The Effectiveness of Implementing a Rain Garden and Permeable Pavement as a Stormwater Treatment

By

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An Undergraduate Thesis

Submitted in Partial Fulfillment for the Requirements of Bachelor of Arts

In

Environmental Science

Carthage College

Kenosha, WI

Abstract:

Stormwater pollution is a huge problem throughout the world. Many people do not understand that stormwater has a huge effect on our lives. Untreated stormwater affects public health, aquatic life, water quality, flooding, and much more. In order to decrease the stormwater runoff and pollution, a stormwater treatment must be implemented. Two beneficial stormwater treatments are rain gardens and permeable pavement. The data was obtained from outside sources. In order to support the hypothesis, raw data was collected from a study done on permeable pavement, and rain gardens, and raw data was obtained from an area with no stormwater treatment. Both rain gardens and permeable pavement showed to have higher hydraulic conductivity rates compared to an area of no stormwater treatment. Statistical analysis also supported the idea that specific pollutants, such as chloride, copper, and lead, decrease in concentration for both the rain garden and the permeable pavement. It is concluded that implementing a rain garden or permeable pavement as a stormwater treatment will decrease the amount of stormwater runoff and decrease specific pollutant concentrations found in stormwater.

Introduction:

The world population has reached over 7 billion people and keeps rising everyday (Census Bureau). With the increase in population comes an increase in urbanization; more houses, more roads, more farms, more pesticides, more factories, etc. Increased urbanization leads to many problems, and one of the biggest issues that correlates with the increase urbanization is the increase in stormwater runoff. Impervious surfaces are one of the primary reasons for the increase in stormwater runoff because of its inability to filter water, which then collects pollutants from the surfaces and turns the stormwater into pollution. These surfaces turn rainwater into a problem because of the amount of pollutants it collects and no place for the water to be captured/or filtered. Runoff is the drainage of freely moving rainwater from the surface such as land, a building and/or a structure (Washington State Department of Ecology). Runoff impacts both the water quality and the water quantity. Problems that are associated with stormwater runoff are the increase in erosion, flooding, and the lowering groundwater infiltration (Census Bureau). Some other problems that are associated with stormwater runoff causes is the increase in nutrients, sediments, pathogens, organic materials, toxic contaminants, debris, freshwater impacts, and thermal stress. The increase in all of these affects the aquatic ecosystem and also threatens our public health. The increase in urbanization causes increase in stormwater runoff and pollutants that are being placed into rivers, lakes, streams, and oceans (Victoria, 1999).

The Environmental Protection Agency (EPA) has done multiple studies over stormwater and found that urban stormwater runoff affects water quality, water quantity, habitat and biological resources, and aesthetic appearance of nearest waterways (US EPA, et 1998). The increase in impervious surfaces such as roads, parking lots, driveways, and buildings are the main factors that contribute to a high stormwater runoff. The high proportion of impervious areas reduces the amount of water infiltrating the soil and this causes the rainfall to be converted into runoff, carrying along with it any pollutants it collects on the surface. The increased surface water flow causes flooding and in order to prevent this in cities, underground pipes are often used to redirect runoff and is then discharged into the nearest water source without going through a cleaning process like water from a sink drain. Since the runoff is not cleaned before discharge, the pollutants are carried and picked up by the stormwater runoff and then deposited into a near by water source such as a lake without any filtration. A study in Santa Monica Bay, California tested to see if stormwater runoff had an effect on public health. It was found that 50% of the people who swam in front of the stormwater drainage pipe developed symptoms such as earaches, sinus problems, diarrhea, fever, and rashes (Torresan, Laura). Those who swam 400 yards away from the stormwater drainage pipe developed no symptoms. Stormwater not only has an effect on the environment, but also on public health. A stormwater treatment needs to be put into place in order to decrease the problems associated with stormwater runoff. Rain gardens and permeable pavement are two stormwater treatments that contribute to the decrease in runoff and the pollutants within the stormwater.

Effects of Implementing a Rain Garden as a Stormwater Treatment

Rain gardens are a man made garden that utilizes natural components such as soil and plants to filter the stormwater within it. Rain gardens are made to work with nature, not against it. Rain gardens are made up of five components, an inlet, a berm, a slope, a basin, and an outlet (Figure 1). The inlet is the location where the stormwater is collected from a storm drainage pipe. Once the inlet captures the stormwater, it then allows the stormwater to be passed over to the berm portion of the rain garden. Plants that can tolerate dry soil conditions are placed in the berm because it is located near the top edges of the rain garden (Cullison). After the stormwater passes through the berm it then hits the slope. The slope is made up of plants that can handle both dry and wet soil conditions. The basin is the next area that the stormwater passes through. The basin is located at the bottom of the rain garden. Plants located in the basin need to be tolerable of wet environments because this is where the stormwater will be the longest. Table 1 is a list of appropriate plants for each rain garden component for the state of Wisconsin. Thirty hours after a rain event (or snow melt) the majority of the stormwater is going to be filtered by the soil and plants within the rain garden. If the rain event is too big for the rain garden then the outlet is there to help with the overflow of stormwater (Cullison).

Table 1: Indicates which Wisconsin native plants that are the best choice for each of the five components of the rain garden. For more information refer to the rain garden manual produced by the Wisconsin Department of Natural Resources (WDNR).

	Scientific Name	**Common Name**
Inlet	Acores calamus and Ins virginca-shiren	Sweet flag and Wild blue flag
Berm	Mertensia virginica and Campanula amencana	Virginal bluebells and Tall bellflower
Slope	Carex Grays	Bur sedge
Basin	Mertensia virginca and Carex lupulina	Virginal bluebells and hop sedge
Outlet	Onoclea serebus	Fern

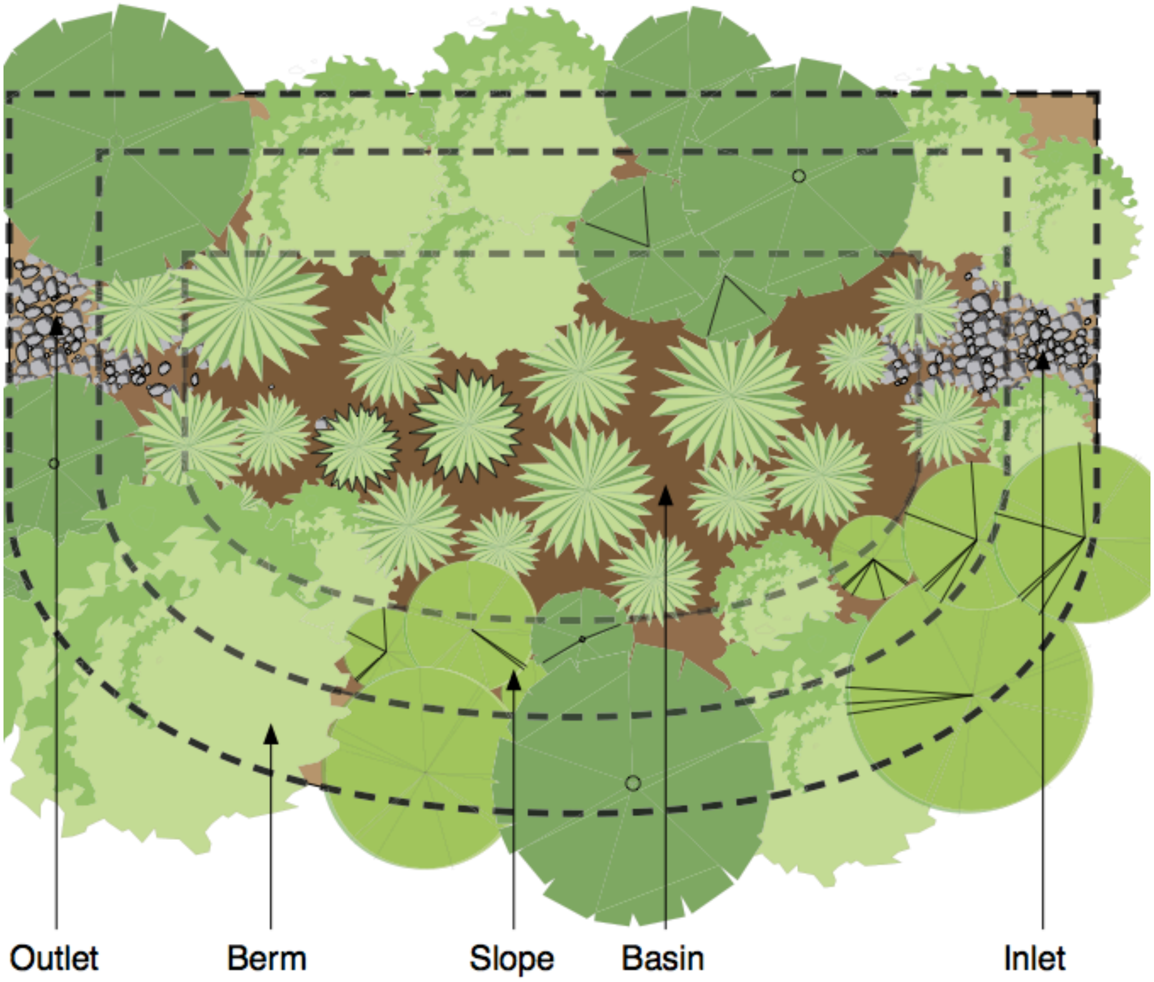

Figure 1: This is typical design for a rain garden (huihawaii.org).

In order to have a successful rain garden, the five components must follow the Best Management Plan (BMP) implemented by the Environmental Protection Agency (EPA). The BMP is a guideline on how to properly construct a rain garden. The BMP states that the recommended side slope of a successful rain garden is 3:1 or 2:1 (in area where spaces are limited). Other recommendations are that one selects native vegetation that is tolerant of varying water conditions. Plant depth should be at least 24 inches for herbaceous plants. The soil within the rain garden recommended by the EPA should be a loam, loam/sand mix or sandy loam capable of supporting vegetation, but still allowing for the stormwater to be filtered. Mulch must also be added to reduce the risk of weeds taking over (Dauphin County

Conservation District). Maintenance also falls into the BMP guidelines for having a successful rain garden. Weeding will need to be done at least twice a month for three years until the native grasses, sedges, and wildflowers that were placed in the rain garden fully mature and can out compete the weeds (WDNR). The BMP guidelines should be followed when constructing a rain garden so that the rain garden can be as efficient as possible on decreasing stormwater runoff and pollutant concentrations.

The benefits of implementing rain gardens as a stormwater treatment are that they filter runoff pollution, recharge local groundwater, conserve water, improve water quality, protect rivers and streams, remove standing water in your yard, reduce mosquito breeding, increase beneficial insects that eliminate pest insects, reduce potential of home flooding, and creates a habitat for wildlife (Rain Garden Network). Rain gardens are able to provide all of these benefits because of the plants and soil within in it. The plants use the bacteria on its roots and its natural biological cycle to clean the water and get rid of pollutants within the stormwater. The soil is also able to absorb most of the water, which allows rain gardens to have high infiltration rates.

Michael E. Dietz did a study that tested the amount of nutrients in stormwater that is retained using a rain garden. The nutrient retention percentage was determined by using tipping buckets and electronic counters to test flow measurements. Dietz also took a weekly passive sampling of bulk deposits, roof runoff, under drains and overflow of the stormwater and soil around the rain garden. Dietz found a retention percentage of nitrate, ammonia, total nitrogen, and total phosphorus within the rain garden (Dietz et. 2005). He found that nitrate had a percent retention of 67%, ammonia was 82%, total nitrogen was 26%, and found a negative percent retention for total phosphorus of -108%. These retention percentages support the idea that rain gardens do reduce pollutant concentrations within the stormwater (Dietz et. 2005). Dietz also found a percent change in the soil of the rain garden. He found a decrease percent change for nitrogen (-18%), phosphorus (-31%), copper (-12%), lead (-24%), and zinc (-43) (Diets et. 2005).

The decrease in percentages of the following elements also provides some evidence supporting the benefits of a rain garden towards the break up of pollutants in stormwater.

Plant affects on Water Pollution

Rain gardens are so successful because of the plants and soil that make up the rain garden. The soil captures the stormwater and the plants absorb and filter it. The inlet component of the rain garden serves as a buffer strip because this part is absorbing the stormwater, retaining the nutrients, and slowing the movement of the stormwater. The movement of stormwater decreases physically because of the amount of vegetation present in this location. Nitrogen is one of the nutrients that is being removed through a variation of mechanisms within the rain garden (Hickey and Doran et. 2004). One way nitrogen can be removed is by uptake into growing plants in the rain garden or, the second way, by microorganisms on the plant roots that convert the nitrogen-to-nitrogen gas. The denitrifying bacterium on plant roots are called Bacillus, Chromobacter, Pseudomonas, and Spirillium (Sinha and Singh, et 2010). Nitrate (NO_3) is an example of a chemical found in stormwater runoff/pollution. Nitrate comes from agriculture, pesticides, livestock, and gold course (Sinha and Singh, et 2010). Nitrate is removed by the plant mechanisms of converting it into gas.

In contrast to nitrogen, phosphorus has no mechanism to remove it to the atmosphere (Hickey and Doran, et. 2004). Phosphorus is found in agricultural runoff and can be removed by the soil particles, sedimentation, or through uptake of growing plants (Hickey and Doran, et. 2004). The uptake of phosphorus may be limited, but the phosphorus can be removed from both surface water and shallow groundwater through the vegetation placed in the rain garden.

Along with nutrients in stormwater there are also metals and radioactive nuclide. This can come from factories, houses, cars, and more. Rhizo-filtration is a bacterium located on plant roots within the rain garden that can remove these metals and radioactive nuclide from the stormwater pollution (Sinha and Singh, et

2010). This mechanism uses the plants aerial organs to obtain contaminants, such as mercury, which is released through the leaves and into the atmosphere as a gas (Sing and Singh, et. 2010).

Case Studies: Rain Gardens

In 2002, a group of engineers and landscape architects in Burnsville, Minnesota were granted money to find a solution to decrease the amount of runoff going into Crystal Lake. Rain gardens were found to be the best solution because it was the least cost efficient compared to the other choice of implementing a bioswale. There were 17 rain gardens, which varied in different sizes, all located in a 20-year old neighborhood in Burnsville. The "sister" neighborhood of Burnsville was used as the control and no rain gardens were placed here. Runoff data was first collected before the installation of rain gardens by installing gauges, which measured how much runoff poured into Crystal Lake from each neighborhood. These gauges would later show how less stormwater was entering the lake, indicating that the rain gardens are decreasing the quantity of stormwater runoff (Barr Engineering et. 2002). After this data was collected, a group of engineers and land architects constructed the rain gardens following the Best Management Practice manual. Once all 17 rain gardens were in placed it was found that the runoff entering Crystal Lake from the neighborhood dropped drastically. Burnsville contributed to 90 percent less runoff going into the lake than the control "sister" neighborhood. The decrease in runoff volume means less chemicals and metals are being released into the lake, which is shown by the reduction in the lakes volume. This decrease will help preserve aquatic populations and the water clarity. Just like in Burnsville, Minnesota, Cuba Street, Wellington also tested rain garden affects on nearby water sources and found that aquatic ecosystems were becoming healthier when rain gardens were put into place because the rain garden caused a reduction of stormwater running off into the nearest water source (Wood, Nicci et 2012). To this day, data from Burnsville, Minnesota is still being collected/analyzed.

The U.S. Geological Survey in the metropolitan council of the Twin Cities conducted by Lan H. Tornes did a study in 2002 that tested the effects of rain gardens on water quality. Five rain gardens were tested in the Minneapolis-St. Paul metropolitan area. All five of the rain gardens selected for the study provided a large range in geomorphic, climate, and engineering designs (Tornes, 2002). This study tested the water quality flowing into and out of rain gardens following runoff events. In order to check the inflow and outflow of the stormwater runoff the installation of inflow and overflow samplers, two ground-water observation wells located beneath the water table, and two soil-moisture lysimeters located in the unsaturated zone were installed at five rain gardens within the Twin Cities area (Tornes, 2002). Not only was the inflow collected for data, but the pH, solid residue, chloride, nitrogen, and phosphorus were also analyzed within the inflow compared to the outflow. The USGS found that the topographic location does have an effect of the effectiveness of rain gardens. A good topographic location for a rain garden is dependent on the texture and hydraulic conductivity of soils and unconsolidated glacial deposits that underlie the sites (Tornes, 2002). It can be concluded from this study and Dietz study that the best soil for a rain garden is 70% sand and 10% clay and the rest silt. It was also found that rain gardens with this sand-silt-clay ratio had a great influence on the high infiltration rates while still allowing plants to be stable.

The USGS also did a chemical aspect to the previous study in the Twin Cites rain gardens. The results of the chemical constituents and nutrient species of water showed a variety of results in all five of the rain gardens (Tornes, 2002). The total phosphorus showed a decline in three of the five rain gardens and an increase in the other two. The increase in phosphorus may be due to the plants excreting the phosphorus. There was also a decrease in total nitrogen in four of the five rain gardens. The one rain garden that did not have a decrease in nitrogen was one of the two that had an increase in phosphorus. The increase in nitrogen and phosphorus for this rain garden may be due to an error in the construction of the rain garden (Tornes, 2002). The decrease in chemical constituents and physical properties show that rain gardens do have an effect on the water quality of runoff and this is shown by the USGS study and the study by Michael Dietz. Implementing a rain garden can provide benefits for improving the quality of lakes, streams, and rivers near the rain gardens.

Effects of Implementing Permeable Pavement on Stormwater Runoff

The second stormwater treatment that can reduce stormwater volume and pollution is permeable pavement. While rain gardens focus on landscapes this stormwater treatment focuses on a substitution for impervious pavements. Permeable pavement is a great substitute for asphalt and concrete when making roads, parking lots, or driveways. Runoff is not only a problem for landscapes, but also a huge problem on streets, in parking lots, sidewalks, and driveways. Impervious surfaces such as roads (95% imperviousness), parking lots (90% imperviousness), and rooftops (90% imperviousness) prevent stormwater and snowmelt from infiltrating into the ground (*Charles River Watershed Association*). This causes most stormwater and snowmelt to remain above the surface and to have unnaturally large amounts of runoff (*Charles River Watershed Association*). The increase in urbanization leads to more roads and parking lots, which leads to the increase of sediments, oil, grease, toxic chemicals from vehicles, pesticides, nutrients from lawns and gardens, bacteria, viruses and nutrients from pet waste and failing septic systems, road salts, and heavy metals from roof shingles and vehicles (*Charles River Watershed Association*). Pervious pavement is a stormwater treatment option that can decrease these pollutant problems. Pervious pavement, or porous asphalt, has many environmental benefits such as green infrastructure, low impact development programs and high infiltration rates (*Charles River Watershed Association*).

Pervious pavement is designed to filter the stormwater through the ground rather than having the water sit on top. "Permeable paving systems allow water to rapidly pass through wider joints and filter through a deeper base of aggregate. Contaminants are contained and excess water is absorbed into the sub grade below the pavement (Virginia DCR)." This stormwater treatment eliminates runoff immediately by filtering 270in to 470in of stormwater per hour (Virginia DCR).

The design of permeable pavement is the most crucial part of eliminating the stormwater runoff. There are six components that produce a successful permeable pavement: the choke course, open-graded base reservoir, open-graded subbase reservoir, under drain, geotextile, and subgrade (Figure 2) (EPA-Stormwater Menus). The choke course is a permeable layer between one to two inches thick and provides a level and a stabilized bed surface for the porous asphalt. This consists of small-sized, open-graded aggregate (EPA-Stormwater Menu). The next layer is the open-graded base reservoir. Open-graded base reservoir is an aggregated layer that is beneath the choke layer. The base reservoir is between three to four inches think and consists of crushed stones about 3/4 to 3/16 inches big. This layer not only stores water, but it also has a high infiltration rate and provides transition between the bedding and subbase layers (EPA-Stormwater Menu). The third part of pervious pavements is the open-graded subbase reservoir. This consists of stone sizes larger than the base, usually around ¾ and 2 ½ inch stones. Like the open-graded base layer, this layer also stores water between the spaces of the stones. The underdrain is the next layer (optional layer). This layer provides additional storage beyond the stone base. This layer uses pipes to move the stormwater to different locations so the storage volume can be greater (EPA-Stormwater Menu). The fifth layer is the geotextile. This is used to separate the subbase from the subgrade and prevent the movement of soil into the subbase and base. The last layer that makes up a successful pervious pavement is the subgrade. This is a layer of soil and is located beneath the aggregate base or subbase. This layer filters the stormwater coming through using soil. The soil is able to absorb the pollutants and take them out before the stormwater is released back into the environment (EPA-Stormwater Menu).

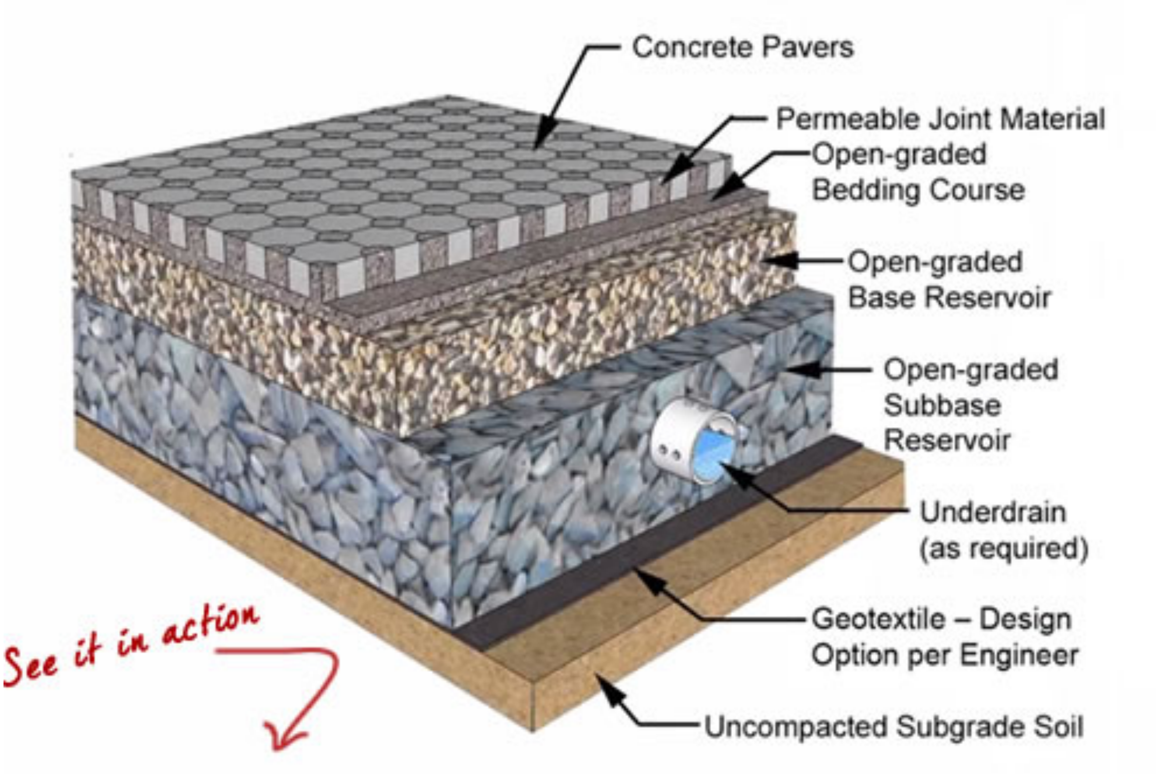

Figure 2: Shows the layers and the location of each of the layers that consists of permeable pavements (masseolandscape.com).

There are multiple benefits of having permeable pavement such as less runoff, replenished groundwater levels, and tax savings. When permeable pavement is being used the stormwater is filtered through the ground whereas the areas with impervious pavement the stormwater sits on top collecting pollutants. Permeable pavement is able to reduce polluted runoff from stormwater, and minimizes impacts on existing storm sewer systems through reduce peak discharges (EPA-Stormwater Menu). Permeable pavement also replenishes and recharges groundwater. Groundwater recharge is when water moves downward from the surface water to the ground water. Plants or anthropogenic technology, such as permeable pavement, can recharge groundwater. Groundwater recharge is good because it helps spread nutrients throughout all zones of the soil rather than accumulate in just the root zone.

Case Studies: Permeable Pavement

Permeable pavement is a great solution to treat stormwater pollution because it has many benefits. Some benefits of permeable pavement is that it decreases the stormwater volume and is also very durable. A study conducted in Massachusetts by the Water Resources Commission (WRC) tested whether permeable pavement still had these same benefits after 4 years. This project was to see if the Massachusetts WRC could improve the water quality of Silver Lake, Massachusetts. The idea was to install Low Impact Development (LID) practices to better improve the stormwater going into the Silver Lake watershed. The idea was to improve a parking lot near the Lake so less runoff would go into the Lake. Permeable pavement was the solution to better retain the stormwater. Both porous pavers and porous asphalt were installed in the parking lot to replace the asphalt that was currently in the Silver Lake Town Beach lot. The purpose of installing two different types of permeable pavement was to showcase which porous pavement worked better or if there were no major differences. The U.S. Geological Survey (USGS) evaluated the benefits of the porous pavement. The USGS analyzed samples from monitoring wells installed beneath the parking lot. Infiltration was the main test of this case study. The USGS found that both permeable pavement designs filtered the stormwater and reduced the amount of stormwater being released into the Lake. It was found that immediately after construction the porous pavement filtered 170 to 500+ inches of stormwater per hour. This is a lot compared to having asphalt, which does not filter the water. After 3 to 4 years it was found that 40 inches of water were being filtered. This number may seem small, but after 4 years of wear and tare the permeable pavement still functions properly. This lower number may suggest that more maintenance needed to be done throughout the 4 years. Maintenance is very important and needs to be done weekly in order to keep the permeable pavement up to date. Weekly maintenance means spending five to ten minutes every other day pulling weeds within the cracks and checking for big significant holes. In a study done in North Carolina, Maryland, Virginia, and Delaware; fourteen permeable pavement systems were put into place. It was found that permeable pavement installed in sand soil environments had high infiltration rates, no mater how old the pavement was and the type of permeable pavement. In order to maintain the permeable pavement so that it does not drop from 150 in. per hour to 40 in. per hour is to make sure that the soil is mostly sandy. These cases indicate the importance of maintenance, type of soil and show the durability of permeable pavement when implemented correctly.

Cost/Benefit Analysis:

The cost of implementing permeable pavement is $7.00 to $15.00 (Virginia DCR, 2011) per square foot and putting in a rain garden cost $5.00-$10.00 per square foot (Barr Engineering Company, 2002). Asphalt is cheaper than permeable pavement and rain gardens. The cost of implementing asphalt is $2.50 to $4.00 (Torresan, Laura). The cost of constructing permeable pavement and a rain garden is higher than constructing asphalt, but the lifespan of permeable pavement and rain gardens is much longer than asphalt. Asphalt has a life span of about 15 years, whereas rain gardens have a lifespan of 20 years, when maintained (Rain Garden Network) and permeable pavement has a lifespan of 30 years, when maintained (EPA-Stormwater Menu of BMPs). The initial cost of the two-stormwater treatments is higher than the impervious asphalt, but the lifespan of the stormwater treatments is much longer. In the long run, rain gardens and permeable pavement are the cheaper options.

Approach:

A successful stormwater treatment can decrease the amount of runoff and decrease the concentration levels of pollutants within the stormwater. The hypothesis is, if a rain garden and permeable pavement are used a stormwater treatment then there will be a decrease in the quantity of runoff and a decrease in pollutant concentrations within the stormwater. Raw data will be obtained for rain gardens, permeable pavement, and an area with no stormwater treatment (just asphalt). Once the raw data is collected and analyzed the hypothesis will either be accepted or rejected.

Procedure:

In order to support the hypothesis, raw data was obtained and evaluated for an area with no stormwater treatment, an area with permeable pavement, and an area with rain gardens. These areas were chosen to represent an area where rain gardens are present, an area where permeable pavement is present, and an area where neither a rain garden nor permeable pavement present. Although the data was collected from three different reports, the concentrations and conductivity rates were all in the same units allowing for data to be analyzed together.

Jeffery Weiss and Miki Hondzo did a study titled, "Laboratory Measurements of Stormwater Quality Improvement in Detention Ponds". This study was done throughout the state of Minnesota by the Department of Transportation and conducted by Weiss and Hondzo. Weiss and Hondzo showed the average concentration of all pollutants found in stormwater runoff on highways. The raw data that was evaluated from this study represented the "area with no stormwater treatment" because the area consisted of impervious pavement (asphalt) and did not consist of a rain garden or permeable pavement.

Derek Booth from the University of Washington supplied the raw data for permeable pavement from his 2003 study titled, "Long-term stormwater quantity and quality performance of permeable pavement systems." The hydraulic conductivity rate (infiltration) and the pollutant concentrations were all obtained from this study. Booth tested four permeable pavements and one impervious pavement (asphalt) in the Washington state area. Water quality and conductivity rates were tested once a month for an entire year. Pipes were used to collect the surface runoff and the subsurface infiltrate (Booth, 2003). Tipping-bucket gauges for each of the permeable pavements and the asphalt were used to collect the water and measure the rainfall. Water quality samples were then analyzed by the Aquatic Research, Inc in Seattle, WA, USA (Booth, 2003).

Rain garden data was obtained through the Stormwater Network that supplied data for three rain gardens in Hugo, Minnesota. Each of the rain gardens were tested for pollutant concentration and the hydraulic conductivity rate three times throughout one year. All three of the rain gardens follow the BMP set by the EPA. Data was collected from the rain gardens by inflow and overflow samplers, two-ground-water observation wells located below the water table, and two soil-moisture lysimeters were installed in the unsaturated zone for each of the rain gardens (Tornes, 2002).

Data Analysis:

Excel was used to analyze the raw data that was obtained. The analysis of the data is represented in line graphs and bar graphs. A line graph was used to show the conductivity rate as time changes. The line graph shows if there is any decrease/increase in conductivity as time increase. Also this type of graph indicates whether the stormwater treatment has a higher conductivity rate than an area with no stormwater treatment (asphalt). Bar graphs were also used to compare the concentrations of pollutants for both stormwater treatments and an area with no stormwater treatment (asphalt). The bar graphs are represented as the mean concentration throughout the first year of the study. Excel was also used to compare the concentrations of specific pollutant of permeable pavement versus an area with no stormwater treatment using the ANOVA-Single Factor feature. The same was done with pollutant concentrations in rain gardens versus an area of no stormwater treatment.

Results:

The general patterns found in the evaluation of the raw data for both rain gardens and permeable pavement is that the two treatments show lower concentrations of specific pollutants compared to asphalt (Table 2).

Table 2: Nationwide mean concentration of pollutants found on highways (Weiss and Hondzo, 2004).

Pollutant	**No Stormwater Treatment (nationwide standard concentration)**	**Rain Garden**	**Permeable Pavement**
Total Phosphorous (mg/L)	0.48	0.1	n/d
Nitrate+Nitrate (mg/L)	0.79	0.94	n/d
Chloride (mg/L)	33	16.8	n/d
Total Copper (mg/L)	0.0527	n/d	0.016
Total Lead (mg/L)	0.254	n/d	0.001
Total Zinc (mg/L)	0.923	n/d	0.023

*No Data found is represented as (n/d)

Permeable Pavement:

Figure 3 shows the concentration of specific pollutants analyzed in an area with asphalt (no stormwater treatment) and an area with permeable pavement. The figure shows that for motor oil, zinc (Zn), and copper (Cu) all have higher concentrations in the area with the asphalt compared to the area with the permeable pavement. The motor oil concentration in the area with asphalt is 0.164mg/L. This concentration more than triples the motor oil concentration found in permeable pavement with a concentration of 0.05mg/L. Cu and Zn also show higher concentration values in the asphalt with values of 0.0160mg/L (Cu) and 0.0229mg/L (Zn) compared the concentrations found in permeable pavement, 0.00298mg/L (Cu) and 0.0116 (Zn). Lead (Pb) and Diesel displayed no difference in concentrations between asphalt and permeable pavement.

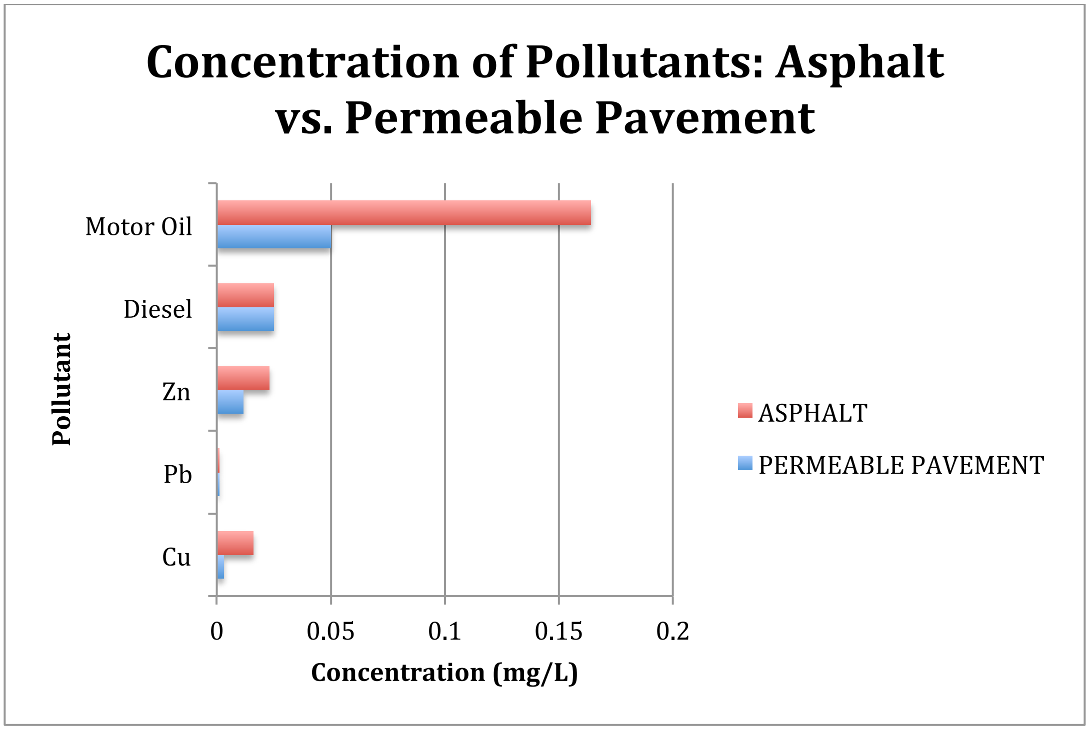

Figure 3: Concentrations of a specific pollutants found in stormwater between asphalt (non stormwater treatment) and permeable pavement (Booth, 2003 and Weiss & Hondzo, 2004).

The infiltration (conductivity) of permeable pavement is shown in Figure 4. Four different types of permeable pavement were compared to asphalt. The four permeable pavements that were analyzed all followed the BMP rules set by the EPA for the construction of permeable pavement. These four permeable pavements were constructed by the same company, but the only thing that differs the four permeable pavements from one another are the materials that make up the pervious surface. The four different permeable pavements were all used in the evaluation rather than just one type was to show that there are multiple different permeable pavements out there and that they still showed higher infiltration rates compared to the asphalt. Turfstone and Uni Eco Stone had average concentrations of 114.33umhos/cm and 113.89umhos/cm. These two permeable pavements had the highest infiltration rates of the four permeable pavements and more than 100% increase in the infiltration rate compared to the asphalt area, which had a concentration of 14.10umhos/cm. The average infiltration rate of all four permeable pavements is 78.57umhos/cm. The higher infiltration rate of the four permeable pavements compared to the asphalt infiltration rate represent that permeable pavement is able to decrease the amount of stormwater runoff much faster than an area with asphalt.

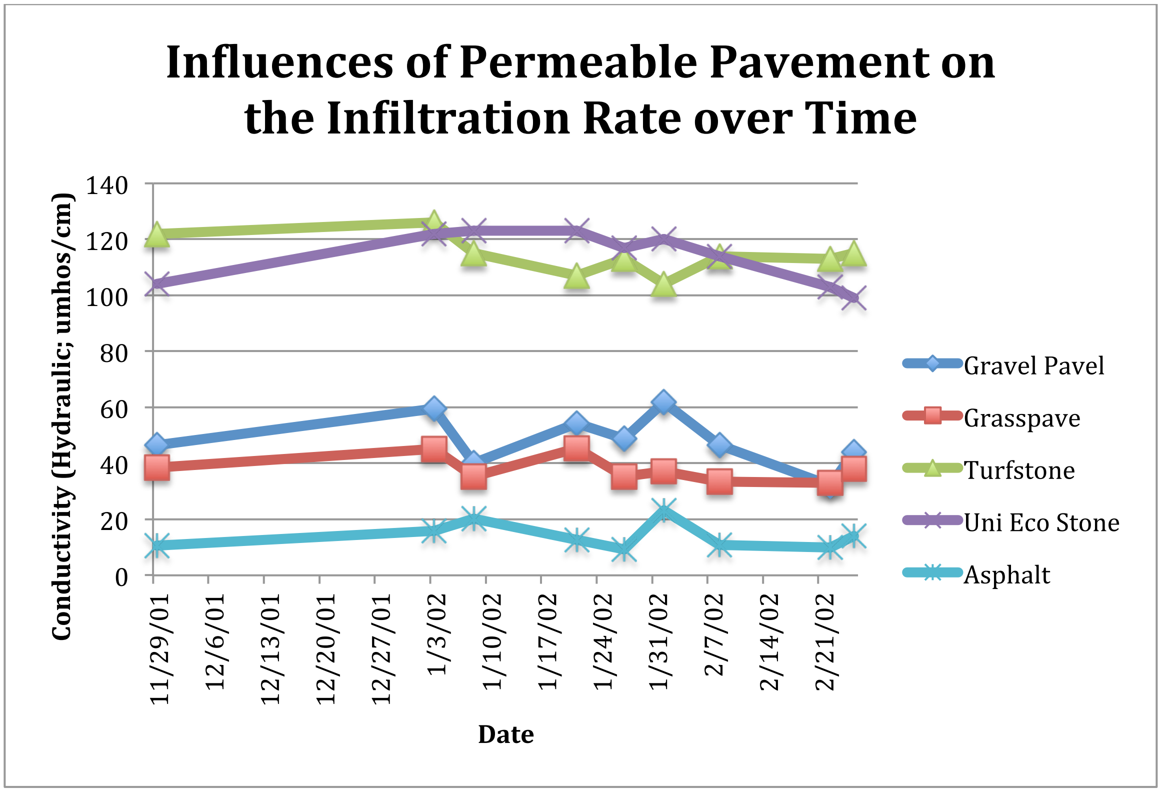

Figure 4: Infiltration rate of four different types of permeable pavement and one impervious pavement (asphalt) over a length of six months. Raw data was obtained from David Booths study "Long-term stormwater quantity and quality performance of permeable pavement systems."

Table 3: The mean concentrations of three pollutants found in stormwater treatment found in permeable pavement and asphalt.

Pollutant	**No Stormwater Treatment (nationwide standard concentration)**	**Permeable Pavement**
Total Copper (mg/L)	0.0527	0.016
Total Lead (mg/L)	0.254	0.001
Total Zinc (mg/L)	0.923	0.023

*Raw Data obtained from Weiss and Hondzo (2003) study and Booths (2003) study.

The p-value compares the average concentration of a specific pollutant found in asphalt to the average concentration of that same pollutant found in permeable pavement (Table 4). For copper, this value shows the statistical difference in the average concentration of copper in asphalt to the average concentration of copper in permeable pavement. The p-value for copper is 0.0465. This number shows statistical significance between the two copper values indicating that the two concentration values are not closely related because the value is less than 0.05. Lead indicates a statistically highly significant value of 0.000205, which strongly supports the hypothesis. Unlike lead and copper, zinc shows a p-value of 0.135. The higher p-value of zinc indicates no statistically significant of a decrease in concentration between permeable pavement and impervious pavement for this specific pollutant.

Table 4: P-values determined using ANOVA between each of the three pollutants found in permeable pavement to an area of no stormwater treatment.

PERMEABLE PAVEMENT	
Pollutant	**P-Value**
Copper	0.0465
Lead	0.000205
Zinc	0.135

<u>Rain Gardens:</u>

The infiltration rates of the three rain gardens evaluated in the Tornes study all showed higher infiltrations rates compared to an area with no rain gardens (asphalt) (Figure 5). The third rain garden had the highest average infiltration rate of 305.33umhos/cm of the three rain gardens. The average infiltration rate of the three rain gardens is 188.11umhos/cm compared to the asphalt area, which had an infiltration rate of 18.96umhos/cm. The asphalt shows a consistent infiltration rate throughout the eight-month study, whereas the rain gardens gradually increased throughout the study. This trend shows that as time passes the infiltration rate of the rain gardens improves.

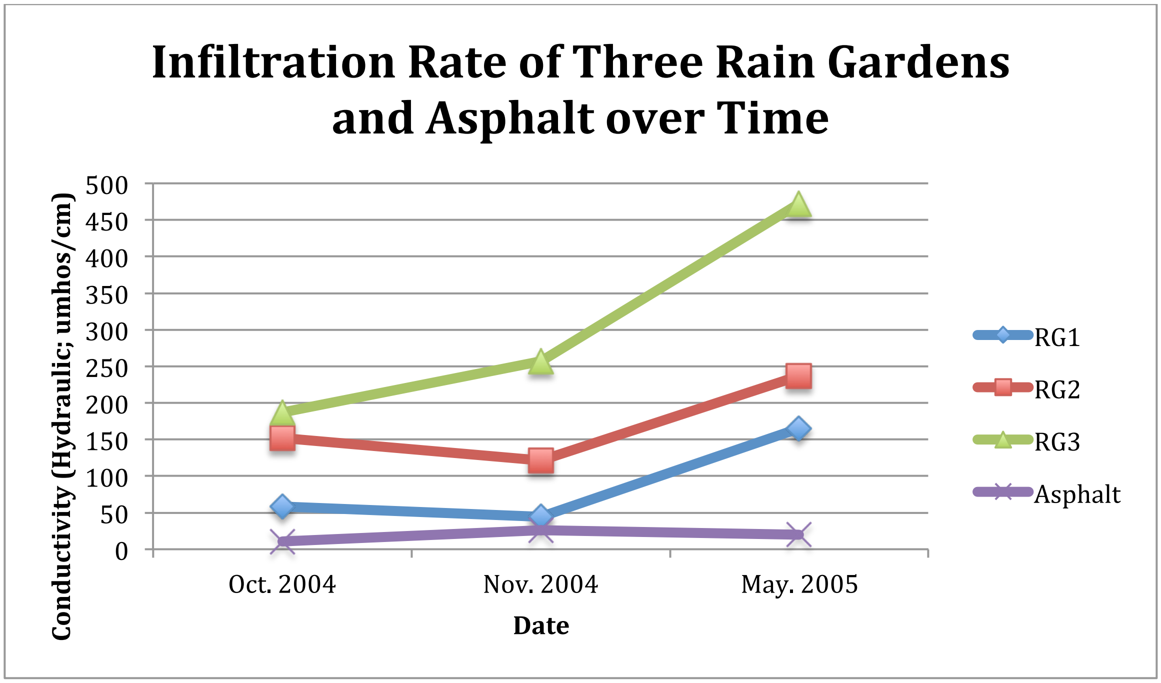

Figure 5: Infiltration rate of three rain gardens and asphalt over an eight-month study (Tornes, 2002).

Table 5: Mean concentrations of the pollutants; nitrate/nitrite, phosphorous, and chloride located in the rain garden study compared to an area with no stormwater treatment.

Pollutant	**No Stormwater Treatment (nationwide standard concentration)**	**Rain Garden**
Total Phosphorous (mg/L)	0.48	0.1
Nitrate+Nitrate (mg/L)	0.79	0.94
Chloride (mg/L)	33	16.8

*Raw Data obtained by Weiss and Hondzo (2004) study and Tornes (2002) study.

The p-values were found for specific pollutant concentrations in rain gardens compared to an area where there was no stormwater treatment (Table 6). The average concentration of phosphorous in rain gardens was compared to the average concentration of phosphorous in asphalt (no stormwater treatment). The p-value for phosphorous is 0.0045, which represents a statistically significance between the concentration of phosphorous found in rain gardens compared to the concentration of phosphorous found in asphalt. Since the value is below 0.05 it shows that these two concentration values of phosphorous are not close to one another, representing that rain gardens do have an impact on the decline of phosphorous concentrations. The p-value for nitrate/nitrite and chloride show no statistical significance.

Table 6: P-values of the pollutants found in the rain gardens analyzed compared to an area of no stormwater treatment.

RAIN GARDEN	
Pollutant	**P-Value**
Phosphorous	0.00451
Nitrate/Nitrite	0.737
Chloride	0.0716

The p-value was also found for the infiltration rates of the rain gardens and the permeable pavement (Table 7). The p-value was determined by comparing the average infiltration rate of the rain gardens to the average infiltration rate of the area with no stormwater treatment (asphalt). The p-value of the infiltration rates shows whether or not the average infiltration rate evaluated for the rain gardens relates to the average infiltration rates evaluated for the area of no stormwater treatment. The infiltration p-value for permeable pavement is also statistically significant with a value less than 0.05 (Table 7).

Table 7: P-values determined for the infiltration rates of permeable pavement and rain gardens versus an area of no stormwater treatment.

Stormwater Treatment	**P-Value**
Rain Garden	0.031
Permeable Pavement	6.75x10-15

Discussion:

The goal of this study was to determine if implementing a rain garden or permeable pavement as a stormwater treatment would decrease the concentration of pollutants in stormwater and decrease the amount of runoff. These two stormwater treatments were compared to areas with no stormwater treatment to help determine if any data supports the idea that permeable pavement and rain gardens can be successful stormwater treatments. The regression model of infiltration rates of permeable pavement and rain gardens do support the second part of the hypothesis stating that these two treatments can of decrease the amount of runoff because both of these stormwater treatments have higher hydraulic conductivity rates compared to an area of no stormwater treatment (Figure 4 and Figure 5). The p-value for both permeable pavement ($6.75x10^{-15}$) and rain gardens (0.0310) is below 0.05 indicating statistical support towards the hypothesis (Table 7). The decrease in specific pollutants such as lead, copper, and phosphorous show statistically significant data supporting the hypothesis that permeable pavement and rain gardens decrease the concentration of specific pollutants. The p-values of lead (0.000205), copper (0.0465), and phosphorous (0.00451) provide statistically support towards the hypothesis (Table 4 and Table 6).

Infiltration rate:

The purpose of this study was to determine whether or not implementing a stormwater treatment, such as a rain garden and permeable pavement, would be beneficial compared to having not stormwater treatment. Hydraulic conductivity (infiltration) was the first factor looked at for this study. The prediction of implementing a rain garden and permeable pavement as effective stormwater treatments for decreasing the amount of runoff is supported by the results. Both permeable pavement and rain gardens show a higher mean conductivity than an area with no stormwater treatment (Figure 4 and Figure 5). In order to have a successful stormwater treatment the conductivity flow rate should be higher compared to an area with not treatment. This means that more runoff is being filtered through each of the treatments. Figure 4 shows the conductivity of four different types of permeable pavement and one impervious pavement (asphalt). All four permeable pavements present higher conductivity rates compared to asphalt. Although asphalt maintained consistency, after one year all four permeable pavements still had a higher conductivity rate. The p-value obtained for the infiltration rate of permeable pavement compared to an area of no stormwater treatment was $6.75x10^{=15}$ (Table 7). This indicates very high statistical significance towards the hypothesis. Supporting the idea that permeable pavement decreases the amount of stormwater runoff.

All three of the rain gardens also showed a higher conductivity flow rate than asphalt (Figure 5). All three of the rain gardens that were analyzed showed an initial hydraulic conductivity higher than asphalt. As time increased, the conductivity rate of the rain gardens became even higher compared to the asphalt, which did not change. The p-value comparing the infiltration rate of rain gardens to an area of no stormwater treatment is 0.0310 (Table 7). This value represents statistical significance towards the hypothesis just like the permeable pavement treatment.

Pollutant concentrations:

Permeable Pavement

The second thing that was evaluated were the concentration levels of pollutants in a rain garden and permeable pavement compared to an area with no stormwater treatment. Weiss and Hondzo supplied the initial concentration of pollutants for an area with no stormwater treatment (Table 2). Asphalt showed a higher concentration for motor oil, zinc, and copper compared to the permeable pavement (Figure 3). Diesel and lead had the same results between asphalt and permeable pavement. The lower concentrations for motor oil, zinc, and copper indicate that the stormwater quality that filters through permeable pavement is better than the asphalt area. The p-values were determined for each pollutant analyzed in both permeable pavement and rain gardens compared to the area with no stormwater treatment (asphalt). Table 4 shows the p-values for the concentrations of copper, lead, and zinc. These were the main pollutants analyzed by the permeable pavement and the impervious pavement. The p-values for both lead and copper support the hypothesis that permeable pavement decreases the concentration of pollutants. More data must be collected to see whether or not zinc has a statistical significance. Since the p-values of copper (p=0.0465; Table 4) and lead (p=0.0002; Table 4) were below 0.05, this supports the second part of the hypothesis stating that permeable pavement has an affect on the reduction of some pollutant concentrations compared to the area with no stormwater treatment

Rain Garden

Rain gardens also resulted in lower concentrations of pollutants (chloride and phosphorus) in stormwater compared to the area with no stormwater treatment. Nitrate/nitrite showed higher concentration levels in the rain garden compared to the area with no stormwater treatment. This increase in nitrate/nitrite may be due to the plants within the rain garden enriching the soil with these two compounds. The lower concentrations of phosphorous and chloride indicate that a rain gardens can serve as an effective stormwater treatment because it has lower concentrations of the two compared to the area with no stormwater treatment. The rain garden p-values are shown on Table 5. Phosphorous, nitrate/nitrite, and chloride were the three pollutants analyzed between the rain gardens and the area with no rain garden (no stormwater treatment). Both chloride and nitrate/nitrite had values above 0.05. Chloride has a p-value of 0.07, which is near 0.05, but is still not statically significant. More data must be collected in order to determine whether rain gardens can decrease the concentration of chloride. Nitrate/nitrite had a much higher p-value of 0.737, which does not support the hypothesis. This high p-value may be due to factors other than stormwater, such as the plants in the garden.

Future Recommendations:

For future recommendations, more data must be obtained from multiple stormwater treatment areas. More data will provide more support towards the hypothesis or null hypothesis. Another recommendation for further research will be to measure more metal pollutants, such as copper, in rain gardens and see if rain gardens can decrease the concentrations of metal pollutants. This data will also help compare the stormwater treatments of permeable pavement to rain gardens. This will help determine which of the two-stormwater treatments is the most efficient on decreasing stormwater runoff and specific pollutant concentrations. One last recommendation would be to test the two-stormwater treatments rather than obtain raw data and analyzing it. Doing the test and collecting the samples at Carthage College would help determine the effectiveness of implementing a stormwater treatment for Carthage College and would help provide supports towards constructing more rain gardens and permeable pavements on campus.

Why should you care?

Carthage College is located right on Lake Michigan and as a Carthage Community it should be our responsibility to take care of it. From driving on the road to putting salt on the sidewalks during winter, all have an affect on the lake. When it rains or snows, the stormwater builds up and collects the pollutants on the ground. The polluted stormwater then goes into the lake affecting the quality and quantity of it. Carthage has one rain garden on campus and some permeable pavement, but the majority of campus is comprised of asphalt and regular gardens. Carthage College should implement a five year plan where the school will gradually add rain gardens and permeable pavement to campus. At the end of the five years all of the roads, sidewalks, and parking lots will all be permeable pavement. One should care about implementing rain gardens and permeable pavement on campus because it will help with the quality/quantity of Lake Michigan, our public health, flooding and much more.

<u>Conclusion:</u>

Today, there are many issues that are associated with the increase in urbanization. One of the biggest issues is the increase in stormwater runoff and an increase in pollutants being collected by the stormwater. One proposed solution that can benefit water quality and decrease runoff is implementing a stormwater treatment such as a rain garden and/or permeable pavement. The first part of the hypothesis indicating that permeable pavement and rain gardens decrease the amount of stormwater runoff is supported. Both, rain gardens and permeable pavement, show higher infiltration rates compared to an area with no stormwater treatment and is statically supported by the p-values obtained. The second part of the hypothesis stated that rain gardens and permeable pavement can reduce the concentration of pollutants in stormwater runoff. Data obtain practically supports this idea. Lead and copper show significant data to support that permeable pavement decreases its concentration. Phosphorous shows significant data that supports that rain gardens decrease this pollutant concentration. By implementing a rain garden and/or permeable pavement as a stormwater treatment, there will be less stormwater runoff and a decrease in specific pollutants.

Acknowledgments:

I would like to thank my academic advisor and professor Dr. Tracy Gartner for her guidance, knowledge, and support for the completion of this thesis. I would also like to thank Dr. Sarah Rubinfeld for her help and advise for the presentation and completion of this thesis. Specifically, I would like to thank Brandon Koltz for all his knowledge on stormwater treatments and all of the studies he introduced me to in order to support my thesis. I'd like to thank the non-profit organization Hui o Ko'olaupoko for the inspiration of doing my thesis on stormwater treatments. Interning down in Hawaii and seeing the effectiveness of rain gardens gave me a lot of appreciation towards stormwater treatments. Finally, I would like to thank Derek Booth, Lan Tornes, Jeffery Weiss, and Miki Hondzo for giving me access to the raw data of their experiments.

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