THE EFFECT OF SEDIMENT ACCUMULATION ON THE HYDRAULIC CONDUCTIVITY OF PERVIOUS CONCRETE

By

SEAN PATRICK WALSH

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ABSTRACT OF THE THESIS

The Effect of Sediment Accumulation on the Hydraulic Conductivity of Pervious Concrete

By: Sean Patrick Walsh

Thesis Director:

Qizhong Guo

Pervious concrete systems can reduce stormwater runoff, minimize non-point source pollution, and increase groundwater recharge. Engineers are often hesitant to use pervious concrete because it costs more than traditional concrete and there is the possibility that the pervious concrete will clog prematurely; thereby removing any of the hydraulic advantages that pervious concrete provides. Pervious concrete clogs because sediment builds on the surface by filling in all the void spaces, thus reducing its hydraulic conductivity. In this study, pervious concrete cores were used to measure the effects of sediment accumulation on their hydraulic conductivity. Established sediment loading rates were used to measure how the hydraulic conductivity changed as sediment accumulated at or near the surface of pervious concrete. The results were used to develop a model to predict the hydraulic conductivity of pervious concrete based on its initial hydraulic conductivity, the amount of sediment deposited at or near its surface and the soil type of the sediment. The model presented here can be used to craft better maintenance plans to extend the life of pervious concrete and use pervious concrete more efficiently.

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I would like to thank Conwego Contractors for donating the concrete cores to this project. I would like to thank Dr. Guo for being my advisor and giving me the time and flexibility needed to complete this project. I would like to thank the PARS and EPA staff at the Edison EPA office especially Mike, Amy, Tom, Yogesh, Jon, Christa and Clarence for giving me a space to work and the materials and time to figure out how to set up the experiment. It took longer than I think all of us expected. I would like to thank Amy Rowe for being there to answer all my questions and giving me great advice when I needed it. I would like to thank the Jillian Thompson, Ben Pearson, Arjun Raju Adimari, Jung Hoon Kim and Mehran Niazi for giving me their time when I needed an extra hand. I would like thank Dr. Christopher Obropta for giving me a very flexible work schedule that allowed me to complete my Master's Degree. I would like to thank Dr. Robert Miskewitz for all his advice, guidance, and patience when listening to me complain about my project and how I never thought would finish. I would also like to thank my Mom, Dad and Brother for all their encouraging words. Finally, I would to thank my fiancée, Sujata Dutta. She has been incredibly helpful during this entire process. She never let me get too down on myself and was always willing to do anything I needed help with to keep the project going including cooking dinner or helping me measure hydraulic conductivity.

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Introduction

Low Impact Development (LID) is a series of techniques and tools that allow stormwater engineers to mitigate the effects that impervious surfaces have on stormwater runoff. LID is intended to reduce the amount of runoff generated from a site for each rain storm and reduce the amount of pollutants carried from the site to a nearby water body. In short, LID is meant to minimize the effects human development has on the hydrologic cycle and water quality. LID employs several different techniques to meet its goals. Constructing rain gardens/bioretention basins, installing green roofs and/or removing impervious surfaces are some of the techniques available to engineers from LID. One of the methods used to remove impervious surfaces is to replace them with pervious surfaces. Pervious concrete (PC) (See Figure 1), pervious asphalt (PA) (See Figure 2), and Turf stone (See Figure 3) are commonly used to replace impervious surfaces that still require the strength found in concrete and asphalt.

Figure 1: Pervious Concrete, (A.G. Peltz 2010)

Figure 2: Pervious Asphalt, (Minnehaha 2010)

Figure 3: Turfstone, (Coutesty of Don Knezick)

Generally, a pervious pavement system consists of a pervious surface, one or more layers of varying gravel sizes, and an underlying subbase. The pervious surface allows rainfall and runoff to flow through and below the surface, which reduces the amount of runoff generated for each storm. PA and PC are similar to traditional asphalt and concrete, but the fine particles typically included in these mixes have been greatly reduced or removed completely. The absence of fines allows void spaces to form in the PA and PC. Some of the void spaces become connected and allow stormwater to travel through them. The hydraulic conductivity of the cores is related although, not completely to the porosity of the PA or PC (ACI Committee 2006). Turf stone is a concrete lattice with soil and vegetation in the empty spaces of the lattice. Underneath the lattice are 2 to 4 layers of stone of varying size very similar to the subbase of PA or PC. The vegetation and soil allow runoff and rainfall to travel through and below the surface instead of over it.

PC is used in parking lots, roadways and sidewalks. The hydraulic conductivity, porosity and compressive strength of the PC vary depending on the mix of the PC. Hydraulic conductivity is defined as measure of the capability of a medium to transmit water. Porosity is the amount of void spaces measured in an object or volume. The compressive strength of the object is the maximum amount of force that can be placed upon a material before it is crushed. The hydraulic conductivity of PC has been measured in the field to have a range of 13 mm/hour to 4,000 mm/hour (Bean et al. 2007). PC has a porosity ranging from approximately 2 to 40% (Thompson 2008). The hydraulic conductivity of pervious pavement changes over time due to use and its location (Gerrits and James 2002). Over time the dominant soil type of the location will affect the hydraulic conductivity of the PC. The dominant soil type collects on the surface of the PC through erosion, wind and other natural forces. The smaller the average particle sizes of the soil type, the greater the effect it has on the hydraulic conductivity (Bean et al. 2007). Studies have shown that the hydraulic conductivity of PC is at its highest soon after installation is complete (Bean et al. 2007). As time goes on the hydraulic conductivity of PC decreases; the hydraulic conductivity can decrease so much that the PC loses all usefulness. At this point, the PC would be considered clogged and has lost all of its utility.

Wherever PC is installed it is recommended to have a subbase for structural integrity underneath the PC which doubles as a storage volume for infiltrated stormwater. The PC infiltrates the stormwater very quickly and the stormwater is held in the storage volume as it slowly infiltrates into the ground. Sometimes, underdrains are installed in the subbase if the dominant soil's hydraulic conductivity is too low. The underdrain can be a perforated pipe in the subbase that releases the stormwater collected in the storage volume to another location (typically the storm sewer system) if the elevation of the stormwater in the storage volume is too high. Underdrains allow PC to continually infiltrate stormwater by controlling the volume of stormwater runoff in the storage volume underneath PC.

The surface of the PC can clog very quickly if it is not maintained properly thus removing the PC's capability to reduce runoff and all of its value as a product. Clogging is the process that reduces the hydraulic conductivity of a system due to physical, biological and chemical processes (Bouwer, 2002). Over time, sediment deposits build up at or near the surface of PC; filling in the void spaces of the PC. This decreases the porosity at the surface thus decreasing the hydraulic conductivity of the PC (Bean et al. 2007, James and Von Langsdoff 2003, Gerrits and James 2002, Wilson 2002 and Haselbach et al. 2006). Sediment deposition comes from vehicle wear and tear, erosion and litter (CWP 2006). The majority of the sediment has been documented to be located within the first 13 to 19 mm from a pervious surface (Bean et al. 2007, James and Von Langsdoff 2003, Gerrits and James 2002, Wilson 2002 and Haselbach et al 2006). Many studies have examined the initial hydraulic conductivity of newly-installed PC and returned years later to re-measure the hydraulic conductivity and to compare those values with the initial ones (Bean et al. 2007, James 2003, and Wilson 2002). The hydraulic conductivity of PC that is ten years old and experienced little to no maintenance will be diminished enough that the difference can be detected from visual observation alone (Bean et al. 2007, James 2003, and Wilson 2002). There is a lack of literature on the topic of the loss rate of hydraulic conductivity over time for PC.

LID methods have been around since the 1970's (ACI Committee 2006). Recently there has been a growing interest in them. More engineers are using these techniques to reduce and/or treat stormwater runoff. Regulatory agencies including the New Jersey Department of Environmental Protection (NJDEP) are creating new regulations that meet or exceed the stormwater management standards set forth by the Clean Water Act. These rules control the flow rates and treatment of stormwater runoff from individual sites.

In subchapter 5, "Design and Performance Standards for Stormwater Management Measures", of the New Jersey Administrative Code Title 5, Chapter 12 "Residential Site Improvement Standards" regulates how each new development in New Jersey over one acre in size treats and discharges its stormwater. The rules encourage the use of non-structural practices but also recognize that the site cannot meet the rules by using non-structural practices alone. The site must demonstrate through hydrologic and hydraulic analysis that 100% of the groundwater recharge achieved annually under pre-development conditions is maintained after development. Or, the groundwater recharge volume for the 2-year storm must not increase after development. The peak flow rate for the 2-, 10-, and 100- year storm must not increase from the pre-development hydrographs. The post construction peak flow rate must be reduced to less than 50%, 75% and 80% of the pre-construction rate for 2-, 10-, and 100- year storm, respectively. It is new regulations like these that require engineers to explore innovative ways to treat and manage stormwater such as PC.

LID methods are more expensive up-front than traditional stormwater methods. If a LID project is built and maintained properly, it will remain functional for a long period of time. If a LID project is found to be failing after installation, the owner of the site must take action to either repair the project or install a new project (both actions will add considerably to the price of the original project). Some of the maintenance plans for LID technology are based on anecdotal evidence not rigorous research. LID projects are seen as more risky by engineers than the traditional methods. Engineers feel more comfortable with traditional methods because they have much more experience using them and understand the systems much better.

For example, if an owner of a property decides to build a shopping plaza on his/her property, the property owner will have to install infrastructure to properly drain the site during storm events. The owner could chose to install PC instead of a typical drainage infrastructure with catch basins and concrete pipes. PC's ability to infiltrate the runoff from very large storms allows the property owner to save money by using a drastically smaller set of drainage infrastructure. Engineers will feel hesitant about using PC because there have been case studies of the PC clogging very quickly after installation due to various reasons (such as improper use and installation). If that happened the parking lot would have to be ripped up and have the traditional system installed. These additional procedures would dramatically increase the cost of the project. It is this kind of risk that makes engineers and property owners wary of using LID methods despite their potential environmental and economic advantages.

Engineers are very interested in how to properly build and maintain LID projects such as PC. Two methods recommended for the maintenance of PC are vacuuming and power washing (Inspection and Maintenance 2009). Street sweeping was originally considered a maintenance practice. Later on, it was found that the street sweeping did not remove sediment from the surface the PC merely moved it around. In a worst case scenario it drove the sediment deeper inside the pervious concrete making it harder to remove (Bean et al. 2007). Vacuuming is recommended on an annual or semi-annual basis (Inspection and Maintenance 2009). The vacuuming removes the sediment from the top layer of the PC rejuvenating hydraulic conductivity. Power washing is considered a maintenance practice of last resort. The power washing will drive the sediment further into the PC but this is only meant to be used on small surfaces where a lens of sediment has developed just below the surface of the concrete and the power washing while driving the sediment further into the concrete will break the lens apart improving the hydraulic conductivity of the pervious concrete at that location (See Figure 4).

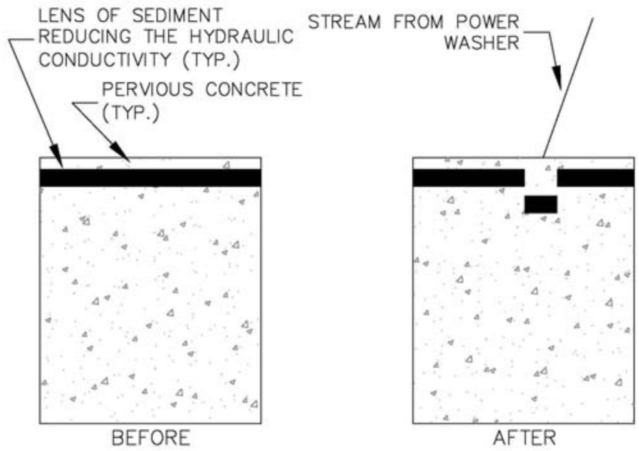

Figure 4: How power washing increases hydraulic conductivity

Not much investigation has been conducted into the incremental change of the hydraulic conductivity. Currently, the existing recommended maintenance practice for PC is to clean it with a vacuum truck a few times a year (Inspection and Maintenance 2009). This practice is not based on scientific research but from experience of site managers and anecdotal evidence. If engineers and site managers had a better understanding of how quickly the hydraulic conductivity decreases immediately after installation they would be able to tailor maintenance plans to specific sites potentially saving site managers money in maintenance costs while preventing the PC from losing its effectiveness. Different soil types have been shown to have an unequal impact on the hydraulic conductivity overtime. Understanding how different soil types affect the hydraulic conductivity would give greater ability to the site manager and/or engineer to modify the maintenance plans based on the surrounding area's characteristics. If a general equation could predict the rate at which the hydraulic conductivity of pervious concrete decreases based on the amount of sediment that has accumulated in the PC, engineers would be able to use PC more efficiently. Engineers could design maintenance plans that would maximize the lifetime of the PC. A small area of PC is capable of infiltrating runoff from a much larger drainage area. This arrangement would also deliver all the sediment from that large drainage area to that small area of PC. The general equation would allow engineers to create a maintenance program designed to mitigate any effect the increased loading rate of sediment would have on the PC and ensure a maximum utility out of the PC.

This study measured the decreasing hydraulic conductivity found in PC due to the accumulation of sediment at or near the surface of the PC. This study used two different types of sediment to quantify the effect that the particle size of a soil type has on the changing rate of hydraulic conductivity. For the sake of this project, it assumes that the PC was recently installed on roadway.

Objective

The objective of the project was to measure and record the declining hydraulic conductivity that occurs in PC through sediment accumulation at or near the surface of the PC. By accounting for the amount of sediment in the PC as time passes; a correlation between sediment accumulation and the hydraulic conductivity will develop. The project was run as two sets of three PC cores. Each set had a designated sediment type (sand or clay). Sand particles range in diameter from 0.0625mm to 2 mm. Particles are considered clay when their diameter is smaller than 2 µm.

The Pine Barrens of southern New Jersey is one of the largest areas with a sandy dominant soil type. The shoreline of southern New Jersey is dominated by sandy soils. There is a stripe of clay soil that runs diagonally across the state. It starts on the southwestern shore of the Delaware River and follows the shoreline until river abruptly changes direction at Trenton. It continues in the same direction across the rest of the state until it reaches the shores of the Raritan Bay. This stripe is approximately 15 miles wide.

Using two different sediments of significantly different particle size quantified a range of impact the particle's size has on the rate of change of the hydraulic conductivity for PC. The measurement of the hydraulic conductivity and sediment accumulation was used to create a model to predict the effects for the two different sediment types at any accumulation rate.

Preliminary Research

The original intent of this project was to determine the minimal amount of sediment it would take to clog porous concrete. This project began with a series of small pilot projects. The purpose of these pilot studies was to develop a proof of concept before moving on to develop the final scope and purpose of the project. The first experimental design of this project was very simple. The PC cores would be placed in an apparatus similar to the apparatus used in the final design. Tap water with suspended sediment would be poured on to the surface of the porous concrete in less than a minute. The volume discharged on the surface of the PC would be equal to the volume of stormwater runoff generated from the New Jersey Stormwater Quality Storm (3.175 cm total in depth). The initial results from this method showed no noticeable accumulation of sediment or decrease in hydraulic conductivity. This method was used to simulate ten years of stormwater passing through the PC. The conclusions from these results were that the suspended sediment remained suspended as it traveled through the void spaces of porous concrete. It was determined that the method needed to be altered to more accurately mimic rainfall.

The experimental design was changed. Instead of directly pouring tap water with suspended sediments, the water would be placed in a bucket that has a few small holes drilled into its bottom. The bucket would be placed above the core. The water would slowly drip out of the bucket on to the surface of the porous concrete. The rate of water discharging to the PC is greatly reduced from the original design. The storm volume was increased to 12.7 cm of simulated rainfall and was discharged over an hour. The volume of the simulated storm was increased due to logistics with using the bucket. This method did not yield any noticeable accumulation of sediment or change of hydraulic conductivity. While the results did not change, the reasons for the results are assumed to be different. The sediment was not able to get to the PC because it settled out of the water column on to the bottom of the bucket. Test results showed that approximately 50% of the sediment deposited at the bottom of the bucket. Once again, this method did not accurately mimic what has been observed in the field numerous times.

The design experiment was reconceived. After reviewing more literature, it was determined that sediment is deposited on the surface on pavement during dry periods. Sediment deposition rates were found in literature. Sediment was taken from a nearby parking lot. The sediment was deposited on the surface of the PC, dry. Then a storm simulated on the PC core using the bucket method described above for several storms. The results from these tests were found to mimic the real-life observations; sediment accumulation and a decrease in hydraulic conductivity were observed. This method was refined to develop the final experiment design that is described in later sections. The bucket was replaced with an automated system to increase efficiency of rain delivery.

Methods

Core Preparation

This project used PC structural cores to measure the effect sediment deposition had on the hydraulic conductivity of pervious concrete. The cores were provided by Conewago Contractors (Hanover, PA). Each core had the same surface area of approximately 167.74 square centimeters on its top (diameter of 14.6 centimeters). A concrete saw with a diamond blade cut the concrete cores between ten and thirteen centimeters thick. This thickness is within the recommended range of thickness for pervious concrete found in the field (Chopra 2007). After each of the cores was cut to the pre-determined thickness, the porosity and initial hydraulic conductivity of each core was measured and recorded. This study used a total of six cores.

Porosity Measurements

The porosity of the pervious concrete was measured by following the method below:

The diameter and height of each core was measured three times at three different locations. The values for diameter and height were averaged and average values were used to calculate the volume of each core. The diameter of a 5 gallon paint bucket was measured at 3 different locations and averaged. The bucket was filled with approximately 20.3 cm of water. After the bucket was filled but before the core was placed in the bucket the exact height of the water was recorded as h1. A core was submerged in the water inside the bucket. The core was tapped on all sides to release the air trapped in the void spaces of the core. The core remained submerged for 30 minutes. After thirty minutes, the core was flipped upside down while still completely submerged. After the core was flipped, the height of the water was recorded (h2, this is the final height of the water). The difference of h2 and h1 was multiplied by the surface area of the water in the bucket (See Equation 1). This volume was divided by the calculated volume of the core and multiplied by 100%. The product is the porosity of each core.

$$A = \pi \bar{R}^2$$

A = Area

$\bar{R}$ = Average Radius

Equation 1: Area of Top of PC Core

Experimental Apparatus Description

After the initial porosity was recorded, the core was placed in the experiment apparatus which was designed to allow the hydraulic conductivity of the core to be measured for the duration of the experiment (See Figure 5). The roof flashing extended to a minimum of ten centimeters above the surface of the core and two and one half below (Figure 6).

Two marks were made on the inside on the roof flashing. One mark was 2.5 centimeters above the surface of the PC and the other was 7.5 centimeters above the surface of the PC. These marks were used to measure the hydraulic conductivity of the cores. After the first layer of roof flashing was secured, the core and the first layer of roof flashing were tightly wrapped in 2.5 cm thick neoprene. The neoprene extended at most 1.75 centimeters above and below the core. The neoprene was held in place with duct tape, temporarily (see Figure 7). The final layer surrounding the core was another layer of roof flashing. The top of the flashing was flush with the surface of the core and the bottom was at least 12.5 centimeters below the bottom of the core. Hose clamps held the aluminum flashing to the core and created a tight seal around the edge of the entire core. At the bottom of the flashing an opening was created to allow water to exit the apparatus after it passed through the core (See Figure 8 for Picture of the Apparatus).

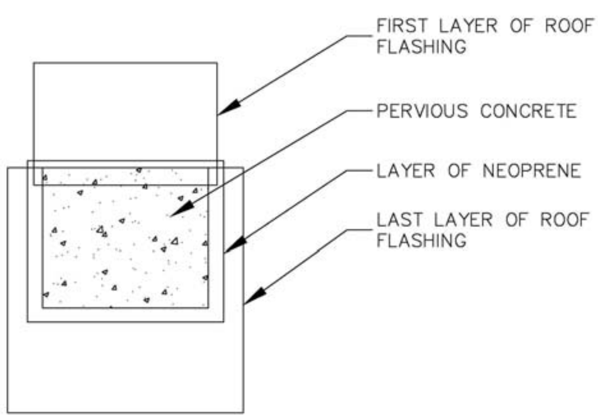

Figure 5: Diagram of Apparatus

Figure 6: First layer of roof flashing

Figure 7: Neoprene wrapped around core

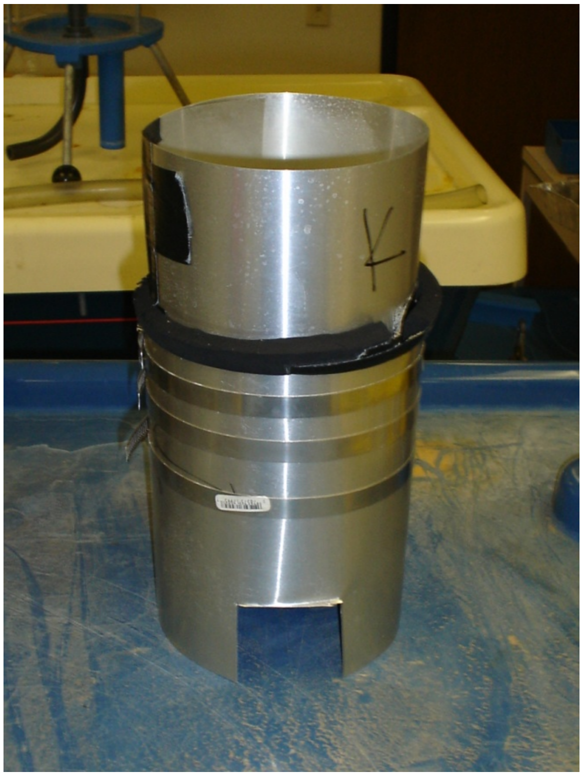

Figure 8: Photograph of core in experiment apparatus

Hydraulic Conductivity Test

The initial hydraulic conductivity and all other hydraulic conductivity measurements taken throughout the project were measured by using a falling head permeability test (Das 1998). Tap water was delivered to the surface of the core. After the tap water had risen above the highest mark on the roof flashing (7.5 cm above the surface of the core) and water was discharging out the bottom of the core (ensuring total saturation of the core), the tap water was shut off and the water's elevation was allowed to fall. The time for the water level to fall from the highest mark to the lowest mark (5 cm) was recorded. The hydraulic conductivity of the core was calculated using the following equation (Das 1998):

$$k = \frac{aL}{At} LN(\frac{h_1}{h_2})$$

Where,

k = coefficient of permeability, L/T

a = cross-sectional area of the core, L^2

L = length of core, L

A = cross-sectional area of specimen, L^2

t = time for water to drop from h1 to h2, T

h1 = initial water level, (L)

h2 = final water level, (L)

The datum of this experiment is the bottom of the core

Equation 2: Falling Head Equation

Sediment Description and Application Procedure

The characteristics of road dirt (or sediment accumulated on the road) vary depending on the dominant soil type of the immediate area, the traffic volume, and the surrounding vegetation (Pitt et al. 2004). Two types of sediment were selected for this project. The sediments were purchased at the New Jersey Sand and Gravel Company located in South Wall, New Jersey (www.njgravelsand.com). Coarse sand and pitcher's mound clay mix were the two products chosen. The sediments have a significant difference in particle size. A particle size distribution test was conducted for each type of sediment in duplicate. The particle size distribution test followed the ASTM D6913 - 04e2 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.

Collecting sediment from the field offered no guarantee that the sediment samples would be sufficiently different. By choosing to purchase the sediment, it would be easier to select two products with significantly different particle size distributions. This would also provide a reliable, consistent source of material if additional sediment would become necessary for later experiments.

Sediment is deposited on road surfaces during dry periods (CWP 2006). Deposition of sediment is typically from the following activities: erosion, vehicle emission, street condition and atmospheric deposition (CWP 2006). Poor quality roads have been recorded to accumulate 3.86 mg/sq. cm. after 2 days of dry weather (Pitt et. al. 1979). After two days of dry weather it was found that the roadway has accumulated 75% of the sediment it would accumulate in over 50 days of dry weather(Pitt 1979) (See Figure 9). On average New Jersey experiences 2 days of dry weather in between measureable amounts of precipitation (Climate 2009).

The loading rate of poor quality roads was used as opposed to high quality roads because poor quality roads have a rough surface and so does PC. This rough surface is one of the factors that allow the poor quality roads to accumulate more sediment than high quality roads in the same amount of time. The sediment deposition rates were averaged by quality of roads not traffic volume.

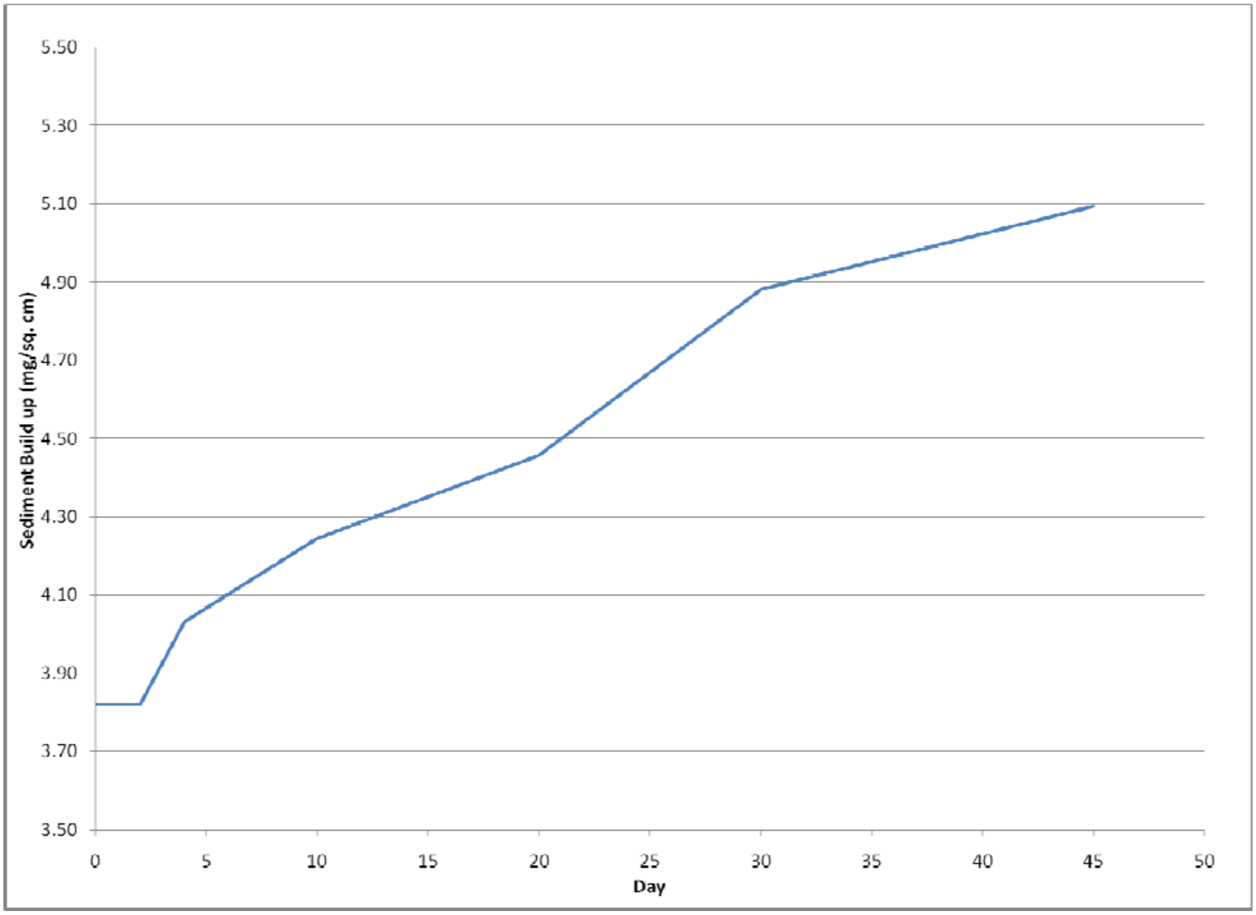

Figure 9: Mass of sediment of build up on surface (Pitt 1979)

Rainfall Simulation

The rainfall was simulated with a H313 Hyrdology Apparatus from TecQuipment (see Figure 10). The H313 is an apparatus with a metal frame that holds a stainless steel tank and a reservoir tank filled with tap water. Spray nozzles above the stainless steel tank simulate rainfall and the tank acts as a catchment area. A rotameter controls the intensity of the storm simulated in the apparatus, which has a storm intensity range of 0.05 to 19 l/min on a 2 m^2 area (TecQuipment 2008).

The researchers chose to try to mimic the volume of a New Jersey Water Quality Storm because it is the smallest design storm in New Jersey regulation. It is also the design storm that most frequently occurs on a yearly basis in New Jersey (Semple *et al.*, 2004). Theoretically, the Hydrology Apparatus should be able to produce a rain intensity of 3.175 centimeters per hour but during the apparatus calibration, it was found that at the lowest setting the rainfall intensity had significant variability and was well above 3.175 centimeters per hour. The rainfall intensities ranged from 7.6 to 17.8 centimeters per hour during the calibration. The H313 is stated to have the capability to mimic a wide range of storm intensities. It has the ability to do this by allowing the spray nozzles to equally distribute the water across the entire drainage area of the apparatus. At very low flow rates the spray nozzles lose their ability to spray and are unable to produce very low intensities. At low flow rates required to mimic low intensities the water simply drips out of the spray nozzle. The Hydrological Apparatus could not exactly simulate the New Jersey Water Quality Storm. The researchers decided to use the Hydrological Apparatus because it was the best option to simulate a rain storm for this experiment. Only they would match the volume generated from the New Jersey Water Quality Storm by using a reasonably small storm intensity considering the limits of the Hydrological Apparatus. The simulated intensity would not have an intensity greater than 12.5 centimeters per hour during one storm and each storm should last between 15 to 30 minutes. Due to the researchers' limited abilities this was the best simulation they could create under these circumstances. This would generate the volume of rainfall produce (530 cubic centimeters, this volume was calculated by multiplying the surface area of the core with the depth of the storm) in a New Jersey Stormwater Quality storm but in a much shorter time. All six cores were run simultaneously.

Figure 10: Photograph of H313 with cores in it

At low flow, each spray nozzle does not spray but drip. This may not wet the entire surface of the core during each storm. The drip method is desirable because this method more accurately replicated the desired storm intensities for this experiment. To ensure that the entire surface of the core was rained upon, a method was laid out to rotate the location of where the drip landed during each storm event. There are five locations for the drip to land. The rotation of the positions will follow the pattern displayed in Figure 11.

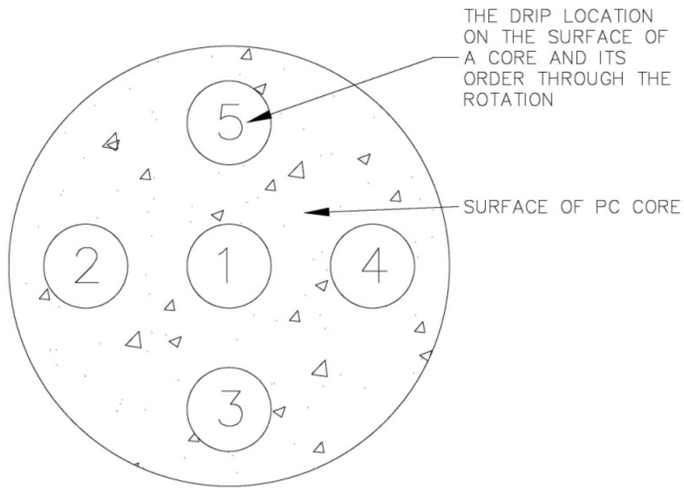

Figure 11: Drip Landing Locations and Order of Rotation for experiment

Calibration of Hydrological Apparatus

At the lowest flow rate, the spray nozzles would not spray but in fact only drip out water. The rate of the dripping water was found to be within the range of acceptable storm intensities. The rotameter would no longer be of any use. A new method of measuring the flow rate was developed without the rotameter, using a scale, a stopwatch and a graduate cylinder. The mass of the graduated cylinder would be measured on the scale and recorded. The graduated cylinder collected water from one of the nozzles for one minute. The new mass of the graduated cylinder with water would be recorded and using the mass of the water and the time, storm intensity was calculated. The mass of the water was converted into volume and that volume was divided by the surface area of the core and divided again by one minute to calculate the intensity produced at that nozzle.

Experiment Design

For the first 5 storms, a hydraulic conductivity test was run after every storm to measure any dramatic change in the hydraulic conductivity that was observed in preliminary research. Once the change in hydraulic conductivity was less than 20% of the previous hydraulic conductivity, the hydraulic conductivity was tested after every two to four storms. This produced between 25 and 50 hydraulic conductivity tests over the course of the entire experiment (85 storms). The testing period varied in the beginning of the experiment. The researchers were trying to determine the best testing frequency. Each hydraulic conductivity test followed the method described above. During most of the experiment the hydraulic conductivity was tested after every two storms (which were determined to be the best sampling period) for a total of 47 hydraulic conductivity tests.

The cores have a surface area of approximately 167.74 square centimeters which would make the loading rate for each core 0.64 g of sediment. Before each simulated storm 0.64 g of sediment were deposited as evenly as possible on the surface of each PC core. The total mass of the sediment deposited on each core was recorded. The core received 85 storm simulations with 85 sediment deposits for a total of 55.08 g of sediment. The hydraulic conductivity of pervious pavers (eco-stone) has been found to be significantly affected after 1.4 kg per square meter of sediment was deposited on the surface of the pavers this would be a total mass of 23.48 g for surface the size of the core (James et al. 2003). While pavers are not PC, they do have a similar structure and function. This data provides a frame of reference for much sediment the researchers should expect to clog PC. This protocol was followed for both sets of cores.

After the initial test, the effluent from each hydraulic conductivity test was collected and tested for total suspended solids (TSS) following Standard Method 2540-D (ASTM, 1997). The entire volume of effluent from each hydraulic conductivity test was filtered and analyzed for TSS in order to quantify the amount of sediment that flushed through the core. The intensity of the storm simulated for this project is as low as possible and no sediment was expected to be in the core effluent after the storm simulations. Preliminary research showed that very little if any sediment was released during the simulated storm events. The total mass of sediment accumulated in the core was recorded and the mass of sediment released due to the hydraulic conductivity test was subtracted from the accumulated total. The TSS tests continued until the amount of sediment measured in the TSS tests was equal to or less than 5% of the total mass accumulated in the core. After the routine tests were stopped, TSS was tested on the effluent after storms 40, 60 and 85. It was assumed that if less than 5% of the sediment was released during the hydraulic conductivity tests, than the simulated storms would not release any significant amount of sediment because the intensity of the storms was drastically smaller than the hydraulic conductivity test.

Results

Porosity Calculations and Measurements

The porosity of each core was measured using the method described above. The results of the porosity test are in Table 1. The average porosity of all the cores was 25.73% with a standard deviation of 3.57%. The dimensions of the cores were recorded to calculate the porosity of each core. The average diameter was 15 centimeters with a standard deviation of 0 centimeters. The average height of the cores was 11.88 centimeters with a standard deviation of 0.4 centimeters. The average dimensions for each core can be found in Table 2. The porosity measurements all fell within the range of porosity of pervious concrete in the literature of 6 to 37% (ACI Committee 2006).

Table 1: Porosity Measurement of Cores

Core	Avg. Porosity
	(%)
Sand 1	20.00
Sand 2	27.41
Sand 3	27.87
Clay 2	28.40
Clay 1	22.49
Clay 3	28.18
Average	25.73
Standard Deviation	3.57
Max	28.40
Min	20.00
Max-Min	8.40

Table 2: Dimensions of Pervious Concrete Cores

Core	Avg. Height	Avg. Diameter
	(centimeters)	(centimeters)
Sand 1	11.54	14.92
Sand 2	11.48	14.92
Sand 3	12.38	14.92
Clay 1	11.91	14.92
Clay 2	11.64	14.92
Clay 3	12.44	14.92
Average	11.90	14.92
Standard Deviation	0.42	0.00
Max	12.44	14.92
Min	11.48	14.92
Max-Min	0.95	0.00

Initial Hydraulic Conductivity Test

The initial hydraulic conductivity was measured three times and the average was used. The standard deviation for the initial hydraulic conductivity tests for all the cores is less than one second (Table 3). An ANOVA test was performed on the hydraulic conductivity results and the times used to calculate hydraulic conductivity. Three measurements of hydraulic conductivity and the time measured to calculated hydraulic conductivity were both found to be significantly different from the measurements of the other cores. (Time P value = 4.68*10^-8 and Rate P value = 3.32*10^-9). The cores do fall into three categories according to the initial hydraulic conductivity results. Sand-1 and Clay-2 have a hydraulic conductivity in between 750 and 1,000 cm/hour. Sand-2 and Clay-1 have a hydraulic conductivity in between 1,000 and 1,250 cm/hour. Sand-3 and Clay-3 have a hydraulic conductivity in between 1,525 and 1,775 cm/hour. The hydraulic conductivity of each core fell into the acceptable range of hydraulic conductivity found in literature (381 cm per hour to 34,798 cm per hour) (ACI Committee 2006). One core from each category was assigned sand as its sediment and the other was assigned clay. While the range in each category differed greatly, it was seen as the best way to examine how two sediment types affect pervious concrete with a wide range of hydraulic conductivities.

Table 3: Recorded Times for each initial Hydraulic Conductivity Test for each Core

	Sand-1	Sand-2	Sand-3	Clay-1	Clay-2	Clay-3
	(s)	(s)	(s)	(s)	(s)	(s)
Initial Test 1	13.13	10.78	8.5	12.83	13.41	7.16
Initial Test 2	14.35	12.44	9	12.94	14	7.69
Initial Test 3	14.25	11.34	9.63	12.34	14.9	7.31
Average	13.91	11.52	9.04	12.7	14.1	7.39
Standard Deviation	0.68	0.84	0.57	0.32	0.75	0.27

Table 4: Results of Initial Hydraulic Conductivity Results

	Sand-1	Sand-2	Sand-3	Clay-1	Clay-2	Clay-3
	(cm/hr)	(cm/hr)	(cm/hr)	(cm/hr)	(cm/hr)	(cm/hr)
Initial Test 1	974.65	1,185.49	1,658.98	1,006.68	956.87	1,826.26
Initial Test 2	891.79	1,027.30	1,566.82	998.12	916.53	1,700.40
Initial Test 3	898.04	1,126.95	1,464.31	1,046.63	861.16	1,788.80
Average	921.50	1,113.25	1,563.37	1,017.14	911.52	1,771.82
Standard Deviation	46.14	79.98	97.38	25.89	48.05	64.62

Sediment Particle Size Analysis

Two samples were taken from each type of sediment. The D50 for Sand-A and Sand-B is an average of 265 micrometers. The D50 for Clay-A and Clay-B is 80 micrometers. While, Clay-A and Clay-B do not meet the USDA standards for Clay, it will be referred to clay throughout this document because it was labeled as pitcher's mound clay from the quarry where it was purchased. A t-test was performed on the mean diameter size. The two types of sediment were found to be significantly different (p-value 0.0007). Particle Size Distribution Curves were developed for each sample (Figure 12).

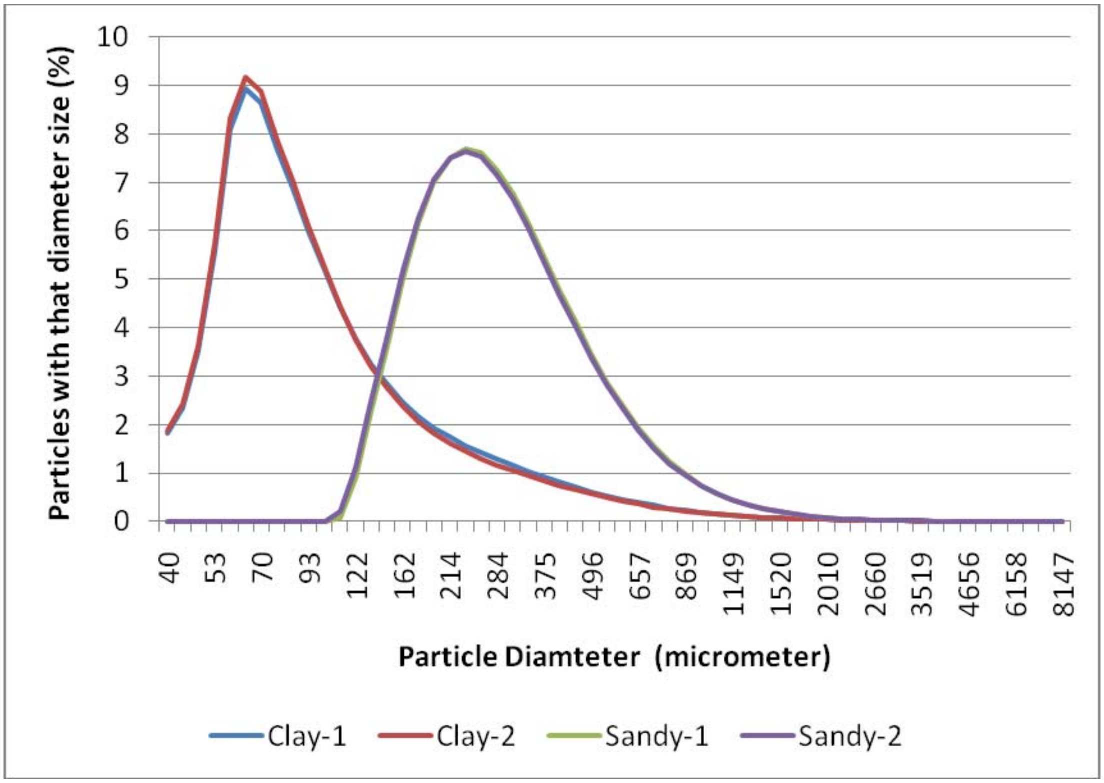

Figure 12: Distribution of Particle Sizes for all four sediment samples

Calibration of Hydrology Apparatus

The simulated storm intensity of each nozzle was measured four times at four different intensities. The storm intensities were compared for each trial to test the consistency of the system for each nozzle. The intensity was measured once from each nozzle during each trial. The largest standard deviation of the storm intensities was 5.26 centimeters per hour. Once again, these results are not as good as the researchers would have preferred but these are the best results they could have with the equipment that was available to them. There was no correlation between smaller storm intensity and standard deviation. This was considered an acceptable amount of variance, due to the limitations of the equipment, to allow the experiment to proceed (See Table 5).

Table 5: Measurements from Calibrating Hydrologic Apparatus

Trial	Average Flow Rate (cm/hour)	St. Dev of Flow Rate. (cm/hour)	Max Flow Rate (cm/hour)	Min Flow Rate (cm/hour)
1	49.17	3.25	53.01	41.91
2	21.82	3.45	26.92	16.36
3	19.91	5.26	25.53	7.90
4	12.52	3.94	18.80	5.11

The Hydrology Apparatus was turned off during each hydraulic conductivity test. Before the storm simulations would begin again, the storms intensity would be measured and recorded. The storm simulation would not begin again, until the measured storm intensity was within the acceptable range of 6.3 to 12.5 cm/hour. After each storm rate was measured, a storm duration time was calculated so each storm produced the same volume of rainfall. The volume was the volume that would be generated during a New Jersey Water Quality Storm (530 cubic centimeters). The record of all the storm intensities can be found in Table 6.

TSS Test Results

The effluent of each hydraulic conductivity test was collected and analyzed for TSS until all of the samples were found to be less than 5% of the total accumulated sediment in each core. The results from the TSS tests can be found in Table 7. The sediment lost during the hydraulic conductivity test was measured to be less than 5% of the total accumulated sediment in each core after nine storms (see Table 8). The effluent from the hydraulic conductivity after the tenth storm was collected and tested to confirm this result.

The effluent from the hydraulic conductivity tests after storms 40, 60 and 85 were tested. These tests were performed to determine if the sediment loss during the hydraulic conductivity test changed as the hydraulic conductivity of each core decreased. The samples for Sand-1 at Storm # 9 and Clay-3 at Storm # 40 were damaged during the testing process and the samples were lost.

Table 6: Record of Simulated Storms

Storm #	Rate	Duration of Storm	Storm # (Cont.)	Rate	Duration of Storm
	(cm/hour)	(min)		(cm/hour)	(min)
1	7.11	27	42	10.16	19
2	7.62	25	44	8.64	22
3	10.67	18	46	10.41	18
4	6.86	28	48	11.94	16
5	9.91	19	50	11.94	16
9	12.45	15	52	8.13	23
10	6.35	30	54	8.13	23
12	7.62	25	56	10.16	19
14	9.91	19	58	10.67	18
16	11.68	16	60	12.45	15
18	12.19	16	62	8.89	21
20	11.94	16	64	9.40	20
22	9.40	20	66	11.68	16
24	11.18	17	68	11.43	17
26	12.45	15	70	8.38	23
28	8.64	22	72	11.94	16
30	11.43	17	74	12.45	15
32	10.16	19	76	8.13	23
34	12.45	15	78	11.43	17
36	10.67	18	80	11.68	16
38	12.70	15	82	12.19	16
40	10.67	18	85	11.18	17

Table 7: Recorded Sediment Lost after Selected Hydraulic Conductivity Tests

	Sand-1	Sand-2	Sand-3	Clay-1	Clay-2	Clay-3
# of Storms	(mg)	(mg)	(mg)	(mg)	(mg)	(mg)
1	44.8	110.7	226.5	68	215.6	123.1
2	67.7	72.5	133.8	49.1	110.4	220
3	45.4	78.7	71.4	40.2	134.3	103.3
4	54.9	31	94.8	62.8	56	114.4
5	48.6	38.2	67.6	55.1	45	118.7
9	n/a	74.1	139.8	118.4	73.8	214.3
10	51.5	74.1	139.8	118.4	73.8	214.3
40	14.2	47.5	81.9	80.3	37.8	n/a
60	32.2	41.6	42.4	47.4	47	416.6
85	47.1	37.7	46.5	44.5	32.5	338.1

Table 8: Percent of Total Accumulated Sediment Lost After Selected Hydraulic Conductivity Tests

	Sand-1	Sand	Sand-3	Clay-1	Clay-2	Clay-3
# of Storms	(%)	(g)	(g)	(g)	(g)	(g)
1	6.89%	17.03%	34.85%	10.46%	33.17%	18.94%
2	5.39%	6.10%	12.46%	3.99%	10.18%	18.69%
3	2.47%	4.45%	4.49%	2.19%	8.27%	6.43%
4	2.25%	1.33%	4.37%	2.57%	2.62%	5.31%
5	1.60%	1.29%	2.48%	1.82%	1.65%	4.41%
9	n/a	1.34%	2.66%	2.12%	1.40%	4.14%
10	0.83%	1.22%	2.42%	1.94%	1.26%	3.82%
40	0.06%	0.19%	0.35%	0.34%	0.16%	n/a
60	0.09%	0.11%	0.12%	0.13%	0.13%	1.32%
85	0.09%	0.07%	0.09%	0.09%	0.06%	0.79%

Table 9: Percent of Total Accumulated Sediment Lost at the End of the Experiment

Sand-1	Sand-2	Sand-3	Clay-1	Clay-2	Clay-3
3.01%	4.58%	7.61%	6.49%	4.92%	23.28%

The total amount of accumulated sediment was accounted for by adding the amount of sediment discharged to the surface of the core before every storm and subtracting the amount of sediment that was lost during the hydraulic conductivity test. If the sediment loss was not measured for a hydraulic conductivity test then the sediment loss from the last measured hydraulic conductivity test was used (see Figure 12, the tabulated results for Figure 12 can be found in the Appendix). The total amount of accumulated sediment in each core was similar except for Clay-3. Clay-3 lost much more sediment for each hydraulic conductivity test than the other cores (on average Clay-3 lost 3.5 times the amount of sediment than the other cores).

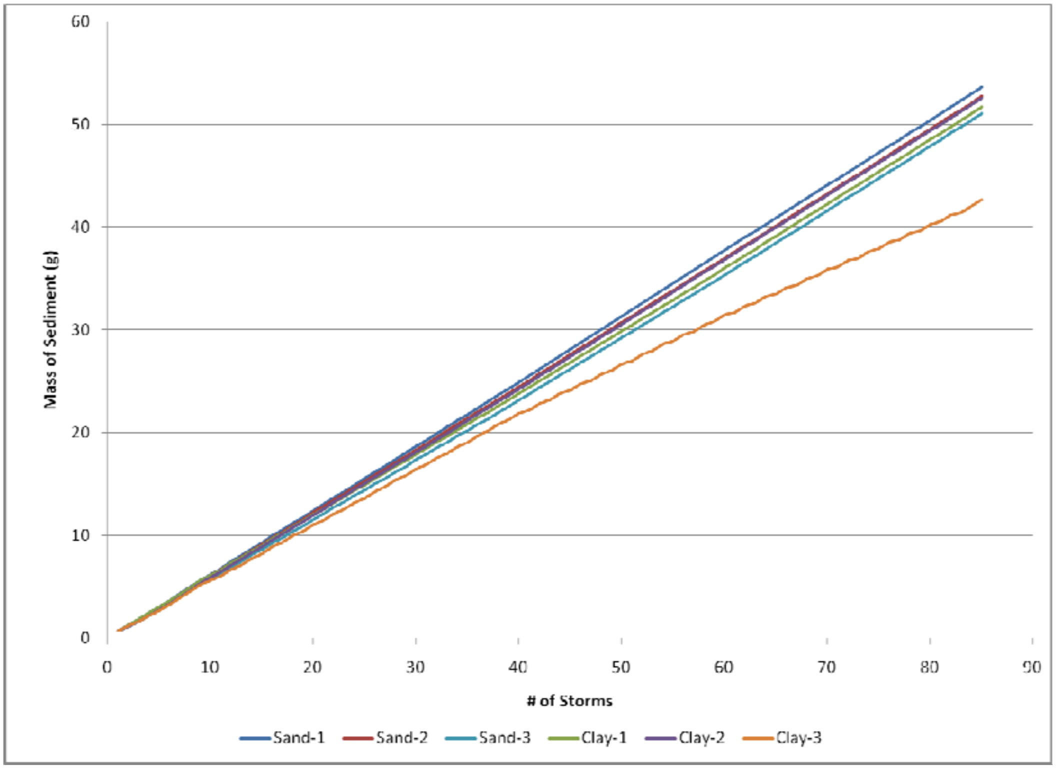

Figure 13: Estimated amount of sediment accumulated in each core

Hydraulic Conductivity Test Results

Initially, the hydraulic conductivity was measured after every storm in order to see any dramatic changes from the initial hydraulic conductivity. After it had been established that there was to be no immediate noteworthy change in the hydraulic conductivity, the plan of the experiment was to test the hydraulic conductivity after every five storms. After storm #9, it was decided that it would be better to measure more frequently. Preliminary research showed evidence of the hydraulic conductivity changing drastically in a matter of a few storms. During most of the experiment the hydraulic conductivity was measured after every two storms. The results of the hydraulic conductivity test plotted against accumulated sediment with trend lines, trend line equation and r-squared value for each trend line (See Figure 13 and 14, the tabulated results for Figure 13 and 14 can be found in the Appendix).

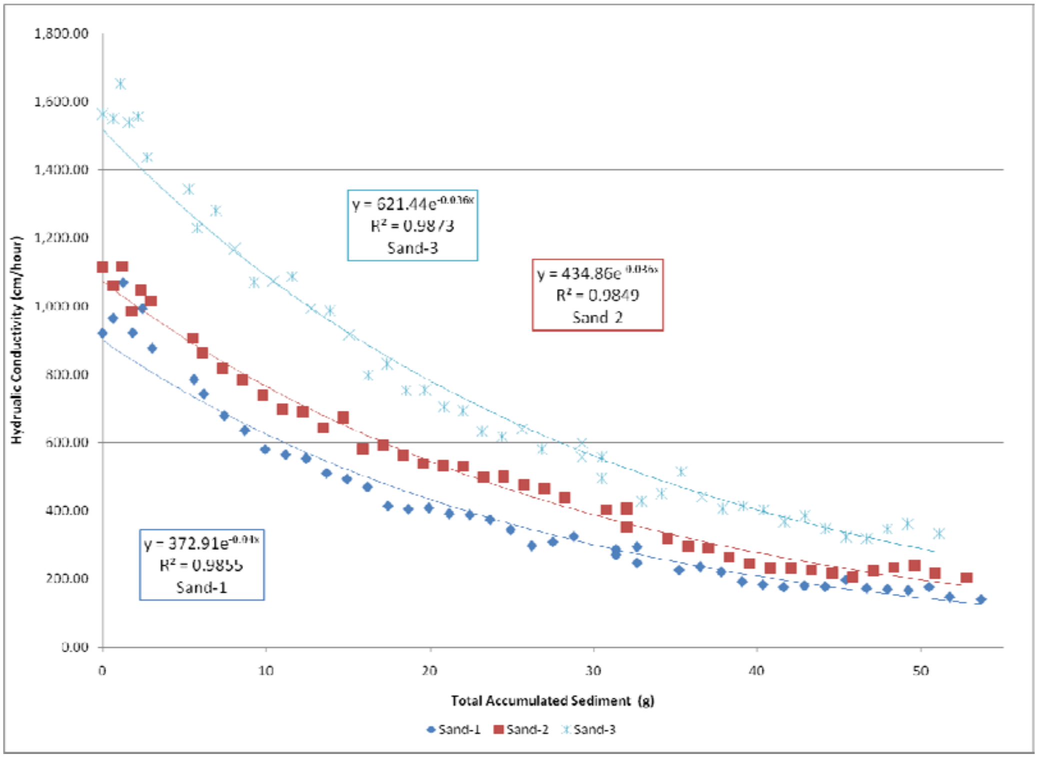

Figure 14: Record of decreasing hydraulic conductivity for cores that had sand as its sediment

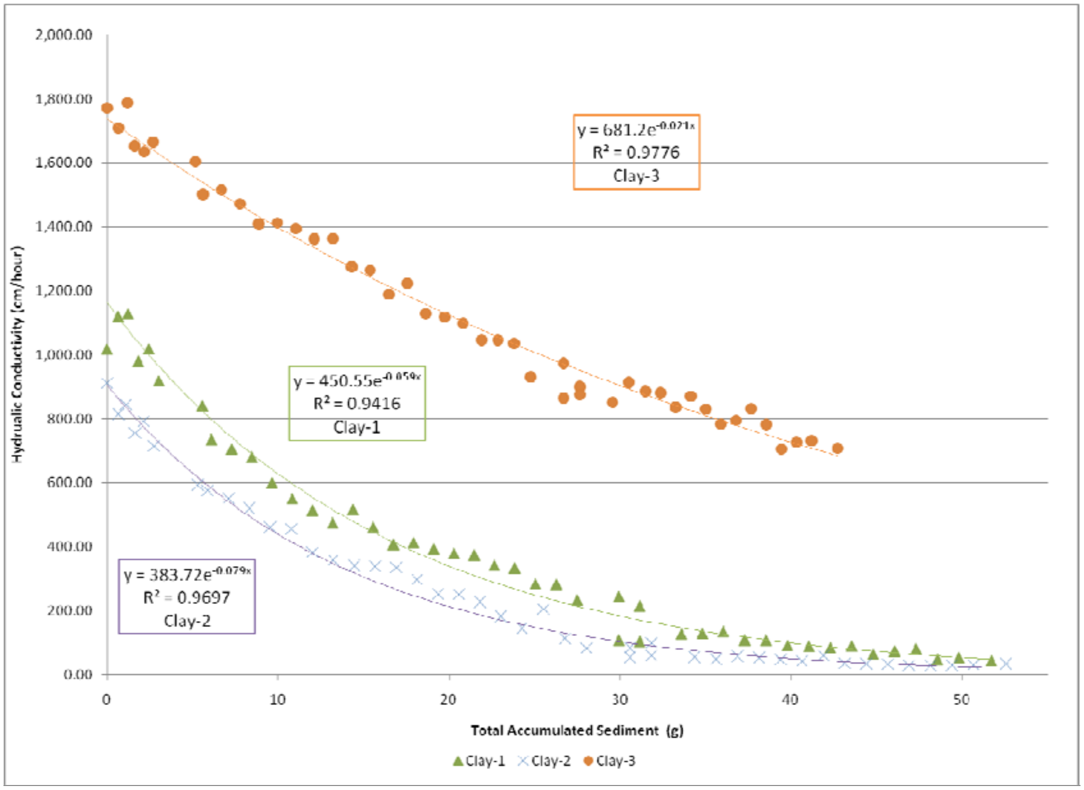

Figure 15: Record of decreasing hydraulic conductivity for cores that had clay as its sediment

Discussion

Particle Size Differences

The only significant difference between the two sets cores for this experiment is the particle size of the sediment. The porosities of the cores were not found to be significantly different (p-value 0.35). The hydraulic conductivity of the PC cores had a wide range matched very well into three pairings based on hydraulic conductivity. Both sets of cores exhibited the same sediment deposition rate and deposition method. The apparati for both sets of cores were constructed with the same material and in the same way. The storm intensity for each core was approximately the same. The only difference between the two sets is the sediment particle size. If there is any difference in the results between the two sets, it is the difference in particle size of the two sediments.

Hydraulic Conductivity vs. Porosity

There was no direct connection between the initial hydraulic conductivity and the porosity of the core (ACI Committee 2006). Three cores had a range of porosity from 20% to 27% with a range of hydraulic conductivity that was less than 250 cm/hour. Meanwhile three other cores had a porosity range of less than one percent while the range of hydraulic conductivities that was approximately 900 cm/hour (see Figure 16). The range of hydraulic conductivity found during this project was similar to the results of previously conducted projects (ACI Committee 2006).

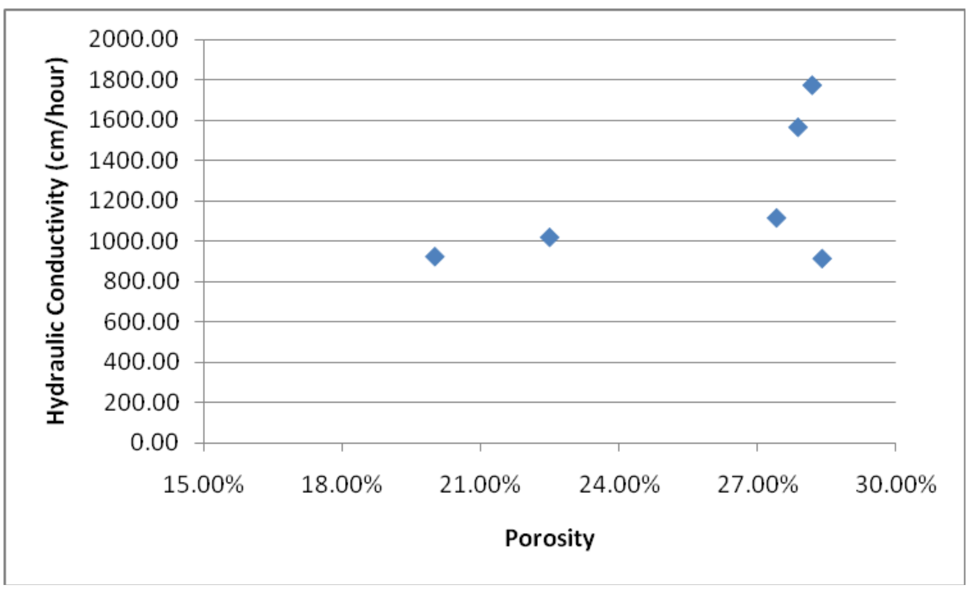

Figure 16: Conductivity of each core plotted along with the porosity

Sediment Loss

During the course of the experiment it was found that the hydraulic conductivity tests did not remove a large portion of sediment from a core. While the first hydraulic conductivity tests took a larger portion of the accumulated sediment than later on, this was only because there was only a small amount of sediment in the core. The amount of sediment that was lost during each hydraulic conductivity test remained constant during the experiment or decreased. Only Clay-3 lost an increasing amount of sediment as the experiment progressed. After plotting the sediment lost vs. the hydraulic conductivity for each test, no correlation appeared except for Clay-3. As Clay-3 had more sediment deposited on it, it would release more sediment. PC used in this context could be viewed as a filter. Typically as more sediment accumulates on to a filter, it releases less and less sediment. The build-up of sediment on the filter cleans water even better by reducing its pore sizes. Unfortunately, the build-up of sediment also requires more and more pressure to pass through the same amount of water at the same rate. This makes the filter inefficient and forces the operators to clean the filter. The PC in Clay-3 seems to be operating differently than expected. This indicates something may have failed in the apparatus. This brings the results of Clay-3 into question.

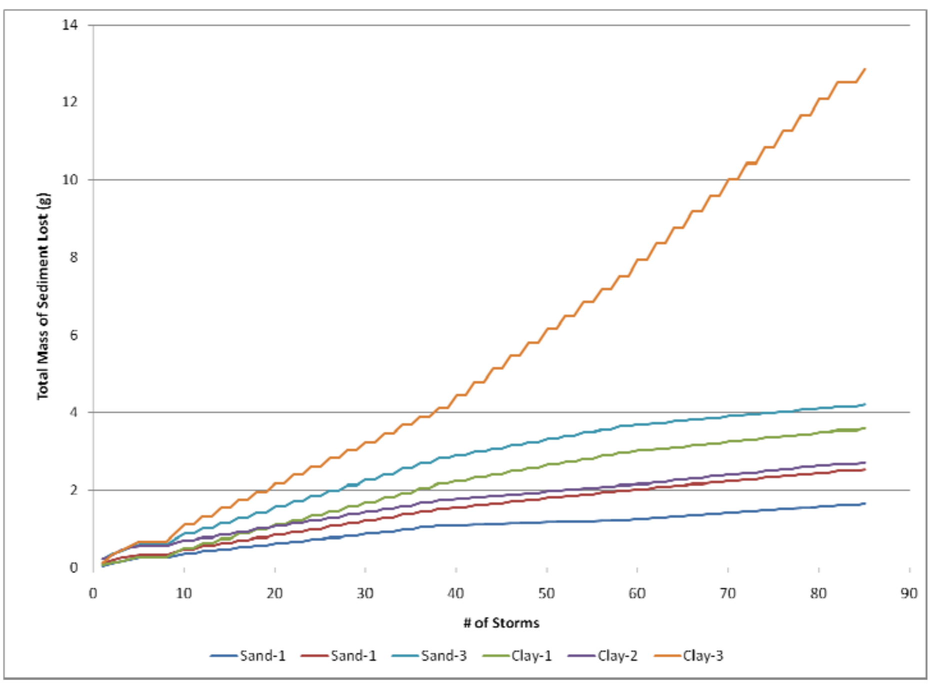

Figure 17: Accumulation of Sediment Lost

Hydraulic Conductivity Predictability

To separate the variables and determine a general equation to predict the loss rate of hydraulic conductivity as sediment accumulates on PC the natural log of the hydraulic conductivity measurements were plotted against the amount of accumulated sediment (See figure 18).

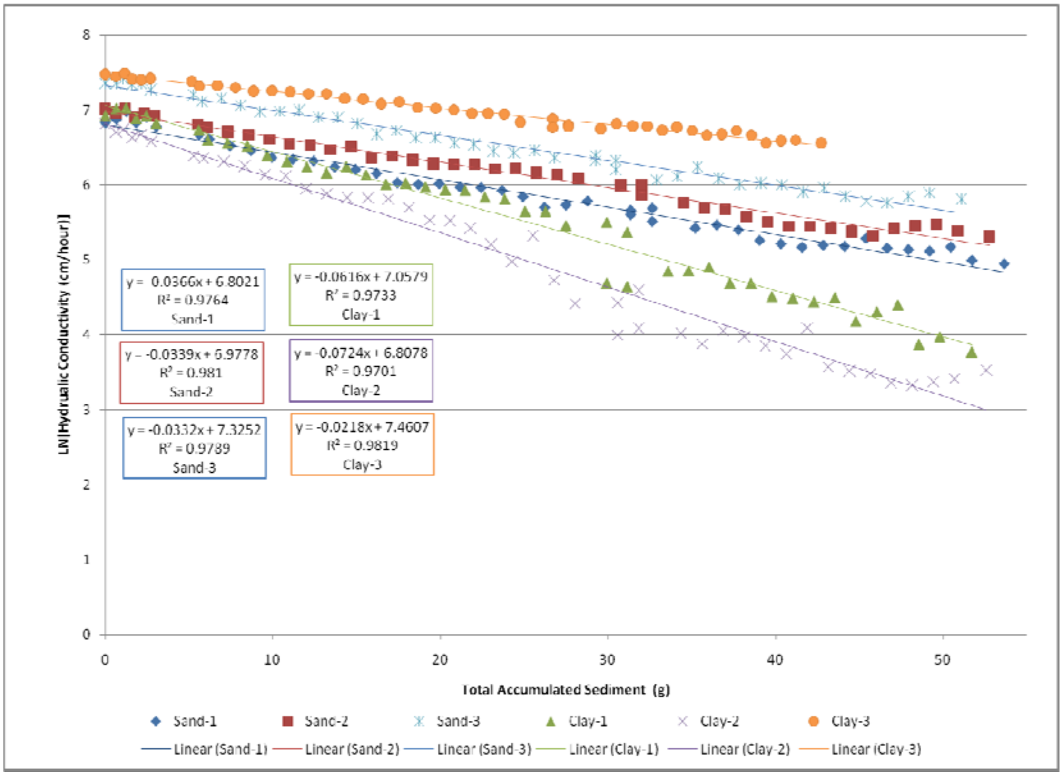

Figure 18: LN of Hydraulic Conductivity from all Cores

The general equation used to model the rate of change for the hydraulic conductivity is y = A * x + B, y equals the LN of the hydraulic conductivity and x equals the amount of sediment accumulated in the PC. A trend line was developed using this equation for each of the cores. While comparing all the trend line equations some patterns appeared. The value for B is the approximately the LN of the initial hydraulic conductivity of each individual core. On average, e^B divided by the initial hydraulic conductivity is equal to

1.00 with a standard deviation of 0.06. The variable A represents the slope of this equation. The slope determines how fast the core loses its hydraulic conductivity. The values of A do appear to separate along sediment types. The cores that used sand as its sediment have the following values for A: -0.0366, -0.0339 and -0.0332. The average value is -0.03457 with a stand deviation of 0.001794. The cores that used clay as its sediment have the following values for A: -0.0616, -0.0724 and -0.0218. The average value is -0.05193 with a standard deviation of 0.02664. When all three values for each type of sediment are compared in a t-test, the two sediment types are not significantly different (p-value = 0.10).

The values for sand match up very nicely and have a proportionally small standard deviation. The values for clay do not match up nicely. The value for Clay-3 is much different than the other two values. It is this value that makes the variables insignificantly different. When the same t-test is run but the value from Clay-3 is removed, the variables are considered significantly different (p value = 0.02).

An outlier test was performed on the value of the A coefficient for all the clay cores. The limits of the outlier were determined using the Chebyshev test (Amidan 2005). The upper and lower limits of an outlier were determined to be -0.02447 and -0.07941. Only Clay-3 was found to be an outlier (See Figure 19). The status of Clay-3's value for A as an outlier along with the physical evidence (increasing sediment loss as the experiment proceed) allows this researcher to conclude that the results from Clay-3's should be removed from the analysis of this project. This evidence points to something malfunctioning in the apparatus that held the core for Clay-3. The researchers believe that for some reason the neoprene surrounding the core was not secured as well in this apparatus and allows water traveling through it to discharge on the side of the core corrupting the results from this apparatus.

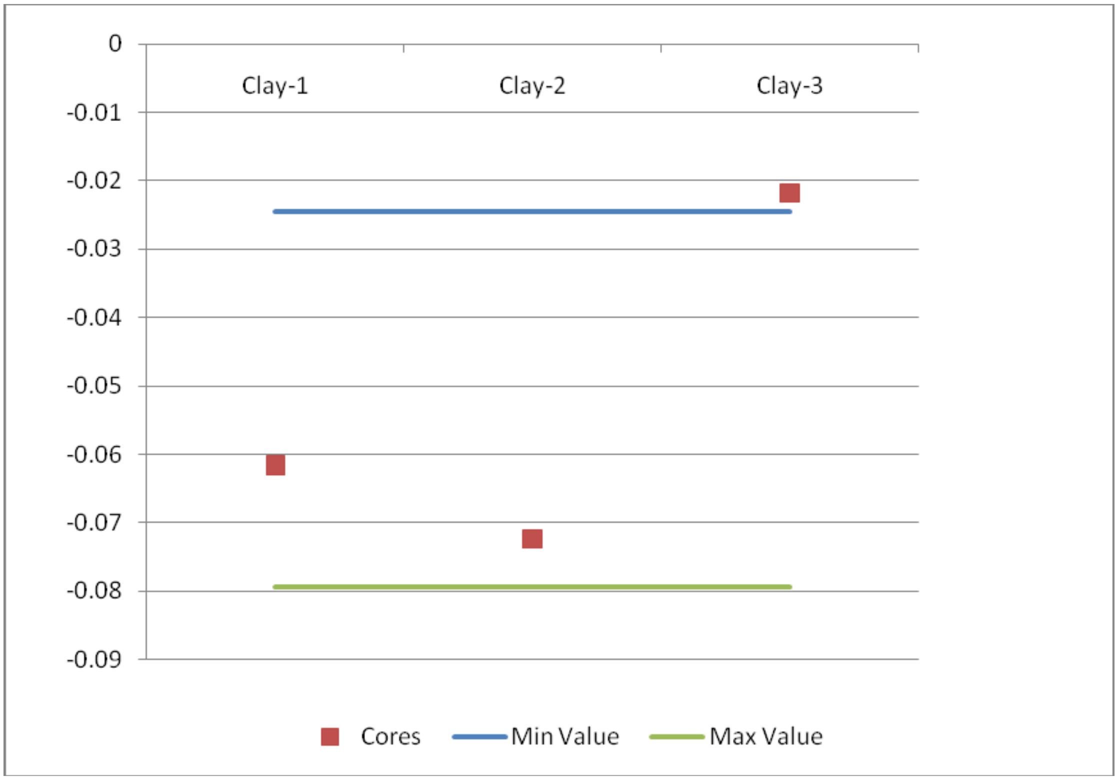

Figure 19: Outlier analysis of coefficient A for clay cores

The goal of this experiment was to develop an equation that would allow engineers to predict how the hydraulic conductivity of PC changes as sediment accumulates. To meet this goal, two general equations were created from the data collected in this project. The equation is the same structure as above. The values for B are the LN of the initial hydraulic conductivity of the PC. The values for A are the average value found for each sediment type. The average for clay will only use the values from Clay-1 and Clay-2 because the results from Clay-3 have been discarded.

This project simulated approximately 252 days for newly installed PC. The drop in hydraulic conductivity may seem dramatic but the sediment deposition rate was the highest recorded deposition rate (Pitt 1979). This rate was chosen to ensure that during the course of the experiment the hydraulic conductivity of the PC would respond to the sediment at a measurable rate.

The proposed general equations are below

$$LN(K_i) = (CM) + LN(K_0)$$

K_0 = Initial Hydraulic Conductivity

K_i = Hydraulic Conductivity

C = Sediment Coefficient

-0.03457 for Sand and -0.067 for Clay

M = Mass of Sediment Accumulated in the PC

Equation 3: General Equation and Constants to Calculate Hydraulic Conductivity

Applicability of Model

The model described above was theoretically applied to several scenarios to show the advantage of tailoring a PC maintenance schedule to specific surroundings instead of using a generic maintenance schedule. While the scenarios used to show the advantages are only theoretical and based on simple assumptions they provide a solid argument for the value of this research and the need for more it's kind to give engineers and planners the tools to use PC more efficiently.

These scenarios assume that a PC parking lot was installed properly and can only clog at or near the surface of the PC due to sediment accumulation. Five different scenarios were developed and evaluated. All five scenarios involve two sets of PC sites. One set has a sediment similar to the sand product in this study and the other has a sediment similar to the clay product in this study. Both sets will have the same sediment deposition rate and will experience rain fall every third day, exactly how the experiment was run. The sediment deposition rate is the average of all the rates found in the literature (0.234 g/(3days*surface area of core)) (Pitt 1979). Both PC sites will have the average initial hydraulic conductivity of all six cores in this experiment (1,104 cm/hour). Each scenario for each sediment type will be evaluated in two ways. The amount of time it takes for the PC to clog using the recommended maintenance schedule (maintenance occurs every six months) will be measured. The model created from this project will determine how the often the PC should be maintained in each scenario to achieve maximum utility. The PC will be considered clogged when its hydraulic conductivity falls below the maximum storm intensity of a 25 year storm in Middlesex County, NJ (2.13 cm/hour) (Semple *et al.*, 2004). This value was chosen because the 25 year storm peak flow is typically used to design drainage systems in New Jersey. The simulation will assume the PC sites are maintained periodically by a vacuum truck. After a vacuum truck passes over a PC site the hydraulic conductivity of the PC will increase by 176%. This is an average level of rejuvenation found in literature (Bean 2007). This value is based on single maintenance events but it is assumed that each maintenance practice will have the exact same effect. PC achieves its maximum utility when the maintenance practice rejuvenates the PC past its initial hydraulic conductivity value.

The first scenario is a parking lot completely comprised of PC. The second scenario is only 50% of the parking is PC and the rest is asphalt. The third scenario is only 33% of the parking is PC and the rest is asphalt. The fourth scenario is only 25% of the parking is PC and the rest is asphalt. The fifth scenario is only 20% of the parking is PC and the rest is asphalt. For the scenarios 2 through 5: the portion of the parking lot that is not PC drains to the PC portion of the parking lot.

Using the recommended maintenance practice, only allowed the parking lot comprised entirely of PC with sand sediment to achieve maximum utility (See Figure 20). As the PC becomes responsible for infiltrating larger drainage areas it clogged faster because more sediment was accumulating on a smaller surface area of PC. Using the recommended maintenance practice, only one scenario had PC as a sound economic decision (Scenario 1 only with sand as its sediment).

By increasing the amount of maintenance practices a year from 2 to a little over 3, Scenario 1 with clay as its sediment becomes a sound economic decision by achieving maximum utility. The model from this study showed that PC can infiltrate the stormwater runoff from drainage areas much larger than its own surface while achieving maximum utility with the proper maintenance. In the most extreme example, (Scenario 5) the PC would become clogged in less 2 years with the recommended maintenance practice. Adding approximately 10 more maintenance practices a year to Scenario 5 allows the PC to achieve maximum utility.

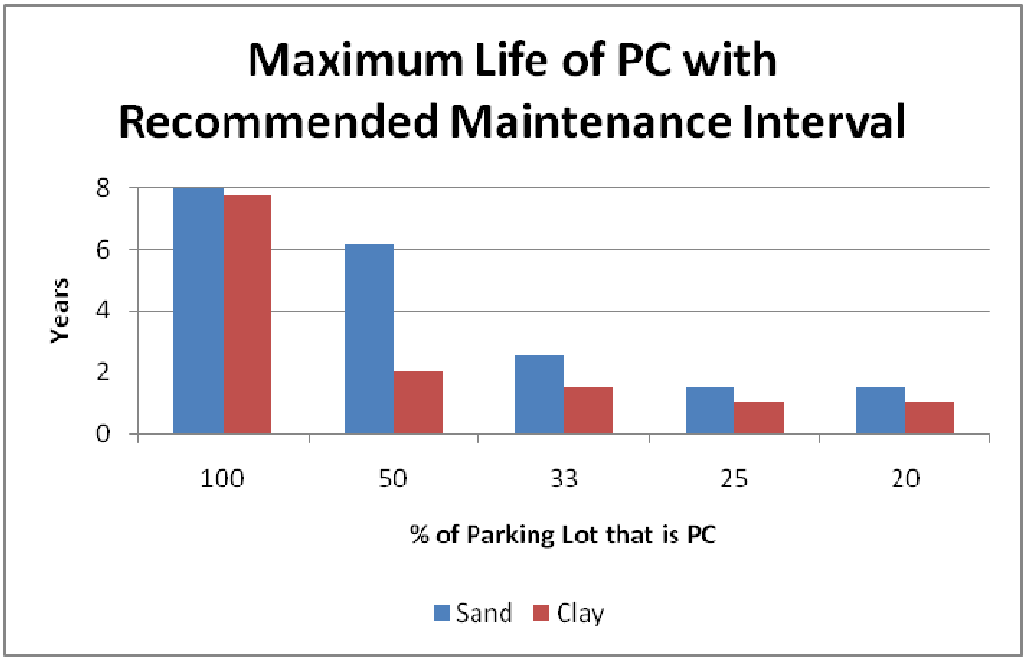

Figure 20: Maximum Expected Lifetime of PC maintained every six months

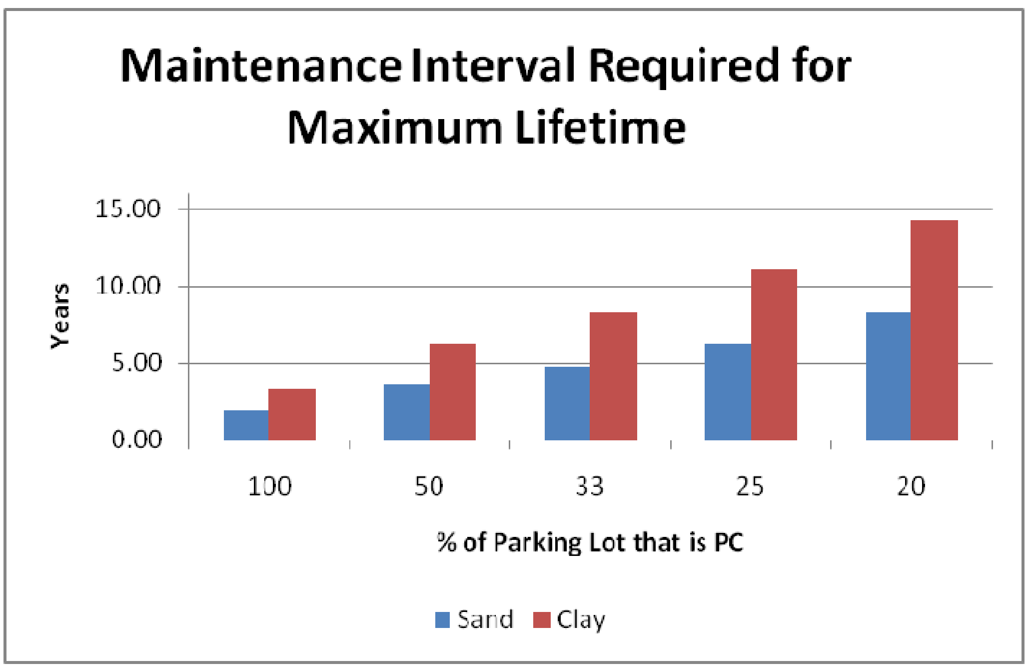

Figure 21: The Recommended Maintenance Period determined by the experiment model

Conclusion

The two largest impediments to using PC in a site design are the cost of the material and the fear that the material will clog prematurely. This project begins to address both of those issues. This project created a method to model the change in hydraulic conductivity as it collects sediment on its surface. The model gives a clearer picture of what kind of utility can be expected from PC. The model can also be paired with monitoring and maintenance programs to promptly respond to any hydraulic surprises during the lifetime of the PC.

PC has a hydraulic conductivity typically 100 times greater than the surrounding soil. Given the proper amount of storage PC can be used to hold and infiltrate large quantities of runoff back in to the groundwater. PC is capable of infiltrating runoff from large impervious surfaces with a much smaller area due to its high infiltration rate. PC would be more affordable if it was used this way compared to how it is typically used. Typically, the PC completely replaces an impervious surface like asphalt. This method is encouraged because engineers worry that if they use only a small amount of PC it will clog very quickly. The model developed in this project alleviates this problem because it accurately predicts when the PC will clog and how often to maintain it to prevent that from happening. Giving engineers the flexibility to use as little or as much PC as their budgets will allow while still receiving all the benefits of using PC for an entire drainage area.

Further Research

Below are recommendations for additional research in this subject and to build off of the success of this project:

- Repeat this study but with a much wider range of sediment types. By expanding the sediment types and repeating the sediment types that have been tested, researchers will more accurately determine the coefficients for each sediment type. Researchers should also study if different sediment deposition rates have an effect on the hydraulic conductivity.

- To establish sediment loading coefficients based on traffic volume, dominant soil type, surrounding vegetation and use or develop a method to rapidly measure the sediment deposition rate of sediment on any surface. This will empower engineers to create maintenance plans for any site.

- Take the results from the expanded study and conduct a field study to confirm the loading rates and the coefficients that will be used to model the change in hydraulic conductivity over time.

- This experiment used tap water for its simulated rain storms. It is recommended that the researchers go back use water that has a much more similar chemistry to rain water to check how the pH of the water could affect the results of this study. Testing how the salt would affect the hydraulic conductivity and accumulation is encouraged.

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Appendix

Table 9: Results from Hydraulic Conductivity Tests

	Sand-1	Sand-2	Sand-3	Clay-1	Clay-2	Clay-3
# of Storms	(cm/hour)	(cm/hour)	(cm/hour)	(cm/hour)	(cm/hour)	(cm/hour)
Avg. Initial Value	921.49	1,113.26	1,563.37	1,017.14	911.52	1,771.82
1	965.09	1,059.68	1,551.31	1,120.17	814.70	1,709.30
2	1,069.99	1,117.11	1,653.15	1,128.98	844.73	1,788.80
3	922.64	985.33	1,539.45	979.93	754.79	1,653.11
4	993.56	1,045.80	1,556.44	1,017.77	792.55	1,634.51
5	877.11	1,015.07	1,437.45	918.60	715.24	1,665.75
9	786.06	907.01	1,342.99	840.31	593.50	1,604.43
10	743.15	862.91	1,229.41	735.51	575.14	1,501.28
12	679.25	818.16	1,281.94	705.00	551.18	1,515.19
14	636.04	783.55	1,169.27	680.84	519.91	1,472.53
16	580.10	738.29	1,071.53	599.05	461.40	1,409.06
18	564.99	696.82	1,074.80	550.30	455.66	1,413.63
20	553.27	688.56	1,087.23	513.34	382.00	1,394.04
22	510.45	643.17	993.75	474.49	358.32	1,362.09
24	493.33	673.68	987.49	516.00	340.72	1,363.51
26	469.62	580.90	917.46	461.76	338.20	1,275.72
28	414.14	591.11	797.14	407.56	334.94	1,264.61
30	405.36	562.49	830.96	414.23	297.58	1,188.74
32	408.72	536.74	752.07	392.81	252.04	1,223.21
34	391.47	531.82	754.49	379.53	250.66	1,128.22
36	388.14	530.50	705.07	374.36	227.23	1,118.57
38	373.64	497.46	693.28	342.50	182.34	1,097.91
40	344.38	499.79	632.92	333.82	144.43	1,046.09
42	297.81	475.61	618.21	284.05	205.20	1,046.09
44	308.59	463.54	638.65	282.49	112.99	1,035.32
46	324.47	437.36	580.06	234.32	82.75	930.02
48	286.99	401.37	599.04	244.98	83.66	972.92
50	294.59	406.48	557.81	214.79	98.84	899.94
52	270.49	402.89	557.81	108.85	54.51	864.82
54	247.29	351.57	495.83	104.06	59.86	875.24
56	226.26	318.70	429.00	127.56	55.73	851.86
58	235.89	294.19	451.24	128.67	48.31	913.77
60	220.30	290.25	513.90	135.10	57.81	885.92
62	191.98	262.85	440.67	108.85	53.33	881.14
64	183.39	245.76	406.85	108.71	47.25	836.60
66	175.69	232.65	414.26	90.82	42.20	870.00
68	180.24	232.87	403.59	88.89	60.20	830.23
70	177.44	224.72	367.80	84.71	35.58	783.47
72	197.24	216.39	386.34	89.65	33.65	795.38
74	172.93	205.49	347.41	65.60	32.56	831.81

76	169.77	224.05	323.20	74.34	28.74	782.06
78	166.59	233.68	318.68	81.43	27.96	705.67
80	176.22	239.28	346.05	48.00	29.21	726.45
82	147.09	218.01	362.13	53.22	30.44	731.74
85	140.53	203.47	333.37	43.45	34.13	707.96

Table 10: Accumulated Sediment in each core during throughout the experiment

Storm #	Core G (g)	Core H (g)	Core K (g)	Core I (g)	Core J (g)	Core L (g)
1	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500
2	1.2552	1.1893	1.0735	1.2320	1.0844	1.1769
3	1.8375	1.7668	1.5897	1.8329	1.6240	1.6069
4	2.4421	2.3381	2.1683	2.4427	2.1397	2.1536
5	3.0372	2.9571	2.7235	3.0299	2.7337	2.6892
6	3.6386	3.5689	3.3059	3.6248	3.3387	3.2205
7	4.2886	4.2189	3.9559	4.2748	3.9887	3.8705
8	4.9386	4.8689	4.6059	4.9248	4.6387	4.5205
9	5.5886	5.5189	5.2559	5.5748	5.2887	5.1705
10	6.1871	6.0948	5.7661	6.1064	5.8649	5.6062
11	6.7856	6.6707	6.2763	6.6380	6.4411	6.0419
12	7.4356	7.3207	6.9263	7.2880	7.0911	6.6919
13	8.0341	7.8966	7.4365	7.8196	7.6673	7.1276
14	8.6841	8.5466	8.0865	8.4696	8.3173	7.7776
15	9.2826	9.1225	8.5967	9.0012	8.8935	8.2133
16	9.9326	9.7725	9.2467	9.6512	9.5435	8.8633
17	10.5311	10.3484	9.7569	10.1828	10.1197	9.2990
18	11.1811	10.9984	10.4069	10.8328	10.7697	9.9490
19	11.7796	11.5743	10.9171	11.3644	11.3459	10.3847
20	12.4296	12.2243	11.5671	12.0144	11.9959	11.0347
21	13.0281	12.8002	12.0773	12.5460	12.5721	11.4704
22	13.6781	13.4502	12.7273	13.1960	13.2221	12.1204
23	14.2766	14.0261	13.2375	13.7276	13.7983	12.5561
24	14.9266	14.6761	13.8875	14.3776	14.4483	13.2061
25	15.5251	15.2520	14.3977	14.9092	15.0245	13.6418
26	16.1751	15.9020	15.0477	15.5592	15.6745	14.2918
27	16.7736	16.4779	15.5579	16.0908	16.2507	14.7275
28	17.4236	17.1279	16.2079	16.7408	16.9007	15.3775
29	18.0221	17.7038	16.7181	17.2724	17.4769	15.8132
30	18.6721	18.3538	17.3681	17.9224	18.1269	16.4632
31	19.2706	18.9297	17.8783	18.4540	18.7031	16.8989
32	19.9206	19.5797	18.5283	19.1040	19.3531	17.5489

33	20.5191	20.1556	19.0385	19.6356	19.9293	17.9846
34	21.1691	20.8056	19.6885	20.2856	20.5793	18.6346
35	21.7676	21.3815	20.1987	20.8172	21.1555	19.0703
36	22.4176	22.0315	20.8487	21.4672	21.8055	19.7203
37	23.0161	22.6074	21.3589	21.9988	22.3817	20.1560
38	23.6661	23.2574	22.0089	22.6488	23.0317	20.8060
39	24.2646	23.8333	22.5191	23.1804	23.6079	21.2417
40	24.9146	24.4833	23.1691	23.8304	24.2579	21.8917
41	25.5504	25.0858	23.7372	24.4001	24.8701	22.2002
42	26.2004	25.7358	24.3872	25.0501	25.5201	22.8502
43	26.8362	26.3383	24.9553	25.6198	26.1323	23.1587
44	27.4862	26.9883	25.6053	26.2698	26.7823	23.8087
45	28.1220	27.5908	26.1734	26.8395	27.3945	24.1172
46	28.7720	28.2408	26.8234	27.4895	28.0445	24.7672
47	29.4078	28.8433	27.3915	28.0592	28.6567	25.0757
48	30.0578	29.4933	28.0415	28.7092	29.3067	25.7257
49	30.6936	30.0958	28.6096	29.2789	29.9189	26.0342
50	31.3436	30.7458	29.2596	29.9289	30.5689	26.6842
51	31.9794	31.3483	29.8277	30.4986	31.1811	26.9927
52	32.6294	31.9983	30.4777	31.1486	31.8311	27.6427
53	33.2652	32.6008	31.0458	31.7183	32.4433	27.9512
54	33.9152	33.2508	31.6958	32.3683	33.0933	28.6012
55	34.5510	33.8533	32.2639	32.9380	33.7055	28.9097
56	35.2010	34.5033	32.9139	33.5880	34.3555	29.5597
57	35.8368	35.1058	33.4820	34.1577	34.9677	29.8682
58	36.4868	35.7558	34.1320	34.8077	35.6177	30.5182
59	37.1226	36.3583	34.7001	35.3774	36.2299	30.8267
60	37.7726	37.0083	35.3501	36.0274	36.8799	31.4767
61	38.3904	37.6167	35.9577	36.6300	37.4829	31.7101
62	39.0404	38.2667	36.6077	37.2800	38.1329	32.3601
63	39.6582	38.8751	37.2153	37.8826	38.7359	32.5935
64	40.3082	39.5251	37.8653	38.5326	39.3859	33.2435
65	40.9260	40.1335	38.4729	39.1352	39.9889	33.4769
66	41.5760	40.7835	39.1229	39.7852	40.6389	34.1269
67	42.1938	41.3919	39.7305	40.3878	41.2419	34.3603
68	42.8438	42.0419	40.3805	41.0378	41.8919	35.0103
69	43.4616	42.6503	40.9881	41.6404	42.4949	35.2437
70	44.1116	43.3003	41.6381	42.2904	43.1449	35.8937
71	44.7294	43.9087	42.2457	42.8930	43.7479	36.1271
72	45.3794	44.5587	42.8957	43.5430	44.3979	36.7771
73	45.9972	45.1671	43.5033	44.1456	45.0009	37.0105

74	46.6472	45.8171	44.1533	44.7956	45.6509	37.6605
75	47.2650	46.4255	44.7609	45.3982	46.2539	37.8939
76	47.9150	47.0755	45.4109	46.0482	46.9039	38.5439
77	48.5328	47.6839	46.0185	46.6508	47.5069	38.7773
78	49.1828	48.3339	46.6685	47.3008	48.1569	39.4273
79	49.8006	48.9423	47.2761	47.9034	48.7599	39.6607
80	50.4506	49.5923	47.9261	48.5534	49.4099	40.3107
81	51.0684	50.2007	48.5337	49.1560	50.0129	40.5441
82	51.7184	50.8507	49.1837	49.8060	50.6629	41.1941
83	52.3362	51.4591	49.7913	50.4086	51.2659	41.4275
84	52.9862	52.1091	50.4413	51.0586	51.9159	42.0775
85	53.6362	52.7591	51.0913	51.7086	52.5659	42.7275