Retention of Lead and Total Suspended Solids in Pervious Concrete

by

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This thesis is dedicated to my dearest friends and family for their encouragement and continued support (and for listening to my crazy rants about concrete and biology). I could never have reached my goals without my mother's unending encouragement and motivation. My father's success and accomplishments in life have helped to set me on the path I have travelled. Wynter, my younger sister, has a tremendous drive and such lofty goals, that she has pushed me to work harder and to achieve more every day. My older sister Autum was always willing to lend a helping hand at every turn. This work is also dedicated to my husband Cody who has been a constant source of support and encouragement throughout school and life.

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ABSTRACT

Pervious concrete, an alternative to conventional concrete, is a material with an increased amount of void space that allows water to pass through the concrete versus ponding and/or running off into catchment systems. This study examines the retention capabilities of lead and Total Suspended Solids (TSS) within an entire pervious concrete system and the effects of different fly ash compositions for pervious concrete along with two different types of crushed stones and a soil layer. A complete pervious concrete system consisted of one formulation of pervious concrete along with one type of crushed stone and the soil layer used in the individual trials of TSS removal and lead retention to determine if a complete pervious concrete system would equal the sum of its parts. The retention of lead by the complete pervious concrete system was compared against the individual results from the parts of the complete pervious concrete system. Among the different formulations of pervious concrete, the specimens with a high loss on ignition showed a higher removal rate of lead but not TSS than those with low loss on ignition, yet the difference in the percentage of fly ash did not show an effect on the removal or retention of either lead or TSS. Of the two types of crushed stone tested, the 3/8” crushed stone retained more TSS than the #57 crushed stone. The amount of lead retained by the #57 crushed stone was not significantly different from the 3/8” crushed stone after the crushed stone was flushed. The dirt layer showed a complete removal rate of lead as did the complete pervious concrete system. The sum of the parts of the pervious concrete system indicate that for maximum removal of TSS and lead, a high loss on ignition fly ash pervious concrete cylinder should be used in conjunction with a 3/8” crushed stone layer.

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CHAPTER ONE: INTRODUCTION

Pervious concrete is a porous alternative to conventional concrete. The general structure of pervious concrete is made of coarse aggregate and limited fine aggregate to provide strength and durability while ensuring minimal packing so the concrete remains pervious (Tennis et al. 2004). By reducing or eliminating fine aggregate, pervious concrete retains a high void space unlike conventional concrete, which has little to no void space. Typical types of coarse aggregate used are crushed stone ranging from 3/8” to 5/8”depending on the region where construction is occurring and available materials.

When making pervious concrete, a precise amount of water must be added to the mix. Without enough water the aggregate will not adhere together and too much water will cause the paste to fill the void space (Tennis et al. 2004). Portland cements and blended cements are used in conjunction with supplementary material to form the paste used to hold the aggregate together. One common supplementary material used in concrete construction is fly ash (Onstenk et al. 1993). The use of fly ash in pervious concrete serves multiple purposes. First, its addition produces higher, long term strength from a denser paste matrix. Secondly, fly ash is a waste byproduct of burning coal and typically disposed of in landfills or ash ponds after removal from electrical power plants. Since fly ash can be used to replace 5-25% of Portland cement in the construction of pervious concrete (U.S. Department of Transportation 2011), the usage of fly ash in concrete alleviates the volumes that coal fired power plants need to dispose.

One defining characteristic of fly ash is loss on ignition (LOI). Loss on ignition determines the amount of organic content in the fly ash and thus determines the amount of air-entraining agents that need to be added and the amount of water to produce the right cementitious mix (U.S. Department of Transportation 2011). LOI’s exceeding 8% are typically not approved in conventional concrete, however pervious concrete does not utilize an air entraining agent thereby opening up “unusable” fly ash to a new application. By using fly ash in the pervious concrete mixtures, the cost of the concrete is reduced due to the inexpensive replacement cost of fly ash compared to Portland cement, with the added bonus of decreased landfill waste. This cost reduction is important since the initial cost of pervious concrete can be up to 1.5 times more than conventional pavement (Wanielista & Chopra 2007).

Pervious concrete can be used for multiple purposes including, but not limited to, parking lots, sidewalks, and trail paths. Pervious concrete is desirable because it reduces runoff by allowing water to filter through the concrete which in turns recharges groundwater (Hein & Schindler 2006). With the extra void spaces, there is also more friction provided by pervious concrete as well which allows a better grip for traffic on the aggregate. Pervious concrete can also be treated with polymer additives to help reduce noise from traffic (Pindado et al. 1999). Pervious concrete has also shown less dependency on deicing salts and plowing due to the warm subgrade temperatures permeating through the pervious concrete melting snow and ice. Pervious concrete is not very suitable to heavy traffic areas and high speeds that require extra strength and durability (Tennis et al. 2004).

When used as a surface for parking lots, pervious concrete allows for water to quickly drain and reduce runoff and pooling (Field et al. 1982). By allowing for this quick draining, pervious concrete may also be mobilizing contaminants found on its surface. Due to many vehicles entering and leaving throughout the day, the amount of contaminant accumulation in parking lots could be substantial. Parking lots can be a source of pollutants because vehicles park for hours and leak fluids and leave behind brake dust (Ferguson 2005). To date, very little research into the interaction between pervious concrete and contaminants has been published.

Lead is a metal of potential groundwater concern associated with pervious concrete. Lead is not commonly found freely in nature but is and has been frequently used for multiple innovations such as pipes, solder, roofing, and batteries. Older uses of lead include paints and gasoline additives, which have been phased out in most countries but are still present in the environment (Glorennec et al. 2010). Lead can be found in soils from deteriorating exterior lead paint; it can be found in drinking water from lead plumbing lines; it can be found in parking lots from lead batteries that have leaked. There is a plethora of sources for lead, but only a few options of where the lead will eventually reside. Once lead is released back into the environment from deteriorating plumbing, paint, gasoline, or batteries, it will travel into the soil and ground water. The bioavailability of lead from contaminated soil is not completely understood, but it is has been well documented that ingesting lead contaminated soil or water is toxic and can cause lead poisoning (Markowitz 2000).

Removal of Total Suspended Solids (TSS) is another concern associated with pervious concrete. TSS, by definition, is particles that are suspended in water and have a diameter greater than 0.45 microns. Anything less than 0.45 microns is considered dissolved since it will pass through the filter paper that has a porosity of 0.45 microns. TSS can consist of organic or mineral material and can be found in most bodies of water (Bash et al. 2001). At construction sites, plants, trees, grass, and other natural soil erosion prevention aids are often removed. During rain events, the amount of TSS will then be amplified by the increased erosion and runoff to streams.

Once TSS enters a waterway, several potential environmental impacts are possible. TSS absorbs heat from sunlight thus increasing the temperature of the water and decreasing dissolved oxygen levels (Bash et al. 2001). In addition, there may also be a decrease in sunlight penetration leading to less primary production (photosynthesis) causing levels of dissolved oxygen to decrease further. TSS can also directly harm aquatic life by blocking gills, smothering larvae, destroying habitat, and reducing growth rates (Bash et al. 2001).

The amount of TSS that can pollute a waterway can vary depending on the surrounding environment. The amount of TSS found at the receiving-waters of the Tuross estuary in Australia was found to be as high as 919mg/L (Drewry et al. 2009). The areas usually associated with high levels of TSS are found at construction sites. At a highway construction site in Pennsylvania, amounts of TSS as high as 1442mg/L were recorded (Kalainesan et al. 2009). The Environmental Protection Agency (EPA) requires measures to capture TSS on construction sites during and after work is completed, but those measures often fail or are not installed correctly.

The Environmental Protection Agency (EPA) deems pervious concrete as one of the Best Management Practices for reducing pollutants in groundwater. Conventional pavement systems would route all TSS to a catchment and require maintenance periodically to ensure good groundwater quality. When runoff containing TSS encounters pervious concrete, the amount of TSS captured within the pervious concrete system should be dependent on the amount of void space available, both in the pervious concrete itself and the gravel layer underneath. Some research has been done to understand the amount of TSS removed from the influent stormwater (Rowe et al. 2008). Not enough data exists on various concrete mixtures to understand the impact that it makes on TSS and lead which was the focus of this research.

CHAPTER TWO: OBJECTIVES

The overall objective of this research was to investigate the lead and TSS removal capabilities of a model pervious concrete system.

The specific objectives of the study were to:

1. determine if the removal efficiencies of lead and TSS differed based on different pervious concrete formulations (different fly ash amounts and different loss on ignitions values).
2. determine if the removal efficiencies of lead and TSS differed based on different crushed stones types.
3. determine whether a complete pervious system resembles the sum of its parts in reference to the parts ability to retain lead.
4. determine the influence of void space on lead and TSS retention.
5. determine the influence of permeability on lead and TSS retention.
6. determine which section of the pervious concrete system was the most efficient at removing lead and TSS.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Composition of Substrates

All pervious concrete specimens were acquired from the Middle Tennessee State University Concrete Industry Management Program laboratory. Cylinders were cast of pervious concrete made using the same materials while varying the amount and carbon content (LOI) of Class F fly ash. Three replicates of the following five compositions were used: 1) 0% Fly Ash (Control Sample); 2) 20% Fly Ash – Low LOI; 3) 30% Fly Ash – Low LOI; 4) 20% Fly Ash – High LOI; 5) 30% Fly Ash – High LOI. The final dimensions of each testing cylinder were 6 inches in diameter by 12 inches in length.

Void space of each cylinder was determined by the Corelok method. Steps in this method include oven drying an individual pervious concrete cylinder for 24 hours, then sealing the cylinder in a vacuum bag, weighing the sample, and then submerging the sample in water. The vacuum bag is then cut and water is allowed to permeate the specimen for eight minutes and a final weight was recorded. The weight difference is used to determine the amount of water within the specimen to determine void space. Permeability was also calculated and determined by sealing an individual pervious concrete block in duct tape and dosing the specimen with 2 to 3 gallons of accurately measured water. The water was poured on top of the specimen while maintaining a ¼ inch head of water across the surface area. Using a stopwatch, the time for the water to stop flowing through the specimen was recorded and permeability was calculated in gallons per minute.

Two types of stone were analyzed. #57 and 3/8" crushed stone were acquired from the Hoover Inc. (Murfreesboro, TN). Both of these stones are commonly used in pervious concrete construction.

The soil collected for use as a substrate for lead testing was also used as the solids to make TSS standards. To assimilate the most common forms of TSS, soil was collected from a construction site on the campus of Middle Tennessee State University. The soil was top soil from the top 2" of the construction site.

3.2 Experimental Procedure

To ensure each substrate was tested identically, a column was built to hold each substrate and allow for repetitive dosing. A shower head was used for dispersing the lead solution evenly over the substrate. The interior dynamics of the shower head were removed to ensure no further contact was made with the standard then necessary. The shower head was connected to ½" PVC piping with a water tight silicone adhesive. A valve was connected to the opposing end of the PVC piping attached to the shower head with a water tight silicone adhesive. The other end of the valve was connected to another section of ½" PVC piping with adhesive, and finally that ½" PVC piping was attached to a funnel (Figure 1). When running a TSS standard, no shower head, PVC piping, or valve was used due to the possibility of trapping TSS within these different parts. Instead, a funnel was placed into a wooden mount at the top of the apparatus and a funnel was placed at the bottom of the apparatus to collect the eluent and direct it into 1 liter bottles (Figure 2). The bottom funnel was equipped with a valve to allow easy transfer between the collection bottles. To hold the substrate (pervious concrete cylinder, stone, or dirt) in a column form, a 6-inch diameter PVC pipe with a height of 12-36 inches was used. A 6 inch diameter end-cap with13 holes of ¾ inch diameter drilled into the bottom was attached to the PVC pipe to allow the eluent to flow freely. Prior to all testing, the PVC column was washed with scrubbed de-ionized water (de-ionized water with a resistivity greater than 18 megaohms). If the PVC piping had been used previously, then soap and water was used to wash the interior of the PVC piping, followed by a rinse with 0.05 molar EDTA and a triple wash of de-ionized water.

When preparing a pervious concrete experiment, 1 liter of scrubbed de-ionized water was passed through the substrate and the eluent was collected for the determination of cylinder absorbtivity. Absorbtivity was defined as the amount of water retained by a clean, dry substrate. After the initial 1 liter flush, the pervious concrete was rinsed with tap water until a constant pH was reached. The absorbtivity and final pH after rinsing the pervious concrete was recorded in Appendix B. Finally, a 6 inch diameter piece of non-woven geo-textile was placed on the bottom of the PVC column with the rinsed pervious concrete placed on top. This procedure was repeated in triplicate for each formulation of pervious concrete.

When preparing a crushed stone experiment, a 6-inch diameter piece of non-woven geo-textile was placed on the bottom of the PVC column. 6 inches was measured on the inside of the PVC piping and a circle was made around the interior of the PVC piping indicating the 6 inch mark. Crushed stone was washed with tap water in a 5-gallon bucket three times and added to the 6 inch fill line and jigged for compaction then additional stone was added to the 6 inch fill line. The crushed stone in the column was allowed to dry in a controlled environment for a minimum of 24hrs. 1 liter of de-ionized water was passed through the substrate and the eluent was collected for the determination of absorbtivity. After the initial 1 liter flush, the crushed stone was rinsed with tap water until a constant pH was reached. The absorbtivity and final pH after washing the crushed stone is displayed in Appendix D. This procedure was repeated in triplicate for each type of crushed stone.

When preparing a soil experiment, a 6-inch diameter piece of non-woven geo-textile was placed on the bottom of the PVC column. 6 inches was measured on the inside of the PVC piping and a circle was made around the interior of the PVC piping indicating the 6 inch mark. Soil was added to the 6 inch fill line and jigged by hand for compaction then additional soil was added to reach the 6 inch fill line.

When preparing a complete pervious concrete system experiment, a 6 inch diameter piece of non-woven geo-textile was placed on the bottom of the PVC column. 6 inches was measured up on the inside of the PVC piping and a circle was made around the interior of the PVC piping indicating the 6 inch mark. Soil was added to the 6 inch fill line and jigged for compaction. Then 6 inches was measured on the inside of the PVC piping from the top of the soil layer and a circle was made around the interior of the PVC piping indicating the 6 inch mark. Crushed stone was added to the 6 inch fill line and jigged for compaction. Finally, a pervious concrete cylinder was placed into the top of the PVC piping.

After column preparation was completed, a 2000mL lead or TSS solution was introduced to the column and the eluent collected. Four 1Liter plastic bottles were used for capturing the eluent and were labeled according to the specific experiment being conducted. Eluent was captured to approximately the 1Liter mark on the bottle, and then the bottom valve was closed. The full bottle was capped and placed out of the way to allow for the next bottle to be used to capture the remaining eluent. Once the 2000mL of either lead or TSS standard had passed through the substrate, the valves were closed and a 2000mL scrubbed de-ionized water flush was added to the top funnel and the collection process repeated.

3.3 Standard Solutions for Testing

A 500 mg/L lead solution was used to dose all substrates. This concentration was chosen based on the highest recorded concentration (525 mg/L) of lead from runoff found in the literature (Göbel et al. 2007). The standard lead solution was prepared using lead nitrate and scrubbed de-ionized water.

A 1000 mg/l solution of TSS was used to dose all substrates. To make a 1000 mg/L TSS solution, the solids used were first standardized. Sieves with openings ranging from 1700µm to 0.45 µm were used to separate the soil. Any particles greater then 1700 µm and less than 0.45 µm were discarded. The soil captured between these sieves was then re-homogenized and oven dried at 105°C for at least 24 hours and used to produce the TSS testing solution.

3.4 Analysis

3.4.1 Analysis of Total Suspended Solids

Analysis of TSS was performed according to EPA guideline 160.2. A vacuum filtration device was used that consisted of a 250mL Buchner funnel attached to a coupler via a clamp that fit onto a round glass vacuum filter flask with a side arm. The vacuum pump was attached to the side arm to apply suction. A glass fiber filter disk (0.45 µm) was placed on the coupler and rinsed three times with 20mLs of de-ionized water while vacuum was applied to the vacuum filtration device. The washed disk was then placed in a pre-weighed aluminum pan and oven dried at 105°C ± 5°C for at least 2 hours. The aluminum pan and disk were cooled to room temperature and weighed again. Once the glass fiber filter disk was washed, dried, and weighed, the disk was then ready to be used to analyze TSS. The disk was placed back on the coupler of the vacuum filtration device and the 250mL Buchner funnel was placed on top of the disk and held in place by the clamp. Vacuum suction was applied and was maintained for the duration of the test.

Each 1-liter container obtained from a TSS experiment was shaken to ensure complete dispersion of the TSS within the sample. 50mL of this solution was poured into a graduated volumetric cylinder and then poured into the Buchner funnel. Once the solution was completely filtered through the glass fiber filter disk, the vacuum was turned off. At this point, the Buchner funnel was removed, and the disk was removed with tweezers and placed back into the original aluminum pan that it was weighed in after drying. The aluminum pan along with the filter disk was placed in an oven at 105°C ± 5°C for at least 2 hours. The pan and filter disk were removed from the oven and cooled to room temperature. The 2 liters from the standard dose results were added together to show amount of TSS acquired during the standard dose. The 2 liters from the water flush were added together to show the amount of the TSS acquired from the water flush. The weight of the pan and filter disk were taken again. To determine the amount of TSS collected, the following formula was used (EPA guideline 160.2):

$$\text{TSS} = \frac{[(\text{grams of soil filter disk + pan}) - (\text{grams of clean filter disk + pan})]}{\text{volume of sample}}$$

3.4.2 Analysis of Lead

Lead analysis was performed using graphite furnace atomic absorption spectrophotometry. A five point standard curve of 0, 5, 10, 20 and 40 ppb was used and an r^2 of 0.99 was the acceptance criteria for each standard curve. Due to the high concentration of lead used for testing, appropriate dilutions of each lead sample was necessary to ensure the concentration was within the acceptable range of the standard curve.

All standards and samples were analyzed on a Shimadzu 6300 Atomic Absorption spectrophotometer with a graphite furnace. A calibration verification standard (CVS) of 10 ppb was ran every ten samples and at the end of each run to verify the instrument was not deviating from the original standard curve. If the CVS was not within ± 10% of the original reading, the standard curve was re-ran and any samples acquired after the last passing CVS were re-ran as well.

3.5 Statistical Evaluation

Removal of lead and TSS between the different compositions of pervious concrete (percent carbon, loss on ignition, void space, permeability) and gravel were analyzed using one-way ANOVAs. When significant differences were observed, a Newsman-Keuls post-hoc test was used to determine differences between groups. Linear regression was used to determine if lead and TSS removal from individual cylinders was related to either permeability or void space. A level of significance of 0.05 was used for all comparisons.

CHAPTER FOUR: RESULTS

4.1 Pervious Concrete

4.1.1 Lead

A significant difference in lead removal was observed between cylinders made with low-LOI carbon and high-LOI carbon with the high-LOI carbon removing more lead (p=0.004) (Figure 3, Appendix A). No significant difference was observed between cylinders made with 30% fly ash and controls (p=0.300) or 20% fly ash cylinders and controls (p=0.133) (Figure 3, Appendix A).

No significant relationships were observed when comparing lead removal from individual pervious concrete cylinders and permeability (Figure 5, Appendix A) or individual pervious concrete cylinders and void space (Figure 6, Appendix A)

4.1.2 Total Suspended Solids

No significant differences (p=0.257) were observed when comparing TSS removal with the percentage of fly ash incorporated into pervious concrete cylinders (Figure 7, Appendix A), the LOI of the carbon used (Figure 7, Appendix A), or between the first two liters of eluent collected and the last two liters of eluent collected (p=0.164) (Figure 8).

No significant relationships (p=0.063) were observed when comparing TSS removal to individual pervious concrete cylinder permeability (Figure 9, Appendix A) or individual pervious concrete cylinder void space (Figure 10, Appendix A).

4.2 Crushed Stone

4.2.1 Lead

The different aggregate sizes did not show a significant difference in the retention of lead (p=0.738) (Figure 11). No significant difference was observed when comparing lead removal and retention for the first two liters of eluent collected compared to the last two liters of eluent collected, regardless of aggregate size (p=0.272) (Figure 12).

4.2.2 Total Suspended Solids

The different aggregate sizes removed significantly different total amounts of TSS (Figure 13) (p=0.012). The 3/8" crushed stone removed more TSS than the #57 crushed stone. When comparing the amount of TSS removed during the standard TSS dose, there was a significant difference between the aggregate sizes with the 3/8" crushed stone removing more TSS during the standard dose (p=0.023)(Figure 14). There was s significant difference seen when comparing 3/8" crushed stone water dose to the #57 crushed stone water dose with 3/8" crushed stone retaining more TSS than the #57 crushed stone (p=0.012)(Figure 14).

4.3 Soil

4.3.1 Lead

No measurable amount of lead was found in the eluent of any sample tested. The soil layer retained all lead that was in the initial dose and retained the lead through a 2 liter flush of water (Appendix E).

4.4 Complete Pervious Concrete System

4.4.1 Lead

No measureable amount of lead was found in the eluent of any sample tested. The complete pervious concrete system retained all lead that was in the initial dose and retained the lead through a 2 liter flush of water (Appendix F).

4.5 Void Space versus Permeability

A relationship was observed when comparing the void space of a pervious concrete cylinder and the permeability of the pervious concrete cylinder with permeability increasing with void space (Figure 15).

CHAPTER FIVE: DISCUSSION

5.1 Overview

When engineers develop new technology or improve on older technology, the major concern is what works the best and is the safest for people. From an environmental scientist's standpoint, what's least damaging to the environment is also a major consideration. Though neither group would want to hinder the other, direct collaboration between these groups is rare. The goal of this project was to test a pervious concrete system that has the potential to benefit engineers by establishing a structural best management practice that can handle stormwater, and assist environmental scientists by reducing the detrimental environmental impacts of polluted stormwater.

5.2 Pervious Concrete

Pervious concrete can be considered beneficial for the environment based on its ability to recharge ground water and prevent water from ponding during heavy rain events (Booth & Leavitt 2003). The research into contaminants that are carried back into the ground water through the pervious concrete is incomplete. Laboratory studies have shown pervious concrete can effectively reduce the amount of TSS and lead (Fach & Geiger 2005). In a field study, Rushton (2001) showed that a pervious concrete system with a swale had a 93% lead removal efficiency and a 92% TSS removal efficiency. This is at a much higher percent than compared to the asphalt systems with a swale that were only 59% to 87% effective for lead removal and only 46% to 83% for TSS removal. In this research, the removal efficiencies of lead and TSS showed similar results to the literature. The pervious concrete systems show an increase in retention of TSS with the ability to allow the TSS into the pervious concrete and be retained there without shedding into the environment when compared to a conventional concrete system. With the retention of TSS within the pervious concrete, over time the concrete may become clogged and thus lead to lower permeability (Coleri et al. 2013). If the permeability of the pervious concrete is reduced, the pervious concrete may begin to shed or allow water to pond instead of infiltrate the system. The size or aggregate used in the composition can assist with helping to decrease clogging (Deo et al. 2010).

To help decrease the cost of pervious concrete, fly ash is used as a supplementary material in the paste used to make pervious concrete. The more fly ash that can be added to pervious concrete without compromising the durability or strength, the more cost effective pervious concrete is as a solution. Based on the results of the present study, the difference in percent composition of fly ash did not show a significant difference in the removal of lead or TSS (Appendix A). When looking at these results from an engineering standpoint, and assuming that durability and strength between formulations are the same, the 30% fly ash pervious concrete would be the most cost effective.

From an environmental standpoint, the cost of pervious concrete should be weighed against the positive and negative impacts of the type of pervious concrete and fillers used. There have been several studies that have shown reduction in lead in runoff water when pervious concrete was used versus traditional asphalt (Pagotto et al. 2000, Brattebo & Booth 2002). In this study, lead was removed by the pervious concrete, but when comparing the amount of lead removal between different concentrations of fly ash, there was no significant difference (Figure 3, 4). When comparing lead removal between different carbon types used (LOI) and fly ash formulations, there was a significant difference. Even though the high LOI samples did not vary greatly from the control sample (0% fly ash), the high LOI samples did remove more lead then the low LOI samples. The lead that was removed by pervious concrete cylinders during the dosing was retained during the water flush as well (Figure 4). This indicates that the lead is being made unavailable, and thus excessive water will likely not cause the lead to leach under typical storm conditions. This observation is not entirely surprising since carbon is known to influence the binding of metals (Eggleton &Thomas 2004). Different properties of organic materials can increase their effectiveness in adsorbing materials such as lead. Carbonization is noted as an effective mean for increasing adsorption capacities (Sreejalekshmi et al. 2009). The influence of carbon content on the removal and retention of lead has never been shown using pervious concrete cylinders before this study. Therefore, taking into account all the data collected from the pervious concrete cylinders, from an environmental perspective, the best type of pervious concrete to use would be high LOI formulations. This would allow power plants to decrease their tipping fees to landfills and sell more fly ash at a reasonable cost.

With land development, the amount of impervious surfaces are increasing and directly tied to this increase is the potential to increase stormwater volume and decrease the quality of the water being directed back into the environment (Brabec et al 2002, Dreelin et al. 2006). The void space and permeability of the previous concrete are factors of interest to help reduce the amount of impervious land coverage. From an engineering standpoint, the greater the void space the better the system will be at preventing the shedding of water and dependency on public utility infrastructure such as catch basins, gutters and piping. An added benefit for increasing the void space is the assumption that with the greater void space there will be a greater removal of solid contaminants, such as TSS. Figure 10 shows in this study there is no significant relationship between the removal rates of TSS and void space. Overall, void space and permeability did not have an effect on the removal rates of lead or TSS (Figure 5, 6, 9, 10). The only added benefit of increasing void space is to increase permeability (Figure 15). From an engineering standpoint and an environmental standpoint, the higher permeability rates associated with higher void space is beneficial due to the fact that water will drain through the concrete and recharge ground water versus shedding.

5.3 Crushed Stone

From an engineering standpoint, the size and type of aggregate used is based on the area and the function of the concrete being laid. Overall, the difference between #57 and 3/8” crushed stone is the compaction of the stone and the ability to allow enough water to pass through the substrate. Based on Appendix D, there was not a significant difference between the retention of water or the amount of time it took for the water to pass through the crushed stone.

The type of sub-base used below a pervious concrete system plays a role in the removal and retention of metals. Fach and Geiger (2005) showed that metals such as lead, zinc, and cadmium can complex with organic components within a substrate. In the present study, the amount of lead removed was not significant. Appendix C shows the amount of lead removed by either type of sub-base used in this study was minimal to none. Figure 12 shows that during the first dose of 2000mL of lead, #57 crushed stone removed more lead then the 3/8” crushed stone, though not significantly. When the crushed stone was flushed with 2000mL of water, the lead that had been removed by the #57 crushed stone was flushed with the water and removed from the crushed stone. 3/8” crushed stone on the other hand retained the lead that had been removed during the 2000mL lead dose. Though there was no significant difference between the amounts of lead retained by either type of crushed stone, the lead that was retained by the 3/8” crushed stone was not released after being flushed with 2000mL of clean water. This increased retention of lead on the 3/8” crushed stone may be due to more surface area on the 3/8” crushed stone than the #57 crushed stone, therefore giving lead more contact with the sub-base and more opportunities for binding. Additionally, 3/8” crushed stone withheld significantly more TSS than that of the #57 crushed stone (Figure 13). This difference could potentially be for the same underlying reason: increased surface area contact when using 3/8” crushed stone.

5.4 Soil

The last and most effective layer of a pervious concrete system is the soil layer. Before a project can begin, an in-depth soil analysis must be performed to determine if the existing soil can be used. If the soil is determined to be inadequate for the project, the soil will be cut out and filled with an appropriate soil from another location. As shown in previous studies, soil is effective at binding and immobilizing lead in the environment (Legret et al. 1996). The soil characteristics such as clay content and pH can affect the retention capabilities of the soil (Cline & Reed 1995). The present study shows the same results with lead being bound within the 6 inch soil layer (Appendix E).

5.5 Complete Pervious Concrete System

An ideal pervious concrete system would be one that performs well under traffic use and reduces any negative environmental impacts. In review of porous pavements by Ferguson (2005), the research compiled showed how porous pavements effectively combine stormwater management with pavement functionality. A complete pervious concrete system can be highly beneficial when the correct parts are used together. In the present study, a complete pervious concrete system was compiled to test whether the sum of the parts were equal to the whole. Therefore, the system in this study was made from the one type of soil, a layer of #57 crushed stone, and a 20% low LOI fly ash pervious concrete cylinder.

The 20% low LOI fly ash pervious concrete specimen and the #57 crushed stone were the least effective at removing lead in the individual studies, however, results using the complete pervious concrete system showed a complete removal of lead (Appendix F). All lead used was completely removed during the lead dose and was retained during the water flush. This was not unexpected due to the soil layer having removed all of the lead during the individual component trials. The parts of the system are not of great concern for their environmental impacts since the overall system removes all lead. Cline and Reed (1995) state that the strength of the retention is dependent on the initial concentration of the contaminants due to the high-energy binding sites filling first. By decreasing the concentration throughout the system before reaching the soil could help with the retention of lead over time.

The individual parts of the system's ability to remove contaminants are pertinent from an environmental standpoint. The more lead that can be removed before reaching the soil layer would be beneficial since binding sites are not unlimited and in the field pervious concrete systems may be in place for a very long time. Further research could be used to indicate at what point the lead would saturate the soil layer and thus need the individual parts of the pervious concrete system to remove lead.

The world that we live in today is one that is based on continuing technological advances. With these advances come both positive and negative aspects. As a society, we demand better utilization of resources towards the nation's infrastructure. In recent years, more emphasis has been placed on working to ensure there is minimal impact on the environment when using advanced technology for building. This study helps to combine both aspects of a developing world alongside environmental concerns.

5.6 Recommendations for Future Research

Five formulations of pervious concrete were tested in the present study. Results showed that high LOI cylinders were more effective at removing lead than cylinders made with low LOI, therefore, it is recommended that more detailed investigations examining different LOI formulations and their influence on lead removal be conducted. The results seen from the relationship of the void space and TSS removal have a significant implication for future research as well. Since no significant relationship was seen between void space and TSS removal, it may be beneficial to examine the specific size of the different voids to determine if a relationship exists. It may be possible that the spaces are too large to capture the TSS. A study into whether changing the physical composition/size of the actual void spaces and how that may correlate to TSS removal would be of great insight.

CHAPTER SIX: CONCLUSIONS

The conclusions drawn from this study are as follows:

- Varied percent replacements of Class F fly ash with different loss on ignitions used in pervious concrete do retain lead at different rates. Fly ash with a high loss on ignition retained more lead. Different compositions of fly ash do not have an effect on the retention rate of TSS.
- The difference between the aggregate sizes did show a significant difference in the retention of TSS. The 3/8" aggregate size retained more TSS than the #57 aggregate size. The difference between the aggregates sizes did not show a significant difference in the removal of lead.
- A complete pervious concrete system retained all lead throughout the system. The sum of the parts indicated that all lead should be retained within the system which was confirmed.
- Void space did not have an influence on the retention of TSS by different pervious concrete formulations.
- The layer within the pervious concrete system that retained lead the most effectively was the soil layer, followed by the pervious concrete layer, and then the crushed stone layer.

FIGURES

Figure 1: Apparatus for Lead Standards

Figure 2: Apparatus for TSS Standards

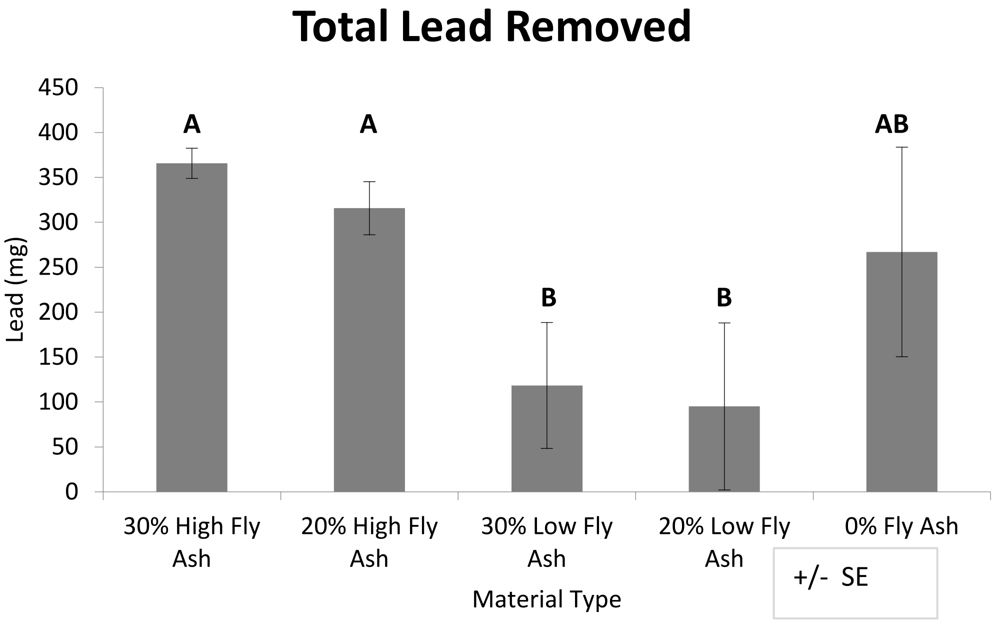


Figure 3: Lead removal for the five formulations of pervious concrete

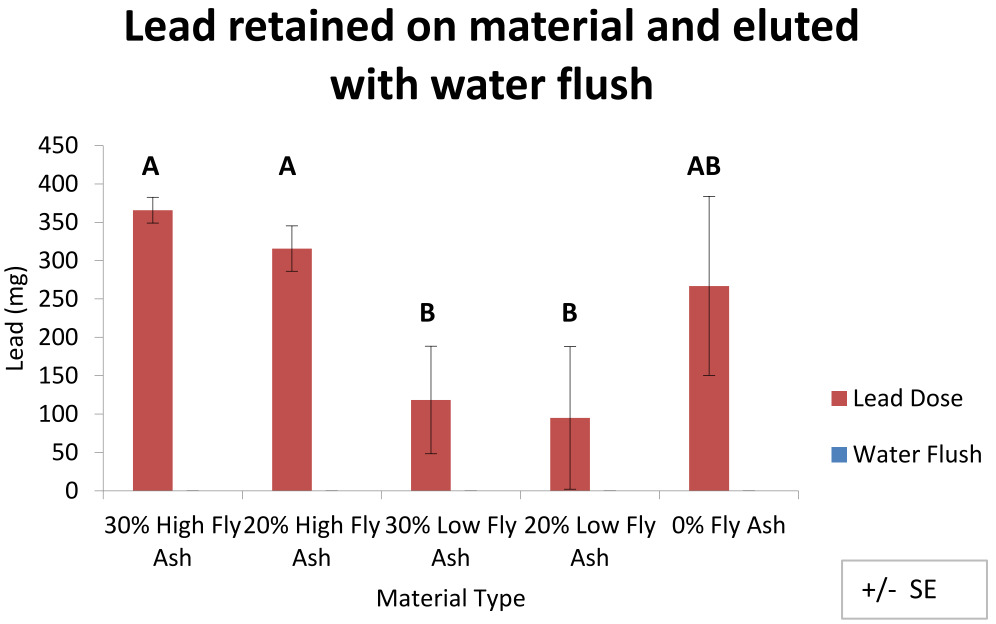


Figure 4: Lead retained on five formulations of pervious concrete and eluted with water flush

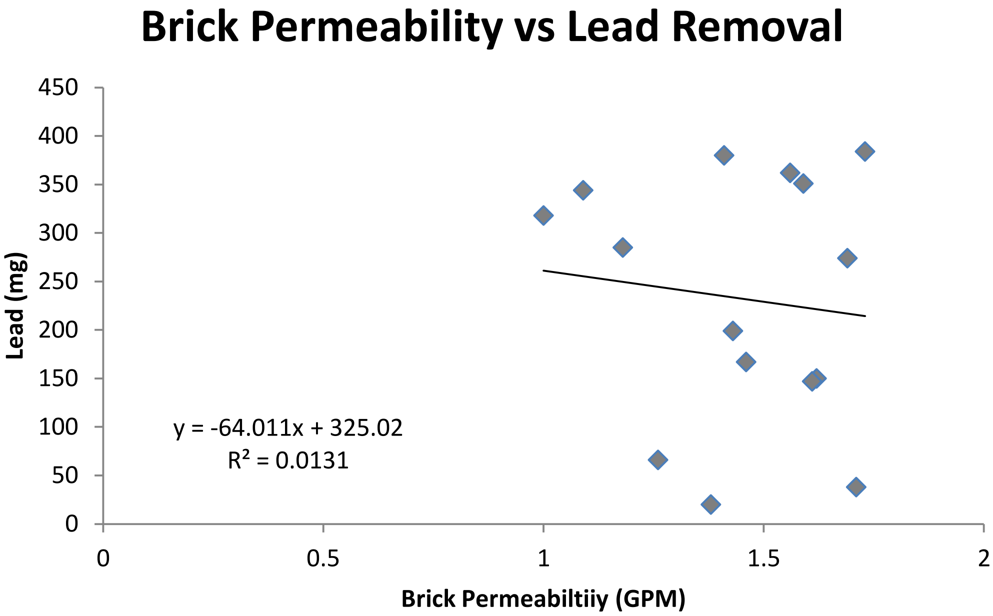


Figure 5: Lead removal compared to permeability

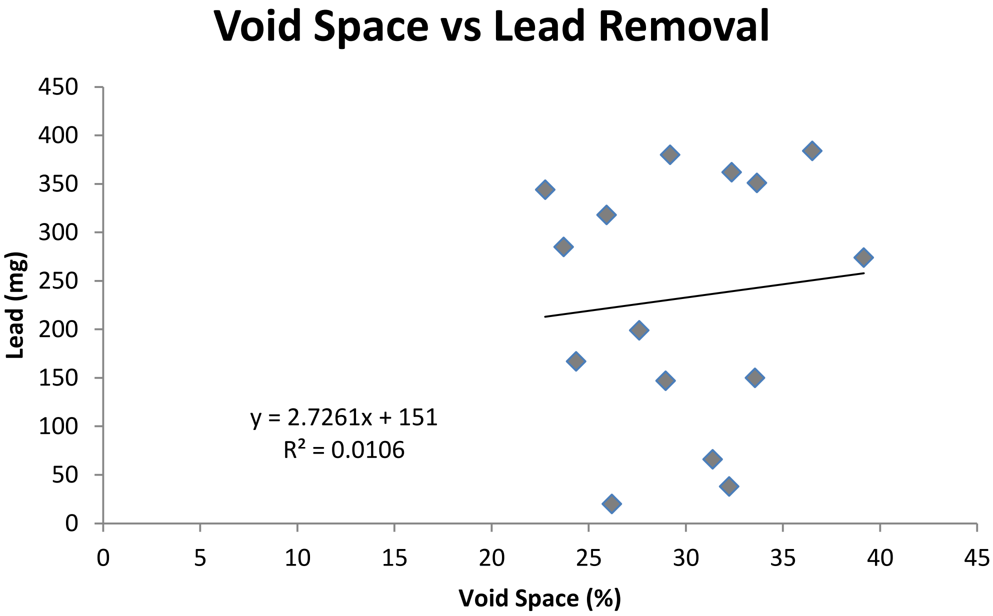


Figure 6: Lead removal compared to void space

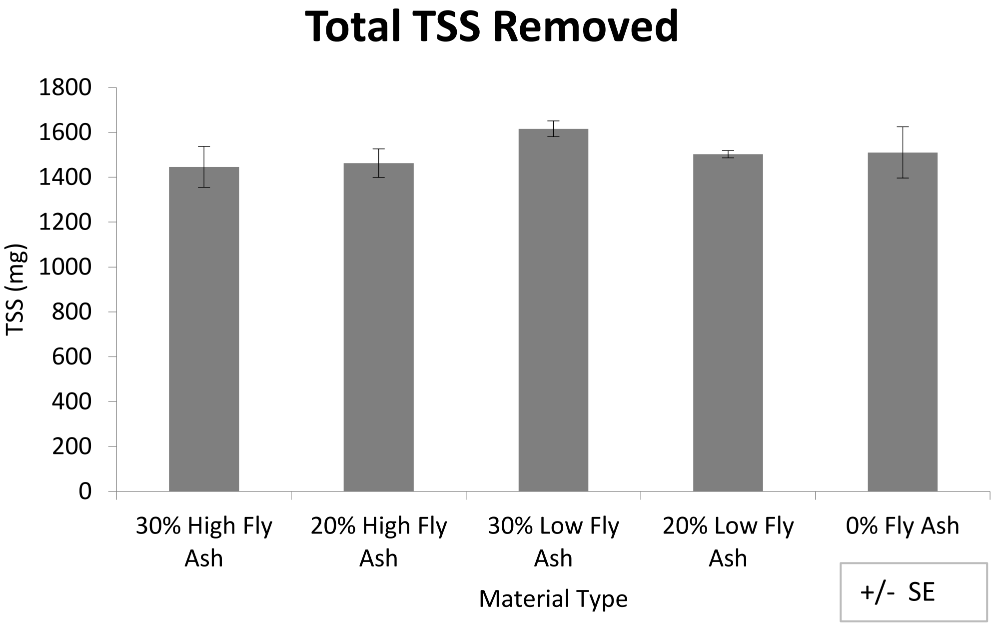


Figure 7: TSS removal for the five formulations of pervious concrete

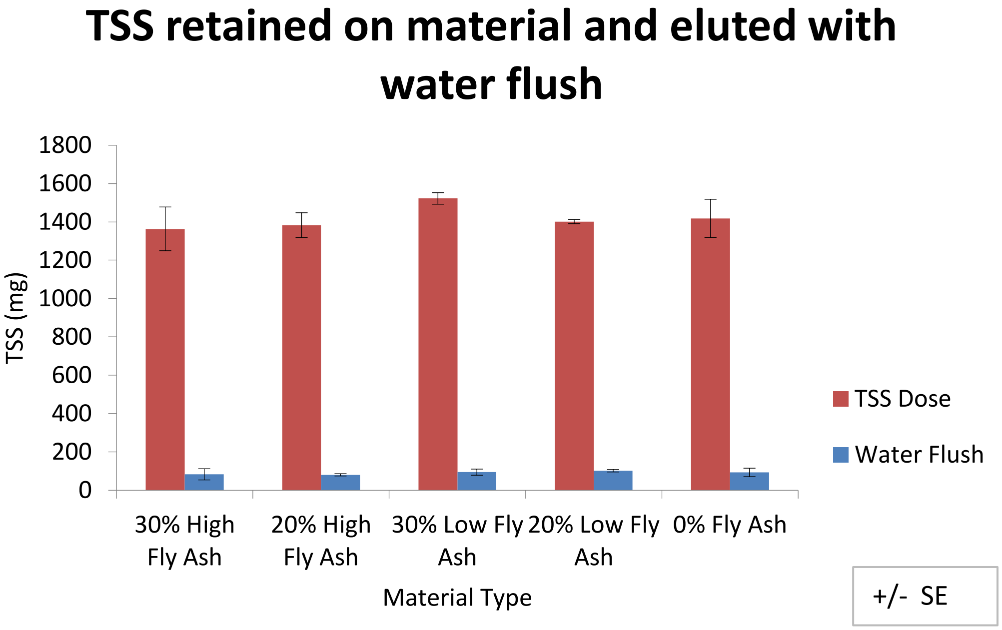


Figure 8: TSS retained on five formulations of pervious concrete and eluted with water flush

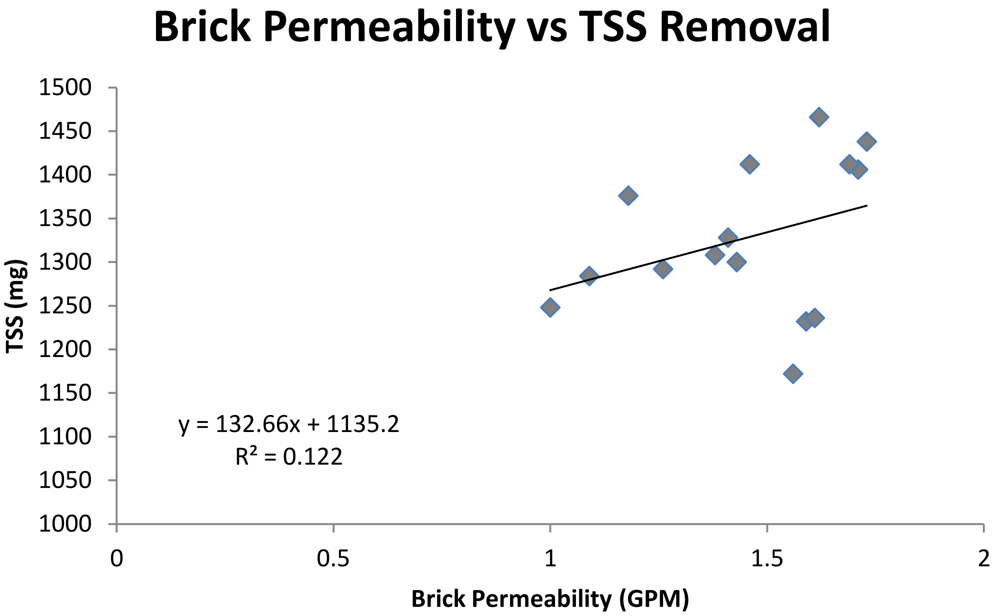


Figure 9: TSS removal compared to permeability

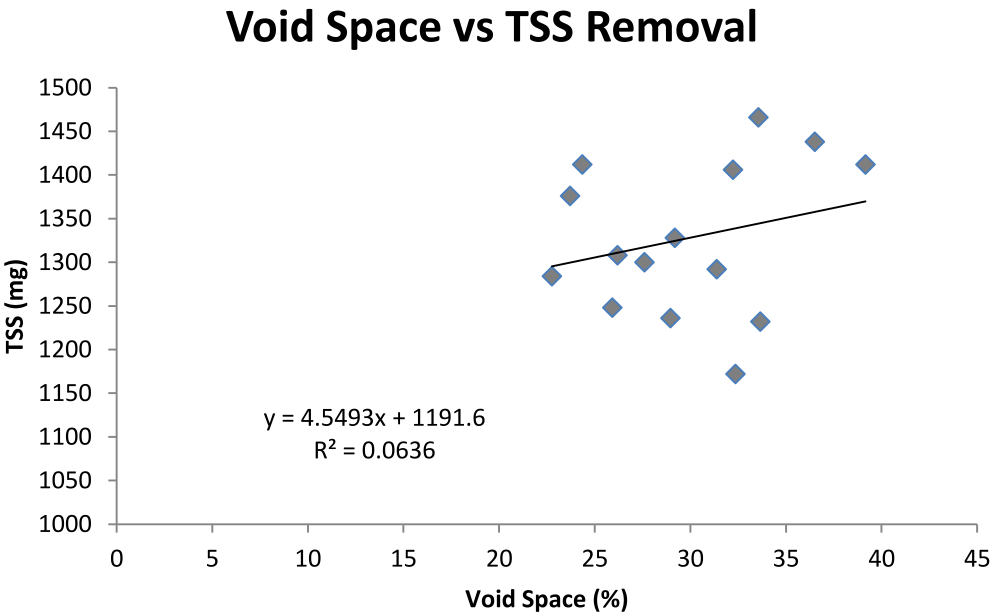


Figure 10: TSS removal compared to void space

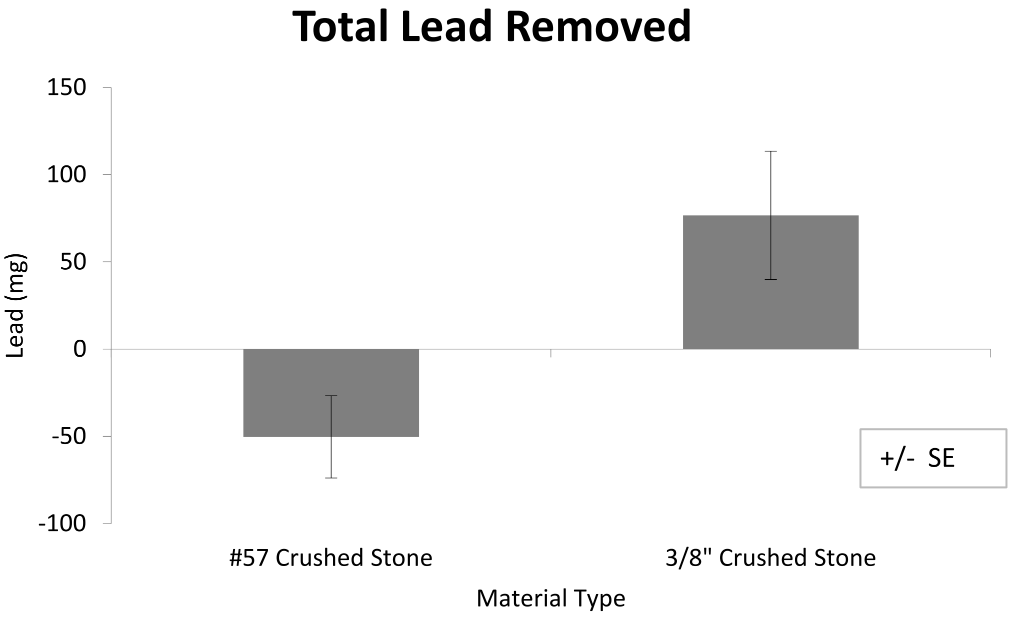


Figure 11: Lead removal for the two types of crushed stone

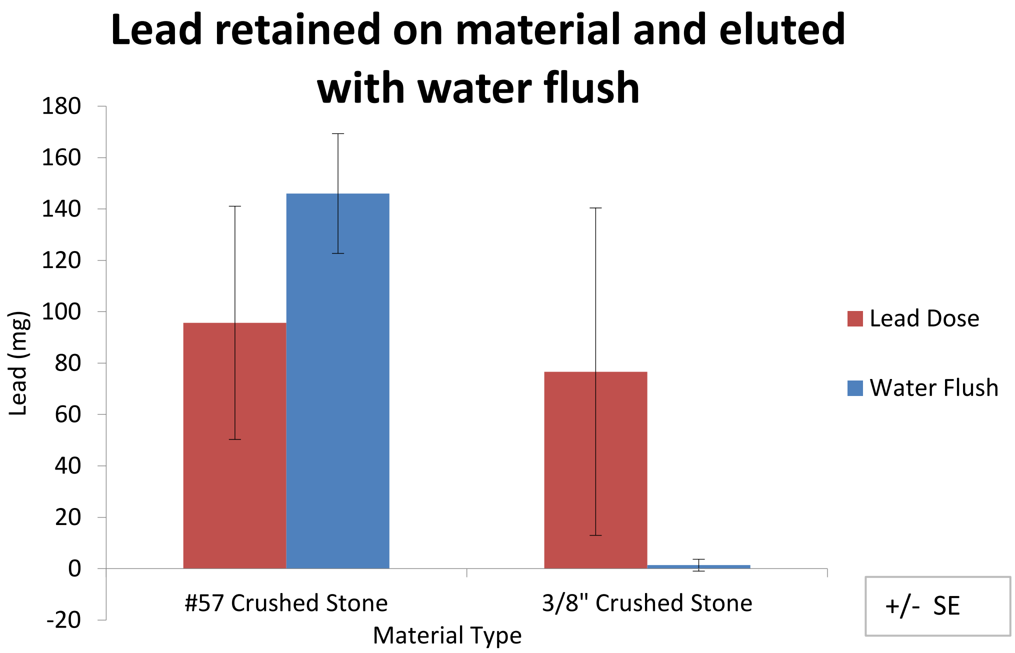
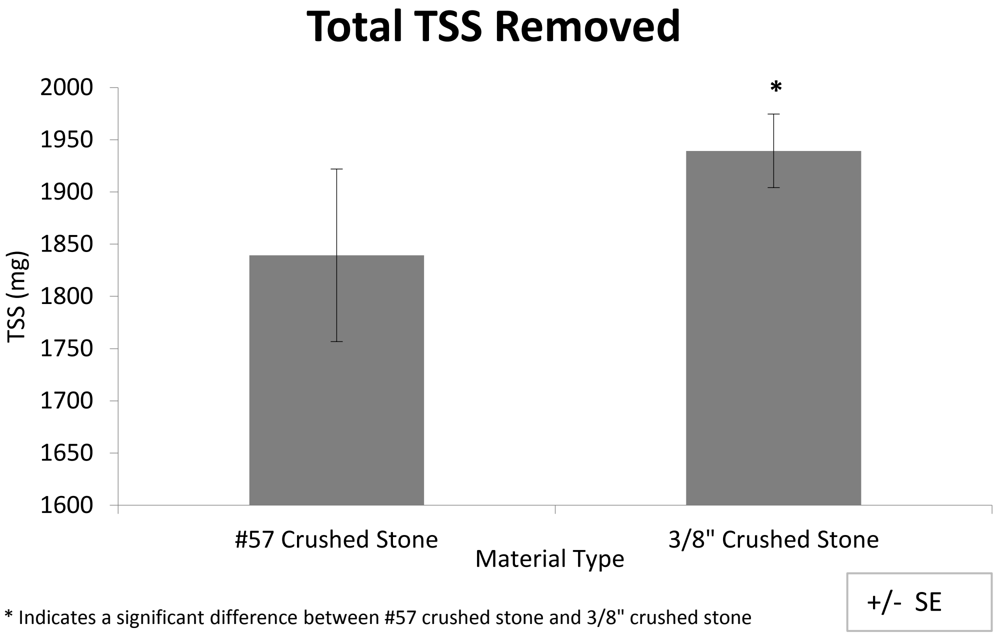
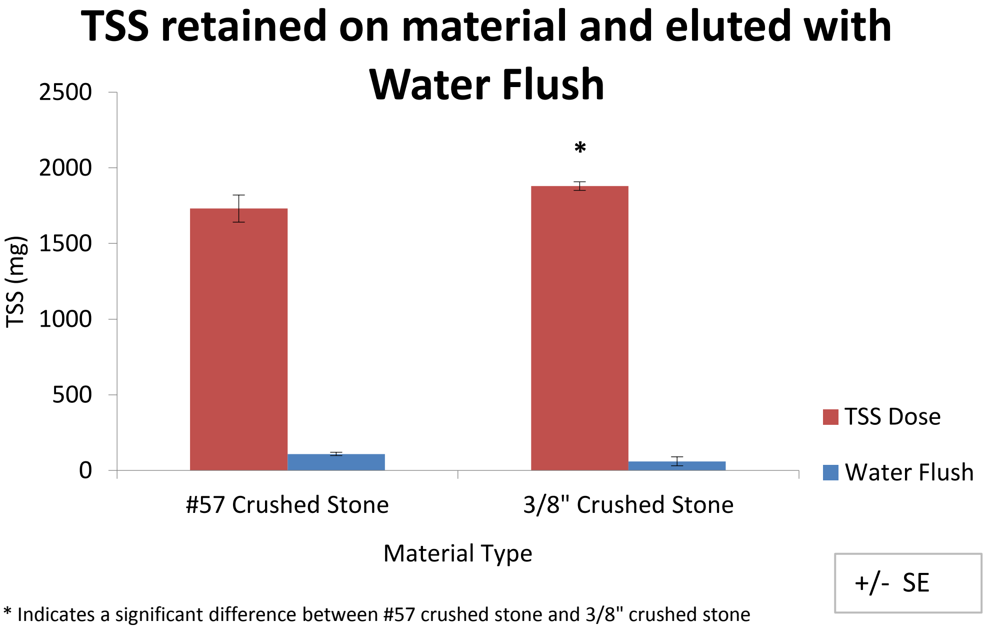


Figure 12: Lead retained on two types of crushed stone and eluted with water flush



* Indicates a significant difference between #57 crushed stone and 3/8" crushed stone

Figure 13: TSS removal for the two types of crushed stone



* Indicates a significant difference between #57 crushed stone and 3/8" crushed stone

Figure 14: TSS retained on two types of crushed stone and eluted with water flush

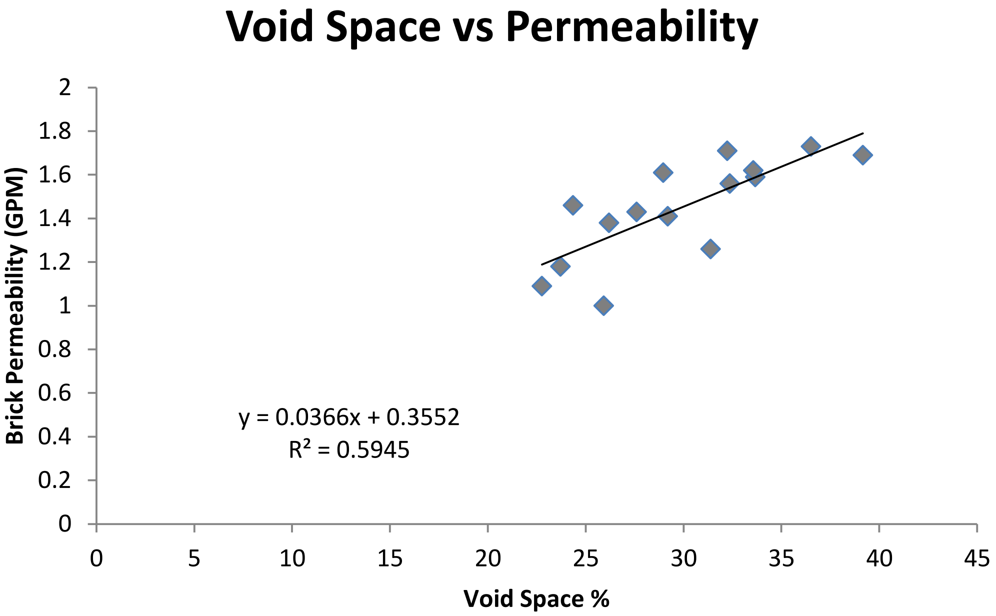


Figure 15: Void space versus pervious concrete permeability

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APPENDICES

APPENDIX A: Comparison of Pervious Concrete Compositions' Permeability, Lead Retention, and TSS Retention

Material Type	Void Space	Permeability (GPM)	TSS Retained (mg)	TSS Retained (%)	Lead Retained (mg)	Lead Retained (%)
30% High Fly Ash	33.66	1.59	1232	61.6	351	35.1
	36.51	1.73	1438	71.9	384	38.4
	32.36	1.56	1172	58.6	362	36.2
Average	**34.18**	**1.63**	**1280**	**64.0**	**366**	**36.6**
20% High Fly Ash	25.92	1.00	1248	62.4	318	31.8
	23.71	1.18	1376	62.8	285	28.5
	22.76	1.09	1284	64.2	344	34.4
Average	**24.13**	**1.09**	**1303**	**63.1**	**316**	**31.6**
30% Low Fly Ash	31.23	1.71	1406	70.3	38	3.8
	33.56	1.62	1466	73.3	150	15.0
	24.35	1.46	1412	70.6	167	1.6
Average	**29.71**	**1.60**	**1428**	**71.4**	**118**	**6.8**
20% Low Fly Ash	31.38	1.69	1292	64.6	66	6.6
	27.60	1.41	1300	65.0	199	19.9
	26.19	1.61	1308	65.4	20	2.0
Average	**28.39**	**1.57**	**1300**	**65.0**	**95**	**9.5**
0% Fly Ash	39.19	1.69	1412	70.6	274	27.4
	29.19	1.41	1328	66.4	380	38.0
	28.96	1.61	1236	61.8	147	14.7
Average	**32.45**	**1.57**	**1325**	**66.3**	**267**	**26.7**

APPENDIX B: Comparison of Pervious Concrete Compositions and Characterizations

Material Type	pH After Wash	Absorbtivity (mL)	Beginning/ End Water (sec)	Last Collection (sec)	Amount Eluent Collected (mL)	Amount Eluent Retained (mL)
30% High Fly Ash	8.78	30	6/40	50	3580	420
	9.01	22	31/29	43	3710	290
	8.64	42	61/43	67	3590	410
Average	**8.81**	**31**	**33/37**	**53**	**3627**	**373**
20% High Fly Ash	8.57	20	5/36	40	3630	370
	8.3	110	5/30	47	3470	530
	8.03	42	4/32	46	3630	370
Average	**8.30**	**57**	**5/33**	**44**	**3577**	**423**
30% Low Fly Ash	8.59	18	5	82	3660	340
	8.12	28	5	72	3630	370
	8.15	40	4	60	3600	400
Average	**8.29**	**29**	**5/38**	**71**	**3630**	**370**
20% Low Fly Ash	8.75	30	5/28	61	3580	420
	8.92	22	5/34	73	3540	460
	9.09	42	6/36	70	3580	420.0
Average	**8.92**	**31**	**5/33**	**68**	**3567**	**433**
0% Fly Ash	8.3	50	5/39	80	3600	400
	8.42	42	5/35	48	3500	500
	8.78	20	6/32	55	3570	430
Average	**8.50**	**37**	**5/35**	**61**	**3557**	**443**

APPENDIX C: Comparison of Crushed Stone Compositions of Lead Retention and TSS Retention

Material Type	TSS Retained (mg)	TSS Retained (%)	Lead Retained (mg)	Lead Retained (%)
38" Crushed Stone	1808	90.4	91	9.1
	1780	89.0	7	0.7
	1870	93.5	132	13.2
Average	**1819**	**91.0**	**77**	**7.7**
#57 Crushed Stone	1512	75.6	-4	-0.4
	1656	82.8	-81	-8.1
	1698	84.9	-66	-6.6
Average	**1622**	**81.1**	**-50**	**-5.0**

APPENDIX D: Comparison of Crushed Stone Composition and Characterization

Material Type	pH After Wash	Absorbtivity (mL)	Beginning/ End Water (sec)	Last Collection (sec)	Amount Eluent Collected (mL)	Amount Eluent Retained (mL)
3/8" Crushed Stone	8.76	5	5/56	83	3900	100
	8.73	11	5/52	70	3510	490
	8.59	7	4/53	80	3065	935
Average	**8.69**	**8**	**5/54**	**78**	**3492**	**508**
#57 Crushed Stone	8.82	15	3/54	77	3810	190
	8.44	8	4/50	8	3955	45
	8.39	12	3/51	80	3455	545
Average	**8.55**	**12**	**3/52**	**55**	**3740**	**260**

APPENDIX E: Retention of Lead in Soil

Material Type	Lead Retained (mg)	Lead Retained (%)
Soil	1000	100.0
	1000	100.0
	1000	100.0
Average	**1000**	**100.0**

APPENDIX F: Retention of Lead in a Complete Pervious Concrete System

Material Type	Lead Retained (mg)	Lead Retained (%)
Complete Pervious Concrete System	1000	100.0
	1000	100.0
	1000	100.0
Average	**1000**	**100.0**