Design

A survey was sent out to all 201 residences on Klusner and Parkhaven in November 2014. One week prior to the survey being sent out and one week prior to the deadline for the survey response, postcards were sent to all residences to alert them of the survey's arrival and deadline. The survey was sent via U.S mail and included a self-addressed, stamped envelope to return the completed survey to Kent State University. The survey was developed to gain a better understanding of homeowner's underlying environmental values, along with attitudes, perceptions, and behaviors toward green infrastructure, stormwater management, and lawn care/maintenance. Responses between homeowners that did participate in the green infrastructure project and those that did not were compared to determine the level of agreement between values, attitudes, perceptions, and behaviors. Comparisons were also made between selected demographic variables to determine the level of agreement between values, attitudes, perceptions, and behaviors.

The survey used closed-ended questions and was separated into two main sections. The first section asked six questions pertaining to general demographics of the homeowner, with an additional question pertaining to the green infrastructure installed on the street to determine if the homeowner had a street side bioretention garden, rain garden, or rain barrels installed on their property. The remaining 35 statements focused on attitudes, perceptions, behaviors, and environmental values. Questions aimed at environmental values used 11 of the 15 New Ecological/Environmental Paradigm (NEP) scale items. The NEP is a measure of endorsement of environmental world view and focuses on the interactions of humans and nature, their right to rule over and change nature, and the limits to growth for human societies (Dunlap et al., 2000). Dunlap and Van Liere (1978) first developed the NEP scale, in response to the prominence of environmental issues facing the nation at that time. The 11 responses selected for this survey focused environmental values that could directly impact homeowners, leaving out four questions that focus more on a world view of environmental values.

The 35 statements pertaining to attitudes, perceptions, behaviors, and the NEP used a 5-point Likert scale (1 = strongly agree, 3 = neutral, 5 = strongly disagree) to assess their level of agreement or disagreement (Table 3-1). Nine statements focused on the attitudes of homeowners that included their general enjoyment of where they live, the maintenance of the green infrastructure, the added value of the green infrastructure, the responsibility of stormwater management, and costs associated newly implemented green infrastructure. Seven statements focused on the perceptions of homeowners toward the maintenance of their street, the effectiveness of the green infrastructure at reducing stormwater runoff, the ability of a homeowner to affect stormwater, and the costs associated with the green infrastructure. Included in the perceptions of homeowners was a question relating to the amount they were willing to pay for green infrastructure on their property with six dollar amount choices ranging from \$0 - \$2000+ (Coded 1 – 6; 1 = \$0, 6 = \$2000+). Seven statements focused on the behaviors of homeowners, which included lawn care and maintenance, use of outdoor space, and the effort involved in maintaining

Table 3-1. Survey responses pertaining to the NEP, attitudes, perceptions, and behaviors of homeowners on Klusner and Parkhaven. All responses used a 5-point likert scale (1 = strongly agree, 3 = neutral, 5 = strongly disagree).

| Question # | Indicator | Response Statement |
|---|---|---|
| 1 | NEP | Humans have the right to modify the natural environment to suit their needs. |
| 2 | NEP | When humans interfere with nature it often produces disastrous consequences. |
| 3 | NEP | Human ingenuity will insure that we do not make the Earth unlivable. |
| 4 | NEP | Humans are seriously abusing the environment. |
| 5 | NEP | The Earth has plenty of natural resources if we just learn how to develop them. |
| 6 | NEP | Plants and animals have as much right as humans to exist. |
| 7 | NEP | Despite our special abilities, humans are still subject to the laws of nature. |
| 8 | NEP | The so-called "ecological crisis" facing humankind has been greatly exaggerated. |
| 9 | NEP | The balance of nature is very delicate and easily upset. |
| 10 | NEP | Humans will eventually learn enough about how nature works to be able to control it. |
| 11 | NEP | If things continue on their present course, we will soon experience a major ecological catastrophe. |
| 12 | Attitudes | Overall, I enjoy where I live |
| 13 | Attitudes | Given the opportunity, I would add green infrastructure to my property |
| 14 | Attitudes | The green infrastructure on my street does not provide enough value to my neighborhood to justify the upkeep |
| 15 | Attitudes | The green infrastructure gardens constructed on my street require too much maintenance. |
| 16 | Attitudes | Stormwater management is the responsibility of the city. |
| 17 | Attitudes | I would be willing to pay for the installation of green infrastructure on my property to help with stormwater management. |
| 18 | Attitudes | I would be willing to pay for a portion of the installation Green Infrastructure on my property. |
| 19 | Attitudes | If it cost less to implement, I would be willing to pay for Green Infrastructure on my property. |
| 20 | Attitudes | The addition of green infrastructure on the street has added value to my home. |
| 21 | Attitudes | The amount I would be willing to pay for green infrastructure on my property is $____________ |
| 22 | Perceptions | Green infrastructure on the street has created problems for the neighborhood. |
| 23 | Perceptions | There is room for improvement of the general maintenance on my street. |
| 24 | Perceptions | The addition of green infrastructure on my street has helped to reduce stormwater runoff. |
| 25 | Perceptions | As an individual homeowner there is little I can do to solve stormwater runoff problems. |
| 26 | Perceptions | Stormwater runoff on my street leads to flooding problems for residents. |
| 27 | Perceptions | Stormwater runoff on my street creates a problem for the environment. |
| 28 | Perceptions | Stormwater management is the responsibility of the individual. |
| 29 | Perceptions | The cost of green infrastructure is too expensive. |
| 30 | Behaviors | I mow my own lawn. |
| 31 | Behaviors | I pay someone to mow my lawn. |
| 32 | Behaviors | Beyond mowing my lawn, I engage in other landscaping activities such as gardening, planting flowers, mulching, etc. |
| 33 | Behaviors | I would have landscaping on my property, if it did not require any additional work from me. |
| 34 | Behaviors | I apply fertilizers to my yard. |
| 35 | Behaviors | I water my yard. |
| 36 | Behaviors | It is important to have my own space where I can enjoy the outdoors on my property. |

landscaping on their property. The 35 statements were randomly ordered in the final survey. Finally, the survey provided the opportunity for open-ended comments regarding the survey and the green infrastructure implemented on the street. Comments were coded as being either positive (1), neutral (2), or negative (3).

### Survey Analysis

Descriptive and statistical analysis of survey results was undertaken. Survey respondent demographics were compared to 2010 Census Tract data to determine how representative the sample was to the overall population. Statistical analysis was used to determine different relationships between the respondents and their determination to participation in the green infrastructure project as well as comparisons of demographics with attitudes, perceptions, behaviors, and environmental values. Survey responses were statistically analyzed using JMP version 11 software.

Non-parametric Wilcoxon each pair comparisons were used to test significance between responses and participation in the green infrastructure project and selected demographic variables. Responses were grouped by attitudes, perceptions, behaviors, and environmental values. Non-parametric testing was determined to be the most appropriate analysis for testing ordinal responses from the Likert scale because ordinal responses only describe the rank or order of responses, not the exact distance between two ordinal values, which may hold different meaning for different respondents (Corder and Foreman, 2009). A value of $p < 0.05$ was selected as the threshold for significance, and significant results are indicated with an asterisks (*).

Survey responses were analyzed by demographics (street, age, gender, education, and years in home) and those with green infrastructure versus those without green infrastructure. Demographic variables for age and years in home were split up to show variances in the respondent population and ensure that each category had at least 20% of the total responses so that no single respondent could be identified by being singled out in a category. For the results and discussion section of this chapter, results indicating the percentage of total respondents include the totals for all respondents, not individual groups, unless otherwise noted. Survey responses with mean values less than 3.00 indicate agreement with the question/response and mean values greater than 3.00 indicate disagreement with the question/response.

## 3.3 – Results

### Homeowner Survey

The survey response rate for both sets of streets was 18%, yielding 36 returned surveys. Table 3-2 provides demographic information on the respondents and the census tracts containing Klusner and Parkhaven. Based on the measures used, survey respondents provided representative data concerning the greater population. The largest groups of respondents were 60 and older (44%), female (64%), white (97%), and have some post-secondary education (42%). The largest group of respondents own their homes (94%) and have lived in their homes for 31+ years (36%) or moved in in the past 15 years (36%). The median household income for the census tract including Klusner is $49,985 and Parkhaven is $56,525.

Of the respondents, 11 have had some sort of green infrastructure installed in their property through this project. Of those 11, ten have street side bioretention gardens, seven have front or back yard rain gardens, and ten have at least one rain barrel attached to their downspout(s). The response rate of homeowners with green infrastructure compared to homeowners without green infrastructure is comparable to the actual participation rates of green infrastructure implementation on the treatment streets. The respondents with green infrastructure on their property also covered the range of demographics for all respondents.

Table 3-2. Descriptive statistics for the demographic variables of age, gender, ethnicity, education level, length of time in home, and ownership status for the respondents on Klusner and Parkhaven. Descriptive statistics for 2010 census data for census tract areas including Klusner and Parkhaven. (Klusner Census Tract 1775.04, n = 4045; Parkhaven Census Tract 1775.03, n = 3617)

| | Survey Respondents Demographics | | Survey Respondents Demographics | | Neighborhood Census Tract Demographics | | Survey Respondents Demographics | | Neighborhood Census Tract Demographics | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Total | | Klusner | | Klusner | | Parkhaven | | Parkhaven | |
| | (%) | (n) | (%) | (n) | (%) | (n) | (%) | (n) | (%) | (n) |
| **Age** | | | | | | | | | | |
| Under 30 | 2.8% | 1 | 4.2% | 1 | 4.8% | 195 | 0% | 0 | 4.5% | 164 |
| 30 - 39 | 11.1% | 4 | 4.2% | 1 | 12.1% | 490 | 25% | 3 | 8.4% | 305 |
| 40 - 49 | 13.9% | 5 | 8.3% | 2 | 19.4% | 784 | 25% | 3 | 18.9% | 682 |
| 50 - 59 | 27.8% | 10 | 33.3% | 8 | 21.1% | 853 | 16.7% | 2 | 22.5% | 814 |
| 60 and older | 44.4% | 16 | 50.0% | 12 | 21.6% | 875 | 33.3% | 4 | 23.1% | 835 |
| **Gender** | | | | | | | | | | |
| Male | 36.1% | | 29.2% | 7 | 47.5% | 1922 | 50% | 6 | 48.1% | 1739 |
| Female | 63.9% | | 70.8% | 17 | 52.5% | 2123 | 50% | 6 | 51.9% | 1878 |
| **Ethnicity** | | | | | | | | | | |
| White | 97% | 35 | 96% | 23 | 97.3% | 3934 | 100% | 12 | 92.3% | 3339 |
| Hispanic or Latino | 3% | 1 | 4% | 1 | 1.9% | 77 | 0% | 0 | 2.7% | 96 |
| Black or African American | 0% | 0 | 0% | 0 | 0.4% | 18 | 0% | 0 | 2.8% | 103 |
| Native American or American Indian | 0% | 0 | 0% | 0 | 0.1% | 4 | 0% | 0 | 0.0% | 0 |
| Asian/Pacific Islander | 0% | 0 | 0% | 0 | 1.0% | 42 | 0% | 0 | 2.3% | 83 |
| Other | 0% | 0 | 0% | 0 | 0.2% | 10 | 0% | 0 | 1.1% | 41 |
| **Level of Education** | | | | | | | | | | |
| High School or less | 25.0% | 9 | 33.3% | 8 | - | - | 8.3% | 1 | - | - |
| Some postsecondary | 41.7% | 15 | 45.8% | 11 | - | - | 33.3% | 4 | - | - |
| Bachelors | 19.4% | 7 | 12.5% | 3 | - | - | 33.3% | 4 | - | - |
| Beyond Bachelors | 13.9% | 5 | 8.3% | 2 | - | - | 25% | 3 | - | - |
| **Year in Home** | | | | | | | | | | |
| 0 -10 | 19.4% | 7 | 12.5% | 3 | - | - | 33.3% | 4 | - | - |
| 11 - 15 | 16.7% | 6 | 16.7% | 4 | - | - | 16.7% | 2 | - | - |
| 16 - 20 | 11.1% | 4 | 12.5% | 3 | - | - | 8.3% | 1 | - | - |
| 21 - 25 | 8.3% | 3 | 8.3% | 2 | - | - | 8.3% | 1 | - | - |
| 26 - 30 | 8.3% | 3 | 8.3% | 2 | - | - | 8.3% | 1 | - | - |
| 31 + | 36.1% | 13 | 41.7% | 10 | - | - | 25% | 3 | - | - |
| **Home Ownership** | | | | | | | | | | |
| Rent | 5.6% | 2 | 8.3% | 2 | 10.2% | 173 | 0% | 0 | 13.8% | 202 |
| Own | 94.4% | 34 | 91.7% | 22 | 89.8% | 1517 | 100% | 12 | 86.2% | 1260 |
| **GI on Property** | | | | | | | | | | |
| Yes | 30.6% | 11 | 20.8% | 5 | - | - | 50.0% | 6 | - | - |
| No | 69.4% | 25 | 79.2% | 19 | - | - | 50.0% | 6 | - | - |

*Behaviors*

Comparisons were made between respondents who have green infrastructure on their property and those who do not (Table 3-3). Comparing behaviors between respondents with green infrastructure and those without did not yield any statistically significant differences. The majority of homeowners, regardless of green infrastructure, report similar behaviors for yard care (Figure 3-1). Most homeowners mow their own lawn (86%) and apply fertilizer to their lawns (75%). Homeowners also tend to engage in landscaping activities other than just mowing (89%) and only half of the respondents water their lawn. Less than half (31%) of respondents indicated they would have landscaping on their property if it did not require any additional work from them. This indicates that those respondents enjoy the benefits of landscaping, but they do not want the added work associated with actually performing landscaping activities. Almost all (94%) of respondents agree that it is important to have their own space where they can enjoy the outdoors on their property.

Demographic variables including street, age, gender, education, and years in home influenced behaviors in several questions regarding behaviors among groups. Respondents that are over the age of 60 (mean = 2.31) or female (mean = 2.13) were less likely to mow their own lawn whereas respondents under 40, 40 – 49, and 50 – 59 (mean = 1.2, 1.2, and 1.4; p-value = 0.0369*, 0.0369*, and 0.0168*) or male (mean = 1.08; p-value = 0.0012*) were more likely to mow their own lawn. Respondents who have lived in their homes more than 31 years were more likely to pay someone to mow their lawn (mean = 3.62, p-value = 0.0296*) than respondents who have lived in their homes less

Table 3-3. Nonparametric comparisons for behaviors, perceptions, and attitudes for responses between respondents with and with out green infrastructure on their properties. Mean values below 3 indicate agreement with the response, means above 3 indicate disagreement with the response. The Wilcoxon Method was used for statistical comparisons, values with (*) indicate significant differenced ($p < 0.05$) between pairings.

| Question/Response | GI on Property | | |
|---|---|---|---|
| | Yes | No | |
| **Behaviors** | Mean | | p-Value |
| B-1. I mow my own lawn. | 1.55 | 1.84 | 0.489 |
| B-2. I pay someone to mow my lawn. | 4.55 | 3.92 | 0.158 |
| B-3. Beyond mowing my lawn, I engage in other landscaping activities. | 1.73 | 2.04 | 0.384 |
| B-4. I would have landscaping on my property, if it did not require any additional work from me. | 3.10 | 3.43 | 0.474 |
| B-5. I apply fertilizer to my yard. | 2.73 | 2.44 | 0.389 |
| B-6. I water my yard. | 3.45 | 2.88 | 0.221 |
| B-7. It is important to have my own space where I can enjoy the outdoors on my property. | 1.82 | 1.75 | 0.379 |
| **Perceptions** | | | |
| P-1. There is room for improvement of the general maintenance on my street. | 1.73 | 2.52 | 0.0295* |
| P-2. The addition of green infrastructure on my street has helped reduce stormwater runoff. | 2.09 | 3.28 | 0.0001* |
| P-3. As an individual there is little I can do to solve stormwater runoff problems. | 4.00 | 3.17 | 0.0108* |
| P-4. Stormwater runoff on my street leads to flooding problems for residents. | 2.00 | 3.13 | 0.0054* |
| P-5. Stormwater runoff on my street creates problems for the environment. | 2.73 | 3.08 | 0.214 |
| P-6. The cost of green infrastructure is too expensive. | 3.18 | 2.83 | 0.377 |
| P-7. Green infrastructure on the street has created problems for the neighborhood. | 3.91 | 2.80 | 0.0011* |
| **Attitudes** | | | |
| A-1. Overall, I enjoy where I live. | 1.73 | 1.92 | 0.508 |
| A-2. The green infrastructure gardens constructed on my street require too much maintenance. | 3.73 | 2.52 | 0.0005* |
| A-3. The addition of green infrastructure on the street has added value to my home. | 2.82 | 3.71 | 0.0365* |
| A-4. I would be willing to pay for the installation of green infrastructure on my property to help with stormwater management. | 3.00 | 4.20 | 0.0065* |
| A-5. I would be willing to pay for a portion of the installation of green infrastructure on my property. | 3.09 | 4.16 | 0.0264* |
| A-6. Stormwater management is the responsibility of the city. | 2.36 | 2.08 | 0.459 |
| A-7. Stormwater management is the responsibility of the individual. | 3.18 | 3.25 | 0.839 |
| A-8. Given the opportunity, I would add green infrastructure to my property. | 2.22 | 3.76 | 0.0034* |
| A-9. The green infrastructure on my street does not provide enough value to my neighborhood to justify the upkeep. | 3.55 | 2.32 | 0.0042* |

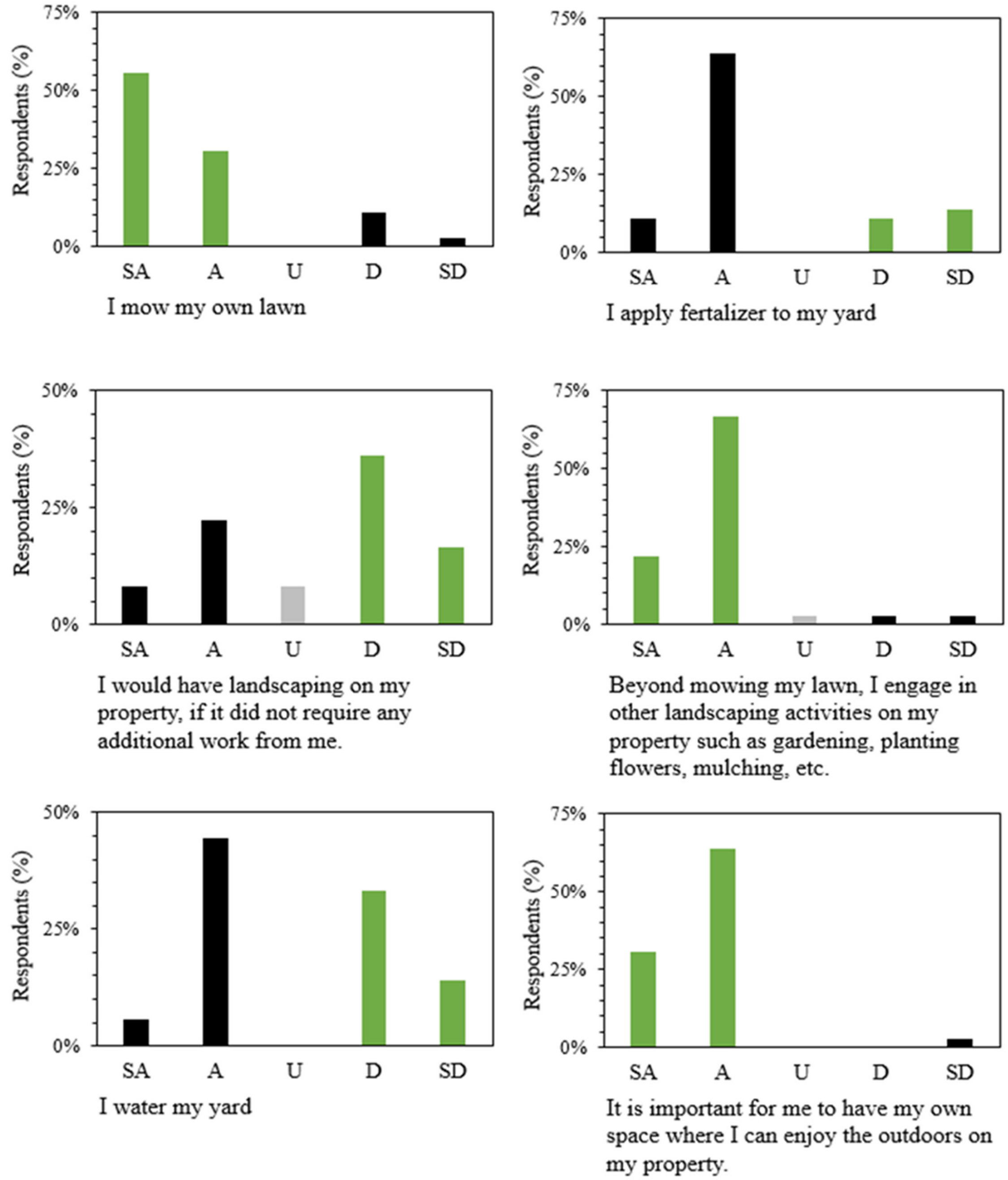



Figure 3-1. Responses to survey questions pertaining to respondents behaviors for both treatment streets. Responses in green indicate positive behaviors and black indicates negative behaviors. (SA = Strongly agree, A = Agree, U = Unsure, D = Disagree, SD = Strongly disagree)

than 15 years (mean = 4.54), which may be related to the responses of those over 60 that were less likely to mow their own lawn. Age, years in home, and education influenced the application of fertilizers to properties where respondents over 60 (mean = 2.06), those that have lived in their home more than 30 years (mean =1.77), or those with some postsecondary education (mean = 2.66) were more likely to apply or have fertilizer applied to their property than respondents under 40 (mean = 3.60; p-value = 0.0342*), lived in their homes less than 15 years or from 16 – 30 years (mean = 2.92, 3.00; p-value = 0.023*, 0.0085*), or those with a Bachelor's degree (mean = 3.57; p-value 0.0323*). Respondents who have lived in their homes over 31 years were also more likely (mean = 2.15) to water their lawns than respondents who have lived in their home less than 15 years and from 16 – 30 (mean = 3.85, 3.22; p-value = 0.0336*, 0.0013*).

*Perceptions*

Responses for all survey respondents pertaining to perceptions are shown in Figure 3-2. Comparisons between respondents with and without green infrastructure showed that perceptions varied depending on the questions, but there were more statistical differences than with behaviors. Statistical differences were seen when asked about the general maintenance of their street. While both groups agreed that maintenance could improve (75%), respondents with green infrastructure more strongly agreed (mean = 1.73; p-value = 0.0295*) with the statement. Respondents with green infrastructure were more likely to have the perception that the addition of green infrastructure has helped to reduce stormwater runoff on their street (mean = 2.9; p-value = 0.0001*) and that as an individual they are able to impact stormwater runoff problems (mean = 4.00; p-

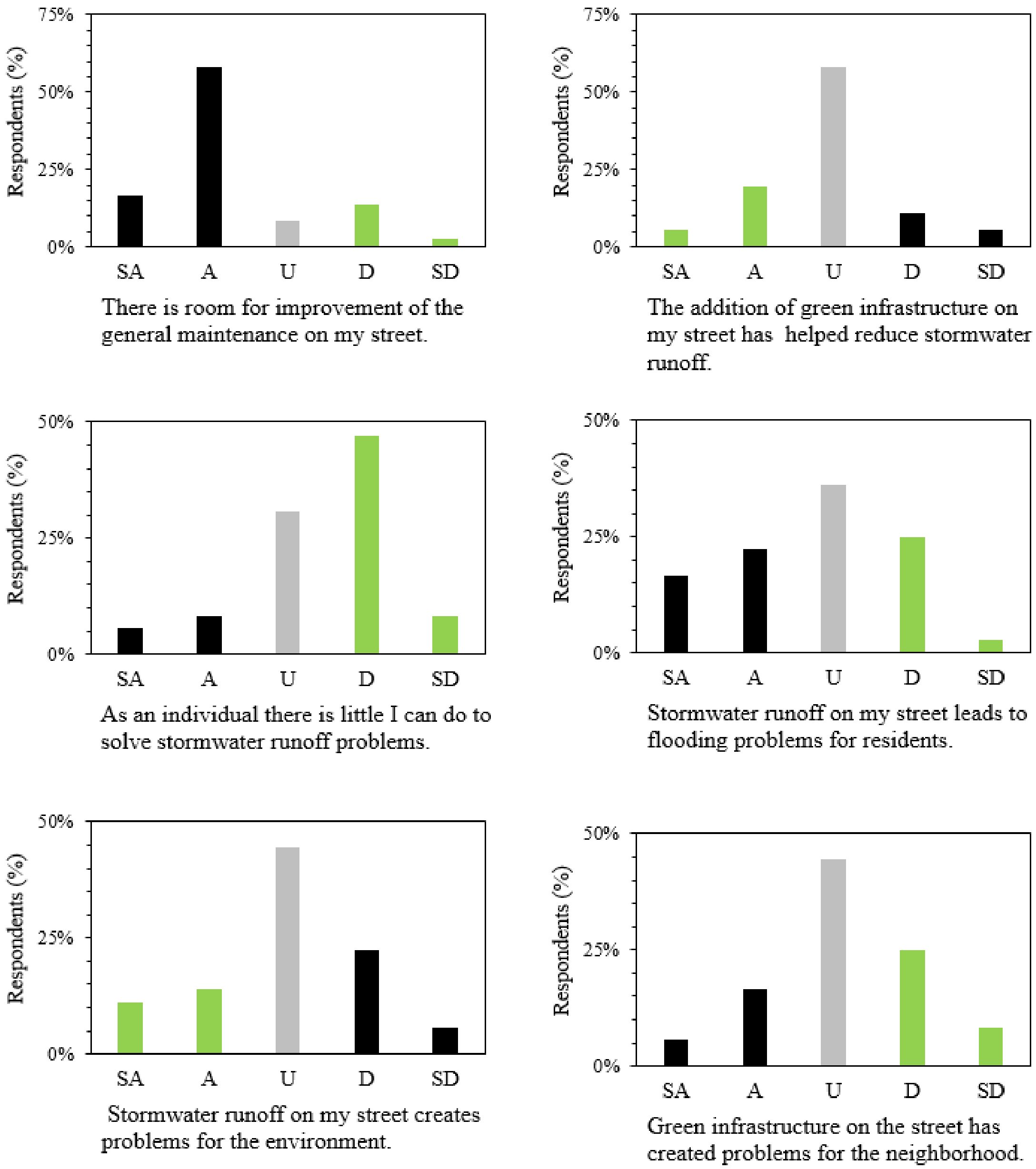



Figure 3-2. Responses to survey questions pertaining to respondents perceptions for both treatment streets. Responses in green indicate positive perceptions and black indicates negative perceptions. (SA = Strongly agree, A = Agree, U = Unsure, D = Disagree, SD = Strongly disagree)

value = 0.0108*). Respondents with green infrastructure were also more likely to agree that stormwater runoff on their street leads to flooding problems for residents (mean = 2.00; p-value = 0.0054*). Overall, both groups (44%) were unsure if stormwater runoff was creating problems for the environment. Those with green infrastructure also had the perception that green infrastructure was not creating problems for the neighborhood (mean = 3.91) whereas those without green infrastructure were unsure or agreed that it was creating problems (mean = 2.80).

Demographic variables also influenced several of the questions regarding perceptions. Overall, about half (56%) of respondents agreed that as an individual they could help with stormwater runoff problems. Respondents with bachelor's degrees (mean = 2.57) or respondents that have lived in their homes for 16 – 30 years (mean = 2.40) more strongly agreed that the addition of green infrastructure on the street has helped to reduce stormwater runoff than respondents with a high school education or less (mean = 3.33; p-value = 0.0280*) or those that have lived in their homes for more than 31years (mean = 3.38; p-value = 0.0265*). Respondents between the ages of 40 – 49 (mean = 1.40), with bachelor's degrees (mean = 1.67), or lived in their homes for less than 15 years (mean = 2.31) agreed that stormwater runoff was leading to flooding problems for residents whereas respondents ages 50 – 59, 60 and over (mean = 3.11, 3.13; p-value 0.0209*, 0.0080*), those with some postsecondary or high school or less educations (mean = 2.93, 3.22; p-value = 0.0169*, 0.0055*), or lived in their homes for more than 31 years (mean = 3.38; p-value = 0.0193*) did not think stormwater runoff was leading to flooding problems for residents. When asked if stormwater was creating problems for the environment, respondents who have lived in their homes for less than 15 years agreed (mean = 2.46) versus respondents that have lived in their homes for more than 31 years disagreed (mean = 3.46; p-value = 0.0150*).

*Attitudes*

Responses for all survey respondents pertaining to attitudes are shown in Figure 3-3. The attitudes of respondents toward green infrastructure on their street were compared between respondents with green infrastructure and those without (Table 3-3). Overall respondents agree that they enjoy where they live (92%) with no statistically significant difference between groups. Respondents with green infrastructure agreed that the green infrastructure added value to their homes (mean = 2.82; p-value = 0.0365*) and that the value of the green infrastructure justified its upkeep (mean = 3.55; p-value = 0.0042*). Those without green infrastructure did not believe there was enough value to justify the upkeep (mean = 2.32) and that it require too much maintenance (mean = 2.52). Overall, respondents either mostly agreed (42%) or were unsure (36%) that the value of green infrastructure justified its upkeep. There was no difference in responses to questions regarding who they felt bore the responsibility of stormwater management. When asked if stormwater management was the responsibility of the individual, many respondents were unsure (21%) and most agreed that stormwater management was the responsibility of the city (78%). If homeowners were given the opportunity to add green infrastructure to their property those with green infrastructure agreed that they would (mean = 2.22; p-value = 0.0034*), whereas those without green infrastructure disagreed (mean = 3.76) and said they would not add green infrastructure to their property.

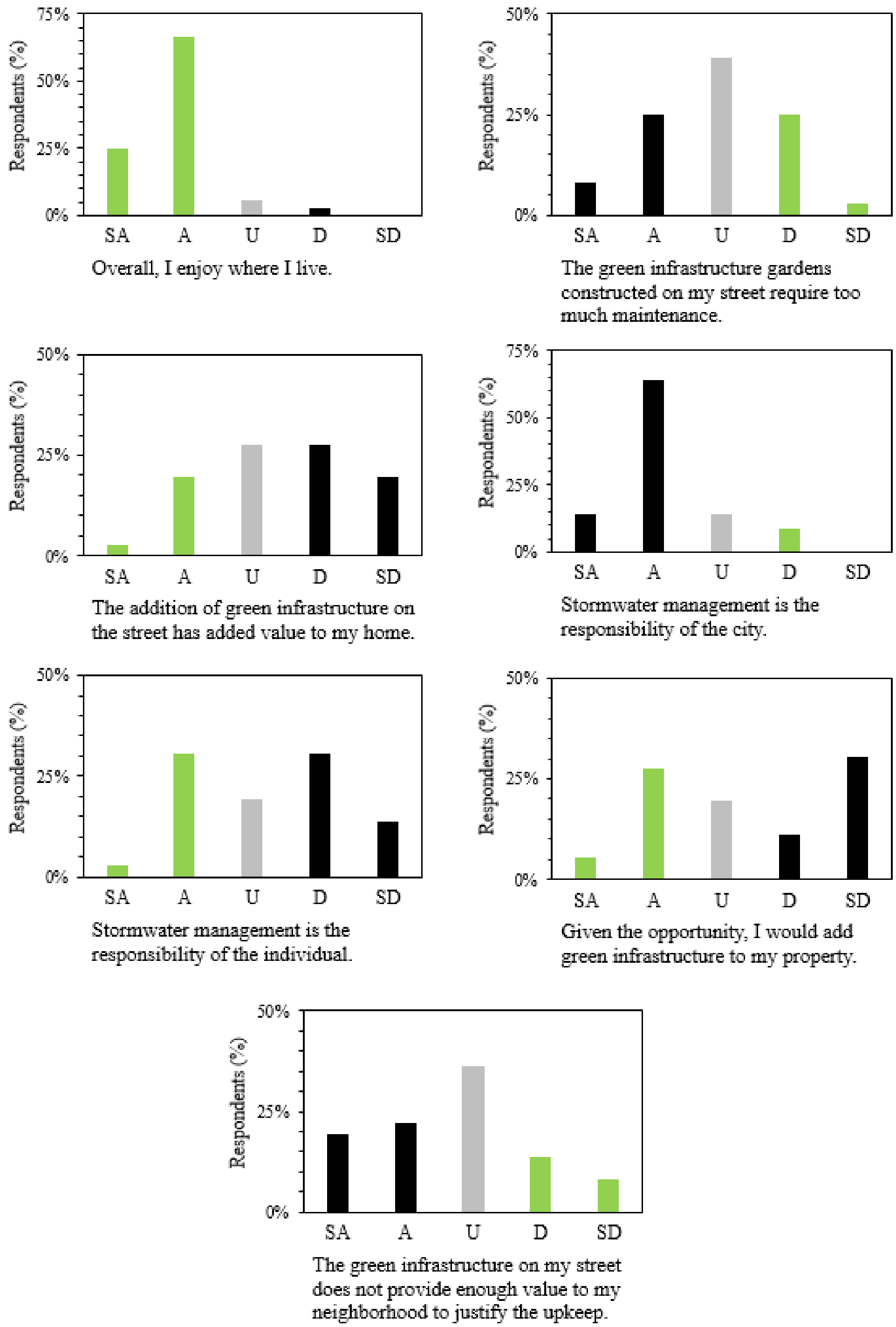



Figure 3-3. Responses to survey questions pertaining to respondents attitudes for both treatment streets. Responses in green indicate positive attitudes and black indicates negative attitudes. (SA = Strongly agree, A = Agree, U = Unsure, D = Disagree, SD = Strongly disagree)

Demographic variables also showed differences in the attitudes of respondents toward green infrastructure and stormwater. Respondents on Klusner (mean = 3.65), residents with some postsecondary or high school or less education (mean = 3.57, 3.89), or those who have lived in their homes for more than 31 years (mean = 4.00) were less likely to add green infrastructure to their property if they were given the opportunity to do so than the residents on Parkhaven (mean = 2.72; p-value = 0.0826), respondents with a bachelor's degree or beyond a bachelor's degree (mean = 2.67, 2.60) or who have lived in their homes for 15 – 30 years (mean = 2.44; p-value = 0.0138*). Respondents with a bachelor's degree disagreed (mean = 3.29) with the response that the green infrastructure required too much maintenance, whereas respondents with an education of high school or less agreed (mean = 2.44; p-value = 0.0453*) that the green infrastructure did require too much maintenance. Respondents on Parkhaven (mean = 2.92) and those with a degree beyond a bachelor's (mean = 2.40) agreed that the green infrastructure has added value to their home, where as respondents on Klusner disagreed (mean = 3.70; p-value = 0.0646) and those with an education of high school or less (mean = 3.89; p-value = 0.0387*) disagreed.

*Willingness to Pay*

Responses for all survey respondents pertaining to willingness to pay are shown in Figure 3-4. Willingness to pay responses included questions from both the perceptions and attitudes categories (Table 3-3). Comparisons of the willingness of homeowners to pay for green infrastructure were made between respondents with and without green infrastructure, as well as demographic variables. For both groups, when asked about whether or not green infrastructure was too expensive, most respondents answered unsure

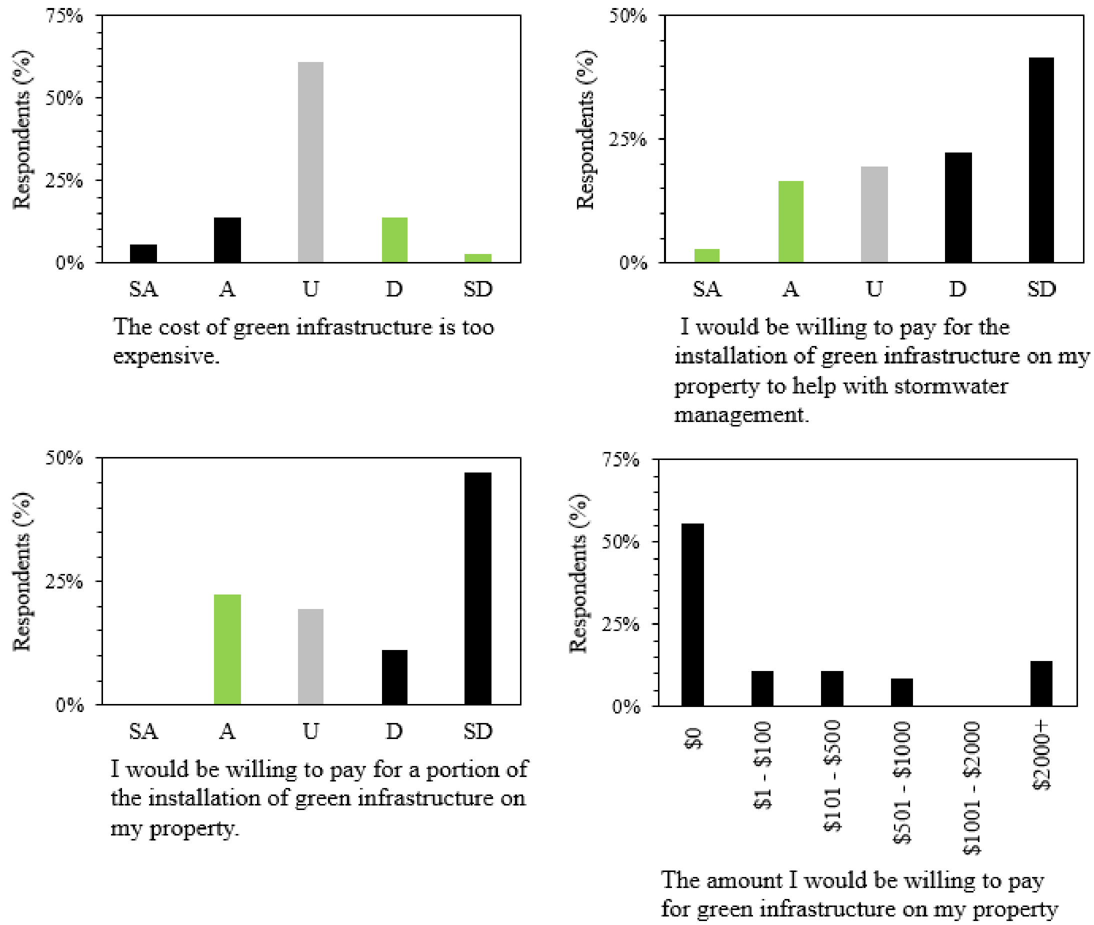



Figure 3-4. Responses to survey questions pertaining to respondents' willingness to pay for both treatment streets. Responses in green indicate positive willingness to pay and black indicates negative willingness to pay. (SA = Strongly agree, A = Agree, U = Unsure, D = Disagree, SD = Strongly disagree). The amount respondents were actually willing to pay was not coded as being either positive or negative.

(61%) and a similar proportion (64%) of respondents indicated they were not willing to pay any money to have green infrastructure installed on their property. There was however, a significant difference between homeowners with green infrastructure that would be willing to pay for a portion of the installation of green infrastructure (mean = 3.09; p-value = 0.0264*) on their property versus those without green infrastructure that were less likely to pay for a portion of green infrastructure installation (mean = 4.16). This relationship was seen again in the question asking if respondents would be willing to pay for the entire cost of green infrastructure treatment on their property. Respondents without green infrastructure disagreed with paying for the entire installation (mean = 4.20; p-value = 0.0065*) whereas respondents with green infrastructure were unsure or in agreement (mean = 3.00).

When asked if green infrastructure was too expensive, respondents from ages 40 – 49 (mean = 2.40), with some postsecondary, and high school or less (mean = 2.6, 2.88) agreed that green infrastructure was too expensive, while respondents from ages 50 – 59 (mean = 3.40; p-value = 0.0409*) and respondents with degrees beyond bachelor's degrees (mean = 4.25; p-value = 0.0010*, 0.0083*) disagreed that green infrastructure was too expensive. Overall, most respondents (78%) indicated that they will be willing to pay less than $500 for the installation of green infrastructure on their property.

*Values*

Questions pertaining to the NEP showed that respondents had similar environmental values regardless of whether or not they had green infrastructure on their property (Table 3-4). The only case where the respondents differed significantly was the

Table 3-4. Nonparametric comparisons for New Ecological Paradigm responses between respondents with and with out green infrastructure on their properties. Mean values below 3 indicate agreement with the response, means above 3 indicate disagreement with the response. The Wilcoxon Method was used for statistical comparisons, values with (*) indicate significant differenced (p < 0.05) between pairings. Pro-NEP response means are indicated in **bold.**

| Question/Response | GI on Property | | |
|---|---|---|---|
| | Yes | No | |
| | Mean | | p-Value |
| NEP-1. Humans have the right to modify the natural environment to suit their needs. | 2.60 | 2.65 | 0.871 |
| NEP-2. When humans interfere with nature it often produces disastrous consequences. | **2.55** | **2.63** | 0.908 |
| NEP-3. Human ingenuity will insure that we do not make the Earth unlivable. | 2.36 | 2.61 | 0.579 |
| NEP-4. Humans are seriously abusing the environment. | **1.91** | **2.83** | 0.101 |
| NEP-5. The Earth has plenty of natural resources if we just learn how to develop them. | 2.00 | 2.17 | 0.418 |
| NEP-6. Plants and animals have as much right as humans to exist. | **1.73** | **1.83** | 0.837 |
| NEP-7. Despite our special abilities, humans are still subject to the laws of nature. | **2.00** | **2.00** | 0.704 |
| NEP-8. The so-called "ecological crisis" facing humankind has been greatly exaggerated. | **4.10** | **3.30** | 0.0217* |
| NEP-9. The balance of nature is very delicate and easily upset. | **2.10** | **2.67** | 0.229 |
| NEP-10. Humans will eventually learn enough about how nature works to be able to control it. | **3.09** | **3.46** | 0.278 |
| NEP-11. If things continue on their present course, we will soon experience a major ecological catastrophe. | **2.10** | 3.17 | 0.0082* |

question, “If things continue on their present course, we will soon experience a major ecological catastrophe.” Respondents with green infrastructure agreed that an ecological catastrophe was possible (mean = 4.10; p-value = 0.0217*) whereas those without green infrastructure were unsure (mean = 3.30). In general, regardless of green infrastructure on their property, respondents had pro-NEP or pro-environmental worldviews on 63% of the responses pertaining to the NEP. Past studies of the NEP have shown an overall tendency for respondents to show agreement with pro-environmental beliefs, especially with responses pertaining to the balance of nature being threatened by humans. However, there is generally less agreement with the idea that there are limits to growth (Dunlap et al., 2000). The responses in this survey hold true to those findings where questions on the survey relating to the balance of nature (NEP-2 and NEP-9, Table 3-4) had pro-environmental mean responses and the response pertaining to growth (NEP-5, Table 3-4) had a negative-environmental mean response.

Comparisons of demographics and NEP responses indicated that almost no differences existed between demographic groups’ responses. The one statistical difference that was found was when asked if humans were seriously abusing the environment, residents who have lived in their homes more than 31 years disagreed (mean = 3.23), whereas residents who have lived in their homes for 15 – 30 years agreed (mean = 1.77; p-value = 0.0061*). Demographic comparisons for NEP-2 and NEP-9 did not show any significant differences and also agreed with pro-environmental mean responses like the findings above when assessed with green infrastructure on the respondent’s property versus no green infrastructure. This is also true for the mean responses for NEP-5 having a negative environmental mean response no matter how the demographics were assessed.

*Open-Ended Responses*

Responses to open-ended questions showed that most respondents were either very positive (1) or very negative (3) toward the implementation of green infrastructure on their street. Of the 36 respondents, 24 commented on the open-ended questions. The mean of these coded responses was 2.33, indicating that more of the comments were negative regarding the green infrastructure. No statistically significant difference existed between open ended responses of respondents with green infrastructure and those without, however the mean response of those with green infrastructure was 1.80 and the mean response of those without green infrastructure was 2.47. This does indicate that the respondents without green infrastructure were more inclined to comment negatively than the respondents with green infrastructure.

Negative comments about the green infrastructure generally included the appearance and maintenance of the gardens in their current state. Some of the negative comments included the lack of upkeep to the green infrastructure. One respondent without green infrastructure on their property stated that, “All these green infrastructures do is collect litter/garbage … taking away from any sort of ‘visual’ benefit” and another respondent without green infrastructure said that “If the infrastructure was kept up weekly, it wouldn’t be such of an eye sore. Right now it looks like a jungle with weeds all over.” The visual appearance of the gardens also received some negative comments from respondents. One responded without green infrastructure stated, “Visually unappealing. We have such small yards that once plants start to grow, it just looks like unkempt weeds" and another respondent without green infrastructure said, "The tree lawns look like a jungle! I don't like the wilderness it portrays. No one wants to pay for this or do the upkeep of the plants. This is a problem of the city to solve about the rain water, not mine." This comment helps to illustrate that the respondent thinks that cities have the responsibility of stormwater management and not the individual.

Positive comments about the green infrastructure on the street were also generally centered on the appearance, as well as the amount of participation. Some of the positive comments included those from respondents with green infrastructure on their property. Several comments from respondents with green infrastructure on their property included, "I am very happy with the rain garden, bioretention garden, and rain barrels installed on my property. I wish more residents had participated" and "I absolutely love the eco restorations on my property and would use more if I could afford it. The rain barrels are perfect. The gardens have color throughout the year. Thank you Metroparks for all you've done." These comments from respondents with green infrastructure on their property show that the green infrastructure is still being positively received, even after they have had some time to live with the green infrastructure on their property. Respondents without green infrastructure on their property also had several positive comments. One respondent stated that, "Our neighbors across the street have one (bioretention garden) on their tree lawn, it's very beautiful, and I do feel that it is helping with stormwater runoff. I think the green infrastructures are a step in the right direction." Positive comments from respondents without green infrastructure show that seeing other residents with green infrastructure is having a positive impact and may encourage others to adopt the practices of their neighbors.

Neutral comments centered on lack of information and the problems with deer in the neighborhood. Neutral comments were from both respondents with and without green infrastructure on their property. The respondents with green infrastructure on their property were most concerned with the deer eating the plants from their gardens, such as, “We have to do something to STOP the deer from eating all the greenery!” Those without green infrastructure included statements about not getting enough information about the project and how costly or difficult it would be to maintain the green infrastructure. They said “I was not given enough information about this project” and “I don’t know how much it would cost or how difficult it would be to maintain.” Overall, the open-ended comments helped to provide further insight into how respondents felt about the green infrastructure.

## 3.4 - Discussion

### Homeowner Survey

This study sought to compare how homeowner's attitudes, perceptions, behaviors, and environmental values correlated to their participation in the green infrastructure project implemented on their street. The participation rates experienced in this study are similar to other rates of participation in a residential stormwater retrofit project (Green et al., 2012). However, this participation rate indicates that more incentive may be needed for homeowners to be inclined to participate in a green infrastructure project. Behaviors and environmental values were not strong predictors for participation in the green infrastructure project, however attitudes and perceptions resulted in more significant differences between respondents with green infrastructure and those without. Questions pertaining to attitudes and perceptions could have been influenced by the implementation of the project itself, where respondents with green infrastructure may be more inclined to agree with the positive performance of green infrastructure at reducing stormwater runoff and the likelihood they would implement green infrastructure on their property regardless of price. Demographic variables for age, education, and years lived in home were the greatest predictors for attitudes and perceptions toward green infrastructure and stormwater management.

The respondents in this survey generally had similar environmental values, regardless of whether or not they had green infrastructure on their property, street, age, education, gender, and years lived in their home. This shows that in this study a person's environmental values were overall not a factor in determining the likelihood of participating in the green infrastructure project. However, respondents with green infrastructure agreed that a catastrophe was possible and their decision to participate in the green infrastructure project could be related to their desire to help change the present course. Respondents with green infrastructure on their property also more strongly disagreed that the so-called "ecological crisis" facing human kind has been greatly exaggerated. This also indicates that respondents with green infrastructure were more inclined to take action to help change the so-called "ecological crisis".

While this study is only a small subset of a larger population, the findings here were opposite of that from Dunlap et el. (2000) where young, well-educated, and politically liberal adults and people from urban areas tended to be more pro-environmental. In this study, those factors did not appear to be an influence, especially given the fact that respondents in this study who participated in the green infrastructure project covered all of the categories for gender, age, education, and years lived in home. Participants' ethnicity was homogenous in this study and income was only used as an average of each streets census data. Similarly, the weak correlation to environmental values and the implementation of green infrastructure or demographic variables was seen, confirming the findings of Baptiste et al. (2015).

Socioeconomic factors may have played a role in the determination of respondents whether or not to participate in the green infrastructure process. The average household income for both neighborhoods surveyed could be considered lower middle class and could have had an effect on the overall participation of residents in the green infrastructure project. The average household income on both treatment streets may also have played a role in the willingness of residents to pay for green infrastructure on their property. The large number of respondents from both the group with green infrastructure and the group without that indicated they were not willing to pay for green infrastructure on their property could be related to their income and a possible lack of disposable income for a green infrastructure project. Another possibility for not wanting to pay for green infrastructure was the fact that residents on the street were already given the opportunity to have green infrastructure installed on their property at no cost to them, so any further participation on the street may need to be provided at no cost to them rather than volunteering to implement green infrastructure on their own. However, respondents with green infrastructure on their property did agree that they would be willing to pay for a portion of the installation of green infrastructure on their property. This could indicate that the respondents who have had the green infrastructure installed on their property do place some value in the green infrastructure, but cannot justify having to be responsible to pay for the entire installation. Further, respondents with more education agreed that the cost of green infrastructure was not too expensive whereas respondents with less education responded that it was too expensive.

Not knowing how much green infrastructure costs can have a large effect on the likelihood a homeowner will seek out implementing it on their own. Overall most respondents indicated that they would be willing to pay less than $500 to implement green infrastructure on their property. However, when asked if the cost of green infrastructure was too expensive, most respondents were unsure. More education and public awareness on the actual costs of green infrastructure may help to increase adoption by individual homeowners if they are able to incorporate it into their long term landscaping plans.

The behaviors of the respondents were very similar regardless of whether or not they had green infrastructure on their property. That the majority of all residents, regardless of participation in the green infrastructure project, apply fertilizers to their yard is similar other studies, where lawn care management behaviors are not always directly related to their environmental beliefs (Robbins et al., 2001). The application of fertilizers was also strongly related to age and length of time in home, where older residents and residents who lived in their homes longest were most likely to apply fertilizers to their property. Some respondents may think that regardless of their environmental beliefs, that keeping a well-maintained lawn shows respect for your neighborhood and a sense of community (Robbins et al, 2001). This could be true for the neighborhoods in this study, because many of the respondents have lived in their homes for over 30 years and could feel a strong sense of responsibility to their neighbors to keep a well maintained lawn. This disconnect can also be related to the disconnect often seen between people's attitudes and behaviors. Kollmuss and Agyeman (2002) argue that many people disconnect their attitudes toward a particular topic, such as climate change, and the negative effect their behavior has on that topic, such as driving a car. Here respondents could be disconnecting the use of fertilizes on their property with greater environmental harm. Using a more integrated approach to green infrastructure, that educates homeowners about the environmental impact of various management behaviors beyond the green infrastructure, could help change other lawn care behaviors as well.

Having a volunteerist attitude (Robbins et al., 2001) toward helping neighbors is a possibility in the neighborhoods surveyed because many of the residents have lived in their homes for a long time and may have strong connections to their neighbors. The demographic responses showed that respondents over 60 were less likely to mow their own lawn and could fall in line with neighbors being "volunteerist" to the older residents. Residents may be inclined to help out an older neighbor regardless of that person's environmental beliefs. However, that may not hold true in this study because the older respondents were the ones more likely to apply fertilizers. While not significantly different, the only behavior that showed a difference from respondents with green infrastructure and those without was watering their own yard and was also significantly different between residents who have lived in their homes over 30 years versus those who have lived there for less than 30 years. This shows that respondents newer to the neighborhood and possibly younger may be more aware of the impacts of watering their yards. This could also be one way where respondents think they can practice their environmental beliefs while still keeping a well-maintained yard that fits in with the neighborhood.

Lived experience could be a strong predictor for participation. Many older residents did not agree that stormwater runoff was leading to flooding problems for residents whereas respondents with green infrastructure on their property agreed that stormwater was causing flooding problems for residents. If respondents do not think that flooding is a problem then they may not be inclined to participate in a stormwater project. Respondents who have lived in their homes over 30 years also did not believe that the green infrastructure was helping to reduce stormwater runoff on the street. Their perceptions and lived experiences could be a strong barrier to the implementation to green infrastructure on their street. Baptiste et al. (2015) relate lived experience to residents who have dealt first hand with CSOs, where residents that have had direct experience with the problems associated with excess stormwater runoff exhibited higher levels of environmental knowledge. In this study, if respondents do not think that stormwater runoff is creating a problem, then it most likely would not be a major environmental concern to them. Also, if older respondents have never exhibited pro-environmental behavior previously in their lives, they most likely are not going to start with a large green infrastructure project on their property and would be more resistant to pro-environmental changes in their neighborhood.

Many homeowners disconnect management practices in their own yards from larger, more diffuse environmental concerns happening outside of their property and believe the common perception that stormwater is not a problem (Keeley et al., 2013). Based on their responses, respondents with green infrastructure on their property agreed that the green infrastructure was helping to reduce stormwater runoff on their street and that as an individual they were able to help solve stormwater runoff problems. This positive response from respondents with green infrastructure could be linked to the desire to want to believe that the green infrastructure on their property was in fact working as intended and that they were doing their part to help the environment, making the connection that management practices on their property lead to overall environmental benefit. However, most respondents agreed that stormwater management was the responsibility of this city. This confirms the results from Keeley et al. (2013) about conveying the importance of public participation with stormwater management.

Once confounding finding in this survey was whether or not respondents would be willing to add green infrastructure to their property if given the opportunity and whether or not the green infrastructure provided enough value to justify its upkeep. These questions were designed to see if respondents without green infrastructure on their property would be inclined to add green infrastructure now that they have seen it on their neighbor's properties. The results show that respondents with green infrastructure would be willing to add green infrastructure to their property, which they have already done, and that those without green infrastructure are not willing to add green infrastructure to their property. Respondents with green infrastructure also agreed that its value justified the upkeep, whereas those without green infrastructure disagreed. This indicates that after actually seeing the green infrastructure on their street and how it functions, respondents without green infrastructure were not more likely to want to have green infrastructure on their property or to realize any value in maintaining green infrastructure. The lack of changed attitudes from homeowners without green infrastructure highlights the challenge for participatory approaches to stormwater management.

A large number of respondents were only willing to add any sort of landscaping to their property if it did not require any additional work from them. This could indicate that many respondents would enjoy having some sort of landscaping but do not care for the maintenance aspect. This response could be indicative of the homeowners who participated in the green infrastructure project since they did not have to do any work to install the green infrastructure and the Metroparks was going to be handling the maintenance for at least the first several years, including the Phase 1 (summer 2013) and Phase 2 (summer 2014) construction periods.

Many of the attitudes towards green infrastructure were more positive from the respondents with green infrastructure than those without. When compared to demographic variables, respondents with more education and respondents that have lived in their homes less than 30 years were more positive toward the addition of green infrastructure on their streets. These respondents were more likely to add green infrastructure to their properties if given the opportunity and also did not think it required too much maintenance. Respondents with more education also agreed that the green infrastructure has added more value to their homes. This could indicate that it is important to target professionals who have lived in their home for at least a few years. Once homeowners become more established in their home and with their community, they may be more likely to add green infrastructure to their property, which can in turn have an impact on other residents. Also, respondents with higher levels of education may have more disposable income to be able to pay for at least a portion of a green infrastructure installation. Urban and suburban municipalities wanting to implement a green infrastructure project may choose to target a more up and coming neighborhood, where young professionals live. Younger urban dwellers may also be more inclined to act on pro-environmental behavior.

The open-ended responses helped to provide insight on green infrastructure upkeep and appearance. Many of the open-ended responses included not enjoying the overgrown appearance of the gardens. The plants selected for the gardens were specified to ensure survival in both wet and dry conditions and resist deer. However, selecting plants that have a less messy appearance may help curb negative perceptions that the gardens look overgrown. Also, implementing a regular maintenance plan, where homeowners become more involved, may help to combat the upkeep issues surrounding the green infrastructure. The Metroparks is currently handling the maintenance of the gardens with help from volunteers. Getting volunteers directly from the street to help with maintenance may help with overall acceptance, if residence see their neighbors interacting with the green infrastructure on a regular basis.

Overall, demographic factors that influenced the likelihood of installing green infrastructure were age, education, and the number of years a respondent has lived in their home. Especially in regards to attitudes and perceptions toward green infrastructure and stormwater management respondents who have a higher level of education, were younger than 60, and have lived in their home less than 30 years, were the most likely to have positive attitudes and perceptions towards green infrastructure. Participatory approaches to stormwater management have many barriers to implementation and acceptance. Targeting the right audience can help to ultimately reach the right people and create meaningful changes to stormwater management in urban areas.

## 3.5 - Conclusion

This study contributes to the understanding of the social acceptability of large-scale green infrastructure implementation and the drivers of homeowner participation. As the need to reduce stormwater runoff in urban areas grows, so will the need to find innovative solutions for stormwater management. Looking to private landowners is a possible solution if wide scale implementation is possible.

A strong understanding of the correlations between participation in a green infrastructure project and the attitudes, perceptions, behaviors, and environmental values can help lead to a successful green infrastructure project. This study found that respondents with green infrastructure already on their property indicate that stormwater runoff is a problem, but they have the ability to help solve stormwater problems as an individual. Respondents without green infrastructure on their property are not inclined to add green infrastructure after having seen the green infrastructure implemented in their neighborhood. Ultimately age, education, and years lived in home were the largest predictors to positive attitudes and perceptions toward green infrastructure and its implementation to help with stormwater management.

Future studies should focus on attitudes and perceptions, and variation across demographic categories. Focusing studies on these relationships could help create more targeted approached to participatory stormwater management. The environmental values seen in this study could also be an artifact of the neighborhood, where people who are similarly minded chose to live near one another. Future studies could compare across neighborhoods, with different demographics, to help determine if the same demographic/value correlation holds true. Finally, future studies may require a better understanding for the costs associated with green infrastructure and the amounts homeowners are actually willing to pay to implement green infrastructure on their property. So far many green infrastructure projects have been implemented at no cost to homeowners. Moving to the possibility of homeowners actually paying for green infrastructure on their property may be more difficult to understand and go beyond their attitudes, perceptions, behaviors, and environmental values.

## 4.1 – Overall Conclusion

This study has brought together the effectiveness of green infrastructure through hydrology, water quality, and social impacts. Continued urban expansion is leading to continued increases in impervious surfaces. Finding unique and innovative solutions to combat excess stormwater runoff from impervious surfaces is necessary to keep up with changing environments. This project shows that it is possible to realize benefits of reduced peak storm flow and total storm volume with the implementation of green infrastructure retrofits in a suburban neighborhood. Depending on the desired outcome of the project, including underdrains in the design can have effects on both peak stormflow and total storm volume. Connections to transportation surfaces is an important factor to consider when employing a decentralized approach to stormwater management.

The water quality analysis conducted in this survey showed that the pollutant loads on the treatment and control street were on the low end of pollutants usually seen in urban areas. Overall, heavy metal contamination is not a major concern to the streets in this study. However, this study did show the importance of needing before-after-control-impact design and sampling. By not conducting water quality sampling before green infrastructure installation, it was not possible to realize the true pollution reduction potential of the green infrastructure investments.

Overall, social drivers play a big role in the implementation of a decentralized stormwater project. Large scale implementation is necessary to realize the hydrologic benefits at the street scale. Being able to change attitudes and perceptions of residents toward the responsibility of stormwater management and their role in helping the environment may help to increase participation in future projects. Ultimately, targeting the right audience will help to successfully implement a large scale green infrastructure project and hopefully keep it maintained for long term benefits.

## References


Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. *Water, Air, & Soil Pollution*, *223*(7), 4253-4273.

Bakacs, M. E., Haberland, M., Mangiafico, S. S., Winquist, A., Obropta, C. C., Boyajian, A., & Mellor, S. (2013). Rain Barrels: A Catalyst for Change?. *Journal of Extension*, *51*(3), 3RIB6.

Baptiste, A. K., Foley, C., & Smardon, R. (2015). Understanding urban neighborhood differences in willingness to implement green infrastructure measures: a case study of Syracuse, NY. *Landscape and Urban Planning*, *136*, 1-12.

Barr, S. (2004). Are we all environmentalists now? Rhetoric and reality in environmental action. *Geoforum*, *35*(2), 231-249.

Bedan, E. S. and Clausen, J. C. (2009), Stormwater Runoff Quality and Quantity From Traditional and Low Impact Development Watersheds. *JAWRA Journal of the American Water Resources Association*, 45: 998–1008

Blaine, T. W., Clayton, S., Robbins, P., & Grewal, P. S. (2012). Homeowner attitudes and practices towards residential landscape management in Ohio, USA. *Environmental management*, *50*(2), 257-271.

Charlesworth, S., De Miguel, E., & Ordóñez, A. (2011). A review of the distribution of particulate trace elements in urban terrestrial environments and its application to considerations of risk. *Environmental geochemistry and health*, *33*(2), 103-123.

Charlton, R. (2007). Fundamentals of fluvial geomorphology. Routledge.

City Data.com (2014). http://www.city-data.com/states/Ohio-Climate.html [Online] Accessed 12/10/2014.

Cleveland Metroparks. (2014). Cleveland Metroparks data on deer population. West Creek Reservation.

Corder, G. W., & Foreman, D. I. (2009). *Nonparametric statistics for non-statisticians: a step-by-step approach*. John Wiley & Sons.

Davis, A. P., Shokouhian, M., Sharma, H., & Minami, C. (2001a). Laboratory study of biological retention for urban stormwater management. *Water Environment Research*, 5-14.

Davis, A. P., Shokouhian, M., & Ni, S. (2001b). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere*, *44*(5), 997-1009.

Davis, A. P., Shokouhian, M., Sharma, H., Minami, C., & Winogradoff, D. (2003). Water quality improvement through bioretention: Lead, copper, and zinc removal. Water Environment Research, 73-82.

Davis, A. P., Hunt, W. F., Traver, R. G., & Clar, M. (2009). Bioretention technology: Overview of current practice and future needs. *Journal of Environmental Engineering*, *135*(3), 109-117.

Deletic, A. (1998). The first flush load of urban surface runoff. *Water research*, *32*(8), 2462-2470.

Dietz, M. E., & Clausen, J. C. (2006). Saturation to improve pollutant retention in a rain garden. *Environmental science & technology*, *40*(4), 1335-1340.

Dietz, M. E. (2007). Low impact development practices: A review of current research and recommendations for future directions. Water, air, and soil pollution, 186(1-4), 351-363.

Dingman, S.L., (2002). Physical Hydrology (2nd Edition), Macmillan, New York.

Dunlap, R. E., & Van Liere, K. D. (1978). The "new environmental paradigm". *The journal of environmental education*, *9*(4), 10-19.

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., & Jones, R. E. (2000). New trends in measuring environmental attitudes: measuring endorsement of the new ecological paradigm: a revised NEP scale. *Journal of social issues*, *56*(3), 425-442.

Dunne, J., and Leopold, L. B.(1978). "Water in Environmental Planning." New York, 818p Print.

EPA.gov (2014a).Greening EPA, Stormwater Management [Online] Available from: http://www.epa.gov/greeningepa/stormwater/ accessed 1/7/2014

EPA.gov (2014b). Combines Sewer Overflows [Online] Available from: http://cfpub.epa.gov/npdes/home.cfm?program_id=5 accesses 1/22/2014

Evans, M., & Heller, F. (2003). *Environmental magnetism: principles and applications of enviromagnetics* (Vol. 86). Academic press.

Feng, W., Hatt, B. E., McCarthy, D. T., Fletcher, T. D., & Deletic, A. (2012). Biofilters for stormwater harvesting: understanding the treatment performance of key metals that pose a risk for water use. *Environmental science & technology*, *46*(9), 5100-5108.

Finger, M. (1994). From knowledge to action? Exploring the relationships between environmental experiences, learning, and behavior. *Journal of Social Issues*, *50*(3), 141-160.

Fraser, E. D., Dougill, A. J., Mabee, W. E., Reed, M., & McAlpine, P. (2006). Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. Journal of environmental management, 78(2), 114-127.

Green, O. O., Shuster, W. D., Rhea, L. K., Garmestani, A. S., & Thurston, H. W. (2012). Identification and induction of human, social, and cultural capitals through an experimental approach to stormwater management. *Sustainability*,*4*(8), 1669-1682.

Gulliver, J.S., A.J. Erickson, and P.T. Weiss (editors). (2010).*"Stormwater Treatment: Assessment and Maintenance."* University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN. http://stormwaterbook.safl.umn.edu/

Heiri, O., Lotter, A. F., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of paleolimnology*, *25*(1), 101-110.

Hood, M. J., Clausen, J. C., & Warner, G. S. (2007). Comparison of Stormwater Lag Times for Low Impact and Traditional Residential Development1. JAWRA Journal of the American Water Resources Association, 43(4), 1036-1046.

Hunt, W. F., Davis, A. P., & Traver, R. G. (2011). Meeting hydrologic and water quality goals through targeted bioretention design. *Journal of Environmental Engineering*, *138*(6), 698-707.

Kaplowitz, M. D., & Lupi, F. (2012). Stakeholder preferences for best management practices for non-point source pollution and stormwater control. *Landscape and Urban Planning*, *104*(3), 364-372.

Kaushal, S. S., & Belt, K. T. (2012). The urban watershed continuum: evolving spatial and temporal dimensions. *Urban Ecosystems*, *15*(2), 409-435.

Keeley, M. (2007). Using individual parcel assessments to improve stormwater management. *Journal of the American Planning Association*, *73*(2), 149-160.

Keeley, M., Koburger, A., Dolowitz, D. P., Medearis, D., Nickel, D., & Shuster, W. (2013). Perspectives on the Use of Green Infrastructure for Stormwater Management in Cleveland and Milwaukee. *Environmental management*, *51*(6), 1093-1108.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental education research*, *8*(3), 239-260.

Lee, J. H., & Bang, K. W. (2000). Characterization of urban stormwater runoff. *Water Research*, *34*(6), 1773-1780.

Lee, J. G., & Heaney, J. P. (2003). Estimation of urban imperviousness and its impacts on storm water systems. *Journal of Water Resources Planning and Management*, *129*(5), 419-426.

Leopold, L. B. (1968). Hydrology for Urban Land Planning: A Guide on the Hydrologic Effects of Urban Land Use. US Geological Survey.

Liu, Q., Roberts, A. P., Larrasoana, J. C., Banerjee, S. K., Guyodo, Y., Tauxe, L., & Oldfield, F. (2012). Environmental magnetism: principles and applications. *Reviews of Geophysics*, *50*(4).

Low Impact Development (2014). http://www.lowimpactdevelopment.org/raingarden_design/ whatisaraingarden.htm, accessed 12/8/2014

Maher, B.A. and Thompson, R., (1999). *Quaternary Climates, Environments and Magnetism*. Cambridge University Press, Cambridge, UK Pp. 44.

Mayer, A. L., Shuster, W. D., Beaulieu, J. J., Hopton, M. E., Rhea, L. K., Roy, A. H., & Thurston, H. W. (2012). Environmental reviews and case studies: Building green infrastructure via citizen participation: A six-year study in the Shepherd Creek (Ohio). Environmental Practice, 14(01), 57-67.

Munroe, Karen E., Ph.D. Department of Biology and Geology. (2013) West Creek Conservancy: A Northeast Ohio Sustainability Case Study

NOAA.gov (2014) National Weather Service Forecast Office, http://www.nws.noaa.gov/climate/xmacis.php?wfo=cle, accessed 12/8/2014.

NOAA.gov (2015) National Weather Service Forecast Office, http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=oh, accesses 2/20/2015.

Novotny, V., & Olem, H. (2003). Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Wiley.

Robbins, P., Polderman, A., & Birkenholtz, T. (2001). Lawns and toxins: an ecology of the city. *Cities*, *18*(6), 369-380.

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., Thurston, H.W., & Brown, R. R. (2008). Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. *Environmental management*, 42(2), 344-359.

Roy, A. H., Rhea, L. K., Mayer, A. L., Shuster, W. D., Beaulieu, J. J., Hopton, M. E., Morrison, M.A., & Amand, A. S. (2014). How Much Is Enough? Minimal Responses of Water Quality and Stream Biota to Partial Retrofit Stormwater Management in a Suburban Neighborhood. *PloS one*, *9*(1).

Rushton, B. T. (2001). Low-impact parking lot design reduces runoff and pollutant loads. Journal of Water Resources Planning and Management, 127(3), 172-179.

Shuster, W. D., Morrison, M. A., & Webb, R. (2008). Front-loading urban stormwater management for success–a perspective incorporating current studies on the implementation of retrofit low-impact development. *Cities and the Environment (CATE)*, *1*(2), 8.

Shuster, W., & Rhea, L. (2013). Catchment-scale hydrologic implications of parcel-level stormwater management (Ohio USA). *Journal of Hydrology*, *485*, 177-187.

Stanley, D. W. (1996). Pollutant removal by a stormwater dry detention pond. *Water Environment Research*, 1076-1083.

Sustainable Cities Institute. (2014). http://www.sustainablecitiesinstitute.org/view/page.basic/class/feature.class/Lesson_Retention_Ponds_Overview Accessed 1/22/2014.

Tornes, L. H. (2005). *Effects of Rain Gardens on the Quality of Water in the Minneapolis-St. Paul Metropolitan Area of Minnesota, 2002-04*. US Department of the Interior, US Geological Survey.

URS (2013), Bid specifications for West Creek Neighborhood Green Improvements, Phase II, 8/5/2013

"US Census Bureau." 2014. Web. <http://www.census.gov>. Accessed 1/20/2014

US EPA. (2001). 'Method 200.7, Trace Elements in Water, Solids, and Biosolids by Inductively Coupled Plasma-Mass Spectrometry', Revision 5.0, EPA- 821-R-01-010, Office of Research and Development, Cincinatti, Ohio, 45268.

US EPA (2009), Incorporating Low Impact Development into Municipal Stormwater Programs, EPA 901-F-09-005, 11 p., United States Environmental Protection Agency, New England. [online] Available from: http://www.epa.gov/region1/npdes/stormwater/assets/pdfs/IncorporatingLID.pdf

Walsh, C. J., Fletcher, T. D., & Burns, M. J. (2012). Urban stormwater runoff: a new class of environmental flow problem. *PLoS One*, *7*(9), e45814.

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP (2005) The urban stream syndrome: current knowledge and the search for a cure. J N Am Benthol Soc 24:706–723

Wang, G., Oldfield, F., Xia, D., Chen, F., Liu, X., & Zhang, W. (2012). Magnetic properties and correlation with heavy metals in urban street dust: a case study from the city of Lanzhou, China. *Atmospheric Environment*, *46*, 289-298.

Web Soil Survey, (2014) http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx Accesses January 25, 2014

Wong, T. H., Fletcher, T. D., Duncan, H. P., & Jenkins, G. A. (2006). Modelling urban stormwater treatment—A unified approach. Ecological Engineering, 27(1), 58-70.

Wong, C. I., Sharp, J. M., Hauwert, N., Landrum, J., & White, K. M. (2012). Impact of urban development on physical and chemical hydrogeology.Elements, 8(6), 429-434.

Wong, C. S., Li, X., & Thornton, I. (2006). Urban environmental geochemistry of trace metals. *Environmental Pollution*, *142*(1), 1-16.

Zar, J. H. (1984). Biostatistical Analysis. 1974 Prentice-Hall Englewood Cliffs.*NJ, chapt*, *7*, 79-96.

Zhang, C., Qiao, Q., Appel, E., & Huang, B. (2012). Discriminating sources of anthropogenic heavy metals in urban street dusts using magnetic and chemical methods. *Journal of Geochemical Exploration*, *119*, 60-75.

**Appendix A**

| **Magnetic Concentration (Evans and Heller, 2003)** | | | |
|---|---|---|---|
| **Parameter** | **Definition** | **Interpretation** | **Cautions** |
| Mass Susceptibility ($\chi$) | Susceptibility is a measure of how magnetizable a substance can become in the presence of a magnetic field and can be used in a general way to describe the various classes of magnetic materials.<br><br>Generally, non-magnetic materials are said para- or diamagnetic because they do not possess permanent magnetization without external magnetic field. Ferromagnetic, ferrimagnetic, or antiferromagnetic materials, which have positive susceptibility, possess permanent magnetization even without external magnetic field. | The larger the value, the more ferrimagnetic material present. | K and $\chi$ are measured in H so diamagnetic and paramagnetic materials contribute.<br><br>$\chi$ can often be better than K because $\chi$ considers changes down core sediment density<br><br>Small SPM particles will have a very high $\chi$. SSD, PSD and MD particles will have a significantly smaller $\chi$. |
| Volume Susceptibility (K) | The magnetization acquired per unit field (H)($\kappa$=M/H) – in SI units, it is dimensionless. | The larger the value, the more ferrimagnetic material present. | Whole core K is a running average Subsamples K is a point by point total |
| Anhysteretic remanent magnetization (ARM) | ARM is magnetization acquired by the combined effects of a large alternating field and a small DC field. | The larger the value, the more ferrimagnetic material present. | Preferentially responds to SD particles because, gram for gram, these acquire more remanence than particle containing domain walls that |

| | | | |
|---|---|---|---|
| | | | allow lower magnetostatic energy configurations to be achieved. |
| Saturation IRM (SIRM or $M_{rs}$) | Saturation Isothermal Remanence - denoted by $M_{rs}$<br><br>Remanence is the magnetization remaining in zero field after a large magnetic field is applied (enough to achieve saturation). | Affected more by SD particle size and magnetite.<br><br>The larger the value, the more ferrimagnetic material present. | Not effective for SPM particles because thermal energy randomizes these so much there is no $M_{rs}$.<br><br>Grain size will affect the outcome of the SIRM. |

| **Grain Size (Evans and Heller, 2003)** | | | |
|---|---|---|---|
| **Parameter** | **Definition** | **Interpretation** | **Cautions** |
| Frequency-dependent Susceptibility ($\chi_{fd}$) | The difference in susceptibility observed when the apparatus being used is driven at two different frequencies. | This is the difference in susceptibility observed when the apparatus being used is driven at two different frequencies. ($\chi_{lf}$ - low-field susceptibility, $\chi_{hf}$ - high-field susceptibility).<br><br>This method is useful for detecting the presence of very small, super paramagnetic particles. | |
| SIRM/$\chi$ | | The larger the value of the SIRM/$\chi$ ratio is, the more SSD and PSD that will be present (finer)<br><br>The smaller the | For SP particles SIRM will be low because they have no memory, but a large $\chi$ is present because SPM particles are easy to move around. |

| | | | |
|---|---|---|---|
| | | value of the SIRM/$\chi$ ratio is, the more MD that will be present (coarser) | This ratio is frequency dependent. |
| ARM/$\chi$ | | Large value number equals finer model grain size | Limitation, if SPM particles are present. The $\chi$ will be large no ARM will be present. |
| ARM/SIRM | | This ratio works because the ARM is more biased to the fine SSD and PSD grains.<br><br>A large number in the ratio means there are lots of SSD and PSD particles. | |
| Day Plot | | 1. Give the sample an SIRM<br>2. DC demagnetization in steps, measure after each step | |

| **Magnetic Mineralogy (Evans and Heller, 2003)** | | | |
|---|---|---|---|
| Parameter | Definition | Interpretation | Cautions |
| IRM Acquisition | The magnetization acquired by a sample after exposure to (and subsequent removal from) a preset magnetizing field, all at fixed temperature (usually, but not necessarily, room temperature) | Isothermal remanent magnetization is the remanence left in the sample after a steady field (1-1000 mT) has been applied for a short time (100 sec) and then switched off.<br><br>IRM acquisition is a useful technique to distinguish between magnetite and hematite.<br><br>1. Apply a high field | 1. Hard (high corecivity) remanence is part of the crystal structure<br>2. Soft (low corecivity) is dependent on domain walls, low energy barriers are moved in remence. |

| | | | |
|---|---|---|---|
| | | 2. All the moments go over their energy barriers<br>3. All the domain walls will go to the edge (MD) | |
| S-Ratio | The main purpose of the S-ratio is to provide a measure of the relative amounts of high-coercivity ("hard") remanence and low-coercivity ("soft") remanence. | $-1(IRM_{-300mT})/SIRM$<br>(All magnetite/all magnetite and all hematite)<br><br>The S-Ratio is a proportion.<br>1 = 100% magnetite/maghemite in a sample<br>0.9 = 50% magnetite/maghemite, 50% hematite/goethite<br>0.5 = almost all hematite/goethite | Cannot really get a hematite value.<br><br>Can never get the exact amount of the mineralogy of the sample. |
| HIRM | HIRM is a measurement of the amount of hard minerals present. | $SIRM + IRM_{-300mT} =$ HIRM<br><br>If HIRM = 0, then the sample is all magnetite<br>If HIRM is positive more hematite is present<br><br>HIRM= (all hematite + all magnetite) - (all magnetite) | HIRM can be problematic when the remanence carried by hematite/goethite is completely masked by a strongly magnetic background signal because the HIRM can have similar magnitude to the measurement errors. |
| Maher and Thompson | | This is a graph on a biplot of magnetic stability versus squareness. | |