Exfiltration Trenches for Post Construction Storm Water Management for Linear Transportation Projects: Laboratory Study

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ABSTRACT

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The exfiltration trench as a best management practice for stormwater management is studied in the document. The exfiltration trench contains three layers such as pervious concrete, gravel and filter media (greensand). All three layers of the exfiltration trench were simulated and tested in the laboratory. Each layer of the exfiltration trench was studied individually. The modeled layers were studied as a system and their treatment efficiency was closely monitored and reported in this study. The permeability, porosity, total suspended solids analysis and cleaning properties of pervious concrete and filter media in removing specific contaminants were determined. At the end of this study two concrete mixes and two filter media were compared and the merits and demerits of each one was reported.

Approved: ____

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CHAPTER 1: INTRODUCTION

1.1.Environmental Impacts of Highways

Transportation is the infrastructure of a community. Developing infrastructure needs comprehensive planning that includes a feasibility study. Environmental impact assessment is a main segment of a comprehensive feasibility study. Environmental impact of development projects such as highway construction can be social and physical; precise management is needed to address all the related issues. Highways have a physical impact on ecology, agriculture, wildlife and so on. Social impacts of highways could be economical, political and cultural.

1.2.Physical Impact of Highways on Environment

1.2.1. Highway Runoff

Physical impact of highways on the environment is a broad topic. In this research only the negative impact of the highway runoff on the environment is analyzed. Among all the regulations that have been passed and put into practice, one of them is the Clean Water Act (CWA). The CWA was passed in 1972 by the U.S. Congress and has since gone through many amendments to ensure that drinking water is clean for every citizen of the US. This act also covers sources that have the potential to contaminate drinking water sources. This act obligates the entire related agency to act responsibly in terms of any threat to public health. The Clean Water Act (CWA) prevents release of all kind of pollutants to the environment from point sources and nonpoint sources. Point sources, which include municipal, industrial and agricultural generated effluent, should meet the requirement imposed by National Pollutant Discharge Elimination System (NPDES). The nonpoint sources, which are mainly the precipitation and snowfall generated runoff, come under the section 319 of USEPA. Since they are not generated from a single point they are called nonpoint sources. Non-point source pollution is major polluting source for water bodies during the rainfall in highways agricultural areas and parking lots. The runoff from the mentioned areas contains chemicals such as metals fertilizers, pesticides which are transported by surface runoff and directed to the water reservoirs these chemicals have severe affect on aquatic life and damage the quality of water. (USEPA, 2010)

1.2.2. Impact of Roadway Runoff on Ambient Water Body

Water that is generated from rainfall and snowfall is distributed to several portions. Some evaporate back, some infiltrate the ground, and the largest portion of water generates surface runoff. This surface runoff finally reaches the receiving water sources. This surface runoff carries some constituents to the receiving water sources. These constituents include the total suspended solids (TSS), dissolved solids (DS), organics, chemicals, metals, polycyclic aromatics hydrocarbons (PAHs), oil and grease, and many others. The organic parts of these constituents degrade naturally and the nonorganic parts such as metals do not degrade naturally, but can change forms. Metals change their forms from one state to another state in terms of their oxidation states; as a result changes occur in toxicity and solubility of metals.

1.2.3. Impact of Traffic on Roadway Runoff

Annual average daily traffic (AADT) is higher in urban areas than nonurban areas. Higher traffic flow has a direct influence on the amount of roadway runoff constituents.

As mentioned above the roadway runoff contains different types of organic and inorganic constituents, and the main source of these constituents is high traffic flow. The constituents are in both suspended and dissolved forms. Metals are the main sources of contamination. Suspension and solubility of metals depends on their chemical speciation. (Kayhanian et al., 2003)

1.2.4. Mitigation and Control

Hamilton and Harrison (1991) discussed different structures to control the quantity and quality of highway runoff. These systems include:

- Vegetative filtration especially along the highways
- Detention ponds
- Stream reservoir
- Infiltration systems
- Exfiltration trenches

All of the mentioned control systems have their own advantages and disadvantages. An infiltration system is a trench filled with crushed stone without any outlet. The infiltration trench is usually constructed after a pretreatment system like a detention pond. The infiltration system receives runoff and redirects it back to the ground.

This research concentrates on exfiltration trenches.

1.3.Problem Statement

Stormwater runoff can contain major water contaminants such as chemical elements, organics, hydrocarbons and pathogens. These constituents are seen in large concentration in highway runoffs. The sources of these constituents are abrasion of pavement surface, vehicle tires, corrosion of vehicle body, de-icing agent in winter, oil & grease and fluid leakage.

Highways in urban areas differ from those in nonurban areas in distinct perspective. First, the flow of traffic in urban area highways is higher than nonurban area highways; this factor is directly proportional to the amount of contaminant in surface runoff. Second, the roadway usually has a limited area, which precludes the construction of a detention pond or surface runoff reservoir. Third, highways are always built on compacted soil where the hydraulic conductivity or water percolation is very low; therefore it takes longer for water to infiltrate into the ground. Considering the above mentioned difficulties it is important to select the best option among all possible best management practices (BMPs) to address surface runoff in urban areas. For controlling the urban runoff there are two major strategies- 1) source control; 2) treatment control. Source control reduces the contamination at the source of generation. Treatment control cleans the water after the pollutants are released from the source. In some processes, both controls are combined in order to meet the treatment objectives. This research mainly focuses on the treatment of highway runoff. In order to achieve this objective, best management practices (BMPs) for stormwater treatment have been studied.

1.4.Research Objectives

The exfiltration trench is selected from the available BMPs for the treatment of stormwater. An exfiltration trench has viable and feasible options to control the quantity and quality of stormwater runoff in highways in urban areas. The exfitration trench is reported to not only treat the stormwater runoff to 50 – 60% of contamination but also act as detention storage during the peak flow. The cost of building the exfiltration trench is low to medium compare to other stormwater BMPs and it is suitable for places with limitations in area and low hydraulic conductivity, like highways (Li, Buchberger, Sansalone, 1999). The components of the exfiltration trenches provided by ODOT in specification and design manual was investigated in this study (ODOT, 2010). The first layer is pervious concrete the second layer is backfill gravel and the third layer is sand. Each layer typically has a depth of 6 inches. The exfiltration trenches would be maintained periodically and at the end of their design life they would be replaced with new ones.

The main objective of this thesis is to examine the components of the exfiltration trench to determine the performance in removing typical highway stormwater runoff contaminants as follows:

- Ability of pervious concrete, the aggregate and filter media to remove specific constituents (TSS and metals).
- Accumulation of contaminants in the pervious concrete and filter media.
- Suitability of pervious concrete and filter media to accommodate different concentrations of runoff.
- Effectiveness of maintenance of media (pervious concrete and greensand).
- Comparison the effectiveness of two concrete mixes and two filter media.

1.5.Scope of Work

This thesis only focuses on the laboratory aspect of this research. Laboratory work was divided into several tasks, which will be explained in details in this study. A literature review was conducted on the characteristics of constituents in stormwater runoff and best management practices. The plan followed mainly Ohio Department of Transportation (ODOT) Material Specifications (ODOT, 2008) design guide and in some instances other technical documents.

Pervious concrete with 35 – 50% porosity was prepared according to Ohio Department of Transportation (ODOT) material specifications (ODOT, 2008) and Ohio Ready Concrete Mix Association (ORCMA) material specifications (ACI 522R, 2008). Each mix was tested for strength, porosity, hydraulic conductivity, total suspended solids, clogging, and freeze and thaw strength. The results of these two mixes as well as two filter media were compared to determine the best performance characteristics.

The second layer is gravel backfill, gravel # 67 (gravel which has specific gradation characteristics). This layer was tested for hydraulic conductivity and total suspended solids.

The third layer of the exfiltration trench is sand which is also called the filter layer. This layer is the most important in terms of filtering the stormwater runoff. Two types of sands were tested. One was ordinary sand and the second was green sand (green sand has a special property in removing some chemicals from filtered water).

All the analyses for the ODOT mix had been done previously. This study focuses on Ohio Ready Mix Concrete Association (ORMCA) pervious concrete mix and greensand with comparison to results of tests with ODOT pervious concrete mix and ordinary sand, which were conducted in another study.

1.6.Thesis Outline

Chapter 1 is an introduction of the topic. Chapter 2 covers the comprehensive literature review. Chapter 3 describes the detailed procedure that is followed to conduct this research. Chapter 4 is the results and analyses of the findings. Chapter 5 discusses the conclusions and recommendations in this research.

CHAPTER 2: LITERATURE REVIEW

2.1. Highway and Environment

Wilson and Stonehouse (1983) investigated environmental impacts of highways. They concluded that highway construction has social and physical impact on the environment. The social impact of highways is directly connected to human and human activities. These activities affect social, economical and political aspect of human life. For example, construction of a highway could bring economic development, social interaction and a change in geopolitics of a community. Physical impacts could be ecosystematic interactions or the distinct relation and interaction of nature and its habitat.

2.2. Stormwater Runoff

Stormwater runoff is the rain and melting snow that flow off impervious surfaces. The flowing water carries nutrients, sediments, organic carbon, pathogens, hydrocarbons, heavy metals, pesticides, and chlorides among other pollutants to receiving water bodies. These pollutants are collected from a wide area by the rainfall; thus, it is called nonpoint contamination source. The main pollutants of stormwater runoff are:

Nutrients:

Phosphorus and nitrogen in stormwater runoff causes the growth of algale which results in the depletion of dissolved oxygen in water.

Sediment:

Suspended materials are main source of the sediments in water and have adverse affect on aquatic life.

Organic Carbon:

Organic matter is degraded by microorganisms and cause depletion of oxygen in water.

Bacteria:

Pathogens are main source of diseases in water and increase the burden in water treatment plants.

Petroleum Hydrocarbons:

Petroleum hydrocarbons in stormwater runoff are closely correlated with traffic. Hydrocarbons are long lasting contamination sources in receiving water body.

Trace Heavy Metals:

Heavy metals are the main source of toxics for aquatic life. The toxicity of heavy metals depends on their oxidation states.

Pesticides

Pesticides also have been detected in stormwater runoff. In some cases they exceed the limit of toxicity in water.

Chlorides:

De-icing agents during winter increase the amount of salts in water which exceed the standard limits. (USEPA, 2004)

The huge amount of the pollutants is washed from impervious surfaces in the initial stage of the runoff generation, which is called first flush.

2.2.1. First Flush

First flush is a term used for the run off with higher concentration of pollutants in the initial stage of runoff generation relative to later stage in rainfall event. Sometimes the term seasonal first flush is also being used for the contaminants which build up during a dry period and wash off during the rainfall season, resulting in a large discharge of contaminant. First flush depends on the catchment surface where the flow is generated. Impervious surfaces result in the quick generation of runoff with higher velocity. High velocity of runoff carries bigger suspended solids and causes more scouring of the surfaces. Highways are almost impervious and surface runoff is generated immediately after the rainfall. Kayhanian and Stenstrom (2005) findings show that 30 to 50% of the pollutants from a single rainfall event exist in 10 to 20% of the runoff volume. This suggests that treating 20% of the flow can treat 50% of the pollutant and the cost of the treating depends more on the volume than on concentration, thus treating the first flush is much more cost effective than treating the entire rainfall event. It has been found by many researchers that BMPs are more effective in cleaning higher concentrations than lower concentrations. There are two main reasons in using the BMPs for the treating of first flushes 1) Treating of the concentrated runoff. 2) BMPs have higher efficiency in cleaning the higher concentrated runoff. In the Figure 2-1 first flush is illustrated during a typical rainfall. (Kayhanian & Stenstrom, 2005) (USEPA, 2004)

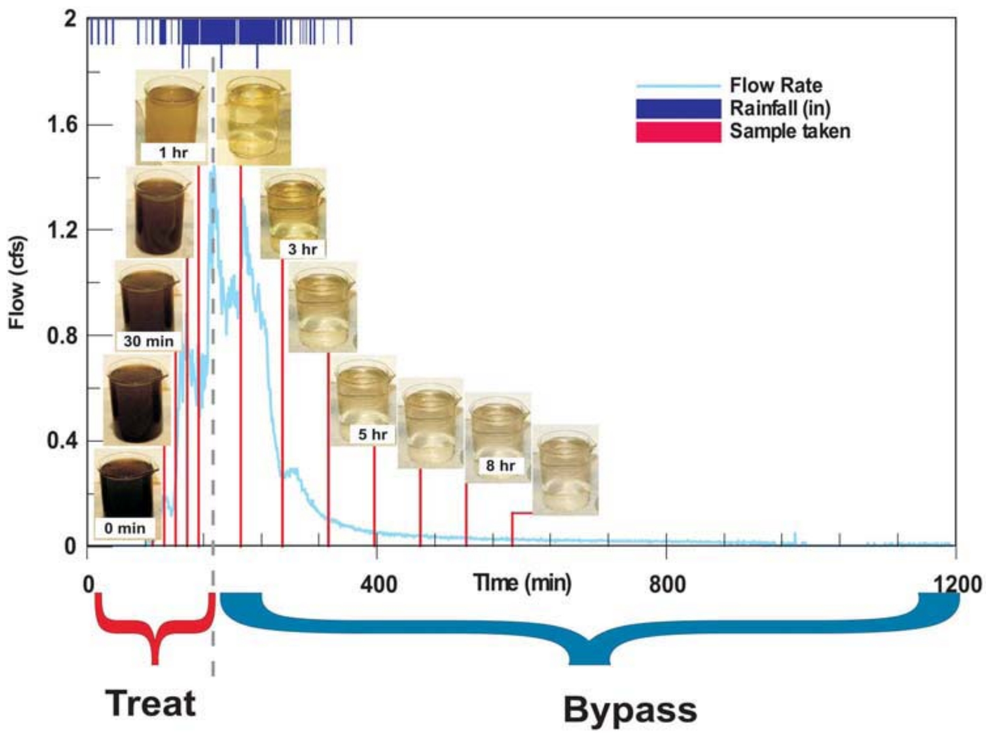

Figure 2-1. First flush illustration (Kayhanian &, Stenstrom, 2005)

2.2.2. Constituents in Roadway Stormwater Runoff

Roadway runoff not only carries dirty water from one place to another but also chemical elements. Findings by Sansalone and Buchberger (1997) show that roadway runoff almost often contains dissolved, suspended particles, organics and chemical elements, especially metals of different kinds, such as Cd, Cr, Cu, Fe, Ni, Zn, and oil and grease. The source of these constituents is different and different factors play a role in the production of these constituents. The sources pointed out by the research are abrasion of pavement surface and vehicle's tires, corrosion of vehicle's body, deicing agents during the winter, climate, gas and fluid leakage near gas stations. Table 2-1 shows the source and impacts of the stormwater runoff constituents. Table 2-2 shows typical constituent concentrations in highway runoff.

Table 2-1. Stormwater Runoff Constituents and Their Impact (Dennison, 1996)

Constituents	Primary Source	Impacts
Suspended Solids	Pavement wear, vehicles, atmosphere, maintenance	Reduce light penetration, clog gills/filters of fish and aquatic invertebrates, and reduce spawning and juvenile fish survival
Chemical Oxygen Demand	Decomposition of organic matter by microorganisms	Deplete dissolved oxygen in receiving waters
Metals	Lead gasoline, tire wear, lubrication oil and grease, motor oil, bearing wear, auto body rust, steel highway structure, moving engine parts, metal plating, bearing and bushing wear, brake lining wear, diesel fuel, asphalt paving	Accumulate in the sediments of urban streams. Lakes and estuaries and potentially may contaminate drinking supplies.
Nitrogen, Phosphorus	Atmosphere, roadside, fertilizer application from nonpoint sources of nutrients	Accelerate eutrophication in downstream receiving waters
Bromide	Exhaust	Methyl bromide is a highly toxic compound in EPA Toxicity Class 1.
Cyanide and Sodium Chloride	Deicing salt	Cyanide is poisonous chemical. High concentration of chloride may affect aquatic life
Sulphate	Roadway beds, fuel, deicing salts	High concentration of sulphate may affect aquatic life
Oil and Grease	Spills, leaks of motor lubricants, etc	Some of them have high toxic effects on aquatic life even at low concentration
Pathogens	Soil litter, bird droppings and trucks hauling livestock and stockyard waste	Exceed federal public health standards for water recreation and shellfish harvesting
Synthetic Compounds	Pesticides, herbicides, tire wear, brake lining wear	Some are toxic to biological systems accumulate via the food chain and cause toxics effects to animal and human lives
Floatable Debris	Plastic and paper products, garden refuse, and glass containers	Degrade the aesthetic quality of the environment and impact the aquatic vegetation and wildlife

Table 2-2. Runoff Constituent Concentration Reported in Previous Research (Guo, 2004).

Constituents	Highway Runoff in Florida (Yousef et al., 1986)	Highway Runoff Concentration at Four Ohio Sites (Corbett and Manner, 1975)				Median Concentrations in Highways Runoff (Sansalone, and Buchberger, 1996)		Three highway sites (FHWA, Aug 1985)			Average Concentration in University parking lot in New Jersey (Forest Service Research 1998)	Average Concentration in Different streets in Hamburg (Dannecker et al., 1990)		Average Concentration in London Orbital M25 motorway (Hares, et al., 1999)		Average Concentration in Highway runoff in Austin Texas (Barret et al., 1998)		
		I271	Belleville (SR 13)	Stone Creek (I 77)	Conneaut (I 90)	ADT = 30000 vpd	ADT = 30000 vpd	ADT= 7400 vpd	ADT= 25500 vpd	ADT= 15600 vpd		ADT= 16200 vpd	ADT= 500 vpd	ADT= 140000 vpd	ADT= 120000 vpd	ADT= 8780 vpd	ADT= 47240 vpd	ADT= 58150 vpd
pH	5.9 – 7.8 S.U	-	-	-	-	-	-	-	-	-	4.37-6.2	-	-	-	-	-	-	-
COD (mg/L)	-	-	-	-	-	49	114	-	-	-	-	-	-	-	-	39	37	130
TSS (mg/L)	-	-	-	-	-	41	142	-	-	-	-	-	-	-	-	91	19	129
Cd. Total (mg/L)	0.0007-0.0089	-	-	-	-	-	-	0-0.05	0-0.007	0-0.003	-	0.0019	0.0014	0.0141	0.0119	-	-	-
Cr. Total (mg/L)	0.0013-0.0097	-	-	-	-	-	-	0-0.08	0-0.04	0-0.015	-	0.011	0.0096	0.105	0.086	-	-	-
Cu. Total (mg/L)	0.01-0.101	-	-	-	-	0.022	0.054	0-0.2	0.02-0.07	0.01-0.015	Very low	0.1435	0.0759	0.274	0.248	0.007	0.012	0.037
Fe. Total (mg/L)	0.026-0.796	-	-	-	-	-	-	0-3.0	1-7	0-2.6	Very low	3.5	6.1	-	-	1.401	0.249	2.824
Ni. Total (mg/L)	0.0011-0.01	-	-	-	-	-	-	0-0.4	0-0.03	0-0.01	Very low	-	-	0.093	0.076	-	-	-
Pb. Total (mg/L)	0.03-0.379	-	-	-	-	0.08	0.4	0-0.4	0-0.05	0-0.13	0.05-0.271	0.2003	0.122	0.081	0.07	0.015	0.003	0.053
Zn.Total (mg/L)	0.013-0.173	-	-	-	-	0.08	0.329	0-1.1	0.05-0.36	0.01-0.14	Very low	0.2362	0.1656	0.208	0.188	0.044	0.024	0.222
Mn (mg/L)	-	-		-	-	-	-	-	-	-	Very low	-	-	0.329	0.279	-	-	-
Ca (mg/L)	-	27-310	23-390	4-690	4-350	-	-	-	-	-	61	14.5	11.7	-	-	-	-	-
Mg (mg/L)	-	4-49	1-20	1-38	1-120	-	-	-	-	-	6	1	1.3	-	-	-	-	-
Na (mg/L)	-	13-1000	160-1700	7-6400	3-1000	-	-	-	-	-	208 (peak during deicing)	3	2.6	-	-	-	-	-
O/G (mg/L)	-	-	-	-	-	-	-	-	-	-	1.5-142	-	-	-	-	1.4	0.4	4.2
Inorganic Nitrogen	NH4 – 0.95 – 3.52 mg/L	-	-	-	-	-	-		-	-		-	-	-	-	-	-	-
	NO3 – 0.3 – 1.93 mg/L	-	-	-	-	0.46	0.76	-	-	-	-	-	-	-	-	-	-	-
Cl^-	1-40 mg/L (peak Value when deicing)	16-2000	190-2900	1-12000	8-1800	-	-	-	-	-	-	-	-	-	-	-	-	-
$SO4^{-2}$	-	18-275	45-98	24-190	3-220	-	-	-	-	-	-	-	-	-	-	-	-	-
$CO3^{-2}$	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
$HCO3^-$	-	63-224	90-268	9-152	3-95	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P	-	-	-	-	-	0.16	0.4	-	-	-	-	-	-	-	-	-	-	-
															-			

2.2.3. Traffic Impact on Roadway Runoff

Researchers have studied the impact of flow of traffic on roadway runoff for long time. Kayhanian et al. (2003) investigated the flow of traffic in highways and its link to the highways' runoff pollution. They differentiated the flow of traffic between urban area and nonurban area. They stated that in urban area flow of traffic depends on many other factors, such as area, population, location, climate and so on. The contamination of surface runoff generated from rainfall directly depends on flow of traffic. The constituents have higher concentration with high daily traffic, however high traffic is not the only source of pollution concentration in roadway runoff. There are other factors such as precipitation duration and intensity, catchment basin and land cover. As an overall conclusion, research shows high traffic has a direct impact on the constituent's concentration in roadway runoff.

2.2.4. Particle Size Distribution in Roadway Runoff

Particle size distribution in the overall roadway runoff is variable and depends on the landscape of the area. Li, et al. (2005) conducted research about particle size distributions from highways and concluded that the surroundings of a highway determine its particle size distribution characteristics. Collection of particles shows that 65 – 90% of the mass of the particles are located in the vicinity of the highways' hydraulic structures and gutters.

Determining particle sizes of solids in roadway run off is one of the important steps in characterizing the best management practices for roadway runoff. Adsorption of chemicals in the particles, which have high surface area to volume ratios, limits the "mobility and bioavailability in their dissolved form" (Kayhanian & Stenstrom, 2005). It has been shown that huge portions of the chemicals from road surfaces are created from pavement and vehicle tire abrasion.

2.3. Federal Regulations for Water Quality

2.3.1. Water Quality from Paved Roads

Many researchers investigated the sources that pollute water bodies. An investigation by Deletic and Maksimovic (1998) pointed out that storm runoff from highways is one of the main sources of pollution to water bodies. This pollution source can bring down the quality of ambient water resources and damage water body environments. In combined sewer systems, storm runoff causes huge fluctuations in treatment systems that results in the impairment of treatment systems and poor quality of water treatment. In highways there are different phases of contaminant creation such as, accumulation of contaminant during dry periods, surface washing accumulation of contaminants in water passage structures like roadside ditches, contamination in sewer system, and changing forms in oxic and anoxic environments in sewer systems.

2.3.2. Clean Water Act

In the US. the Federal Water Pollution Act (FWPCA) was created in 1948 in order to oversee the water quality in interstate and navigable waters. In 1972 the FWPCA was amended and enforced the standard system of water quality for fishable and swimmable water by 1983 and total clearance of pollutant from navigable water by 1985. In 1977 the act named Clean Water Act (CWA) was enacted. In 1987 amendments for specific standards for stormwater were added. CWA aims to maintain the quality of water in view point of chemical, physical and biological pollution. CWA requires all the related organizations from local to federal to act accordingly in order to have quality water for every citizen. Under the CWA, states and USEPA are responsible to regulate the point and nonpoint sources of contamination. The point source which includes municipal, industrial and stormwater discharge should meet the National Pollutant Discharge Elimination System (NPDES).

2.3.3. National Pollutant Discharge Elimination System (NPDES)

NPDES aim is to regulate the water effluent standards. Construction activity such as excavation, grading or clearing needs to meet the NPDES phase I and phase II rule by applying for a permit. Phase I covers the construction area of 5 or more acres. Permits require comprehensive stormwater pollution prevention, using BMPs. Phase II rule covers construction area of 1 – 5 acres, which excludes the routine maintenance and only requires the original line and grade. "General construction permits which are issued by the EPA only focuses on erosion during construction, not on post-construction stormwater management. Municipal permits are required to address post-construction stormwater management for existing areas and new development." (USEPA, 2004)

2.4. Best Management Practices (BMPs)

The regulatory requirement of the federal, state and local institution defines the goal and objectives of BMPs. The following are the governing factors in the type and selection of BMPs for specific areas:

2.4.1. BMP Types

For controlling the urban runoff there are two major strategies - 1) source control; 2) treatment control. Source control reduces the contamination at the source of generation. Treatment control cleans the water after the pollutants are released from the source. In some treatment processes both treatments are combined in order to meet treatment objectives. There is distinction between the two, but in some cases the distinction is not vivid such as cleaning particles from the highway surface provides both source control and treatment.

2.4.1.1. Treatment BMPs Cleaning Processes

- <u>Settling</u>: When the particles in the water have higher specific gravity than the water they settle. Removal of suspended solids occurs mostly by settling. Due to the sorption or attachment of pollutants to the suspended solids, these pollutants also settle and are removed from the water.
- <u>Filtration</u>: Sediment and particulate pollutants are removed by filtration. Usually sand and peat are used as filtering media.
- <u>Sorption</u>: Some particles in water hold negative charges at their surfaces; the metals and organic matter are sorbed to the surface of these particles; this

phenomenon represents the cation exchange capacity. The particles with sorbed pollutants are removed by the filtering media.

- Phytoremediation: The metabolism of plants degrades the organic pollutants in the soil or water. These degradations mostly occur in the root zone of the plant by bacterial activity.

- Multiple Treatment BMPs: Series of BMPs usually guarantee quality treatment, called Train Treatment BMPs. (USEPA, 2004)

2.4.2. BMP Selection

Thurston (2006) concluded in his research that stormwater runoff in urban areas alters the ambient water reservoirs due to the loading of organic and nonorganic matter. In urban areas the natural fate and transport of the suspended and dissolved constituents is different from those in nonurban areas. Urbanization develops impervious strata in watersheds and this impervious stratum contributes to the generation of surface runoff and reduces the subsurface runoff. These fast generated streams are the main reason for higher peak flow, which is undesirable for receiving treatment systems. The second problem is that impervious strata prevent water infiltration to the ground, and this problem has two impacts: first it increases the surface flow and second, it reduces the ground water table. Several best management practices have been suggested to deal with stormwater surface runoff. For smaller communities with population <100,000, USEPA suggests cost effective criteria such as pervious pavement instead of advanced and expensive alternatives. (USEPA, 2004)

2.4.3. BMP Selection Criteria

There are many factors that are important in selection of BMPs for a specific site:

- Small area versus large area controls: Small area versus large area (onsite and regional approach) consideration is very important and has direct impact on the selection of appropriate BMPs. Both small area (only the site that needs BMPs) and large area (BMPs application not only in the site but also the area around) BMPs have their advantages and disadvantages.
- Catchment area: Downstream receiving water body has direct influence on the design and selection of BMPs. Analysis of watershed prior to design of the BMPs should be included on feasibility study of the BMPs.
- Soil Property of Site: Geotechnical testings (gradation of soil, type of soil and permeability) are needed for the analysis of the soil properties in the field.
- Environmental Impact: Maintenance, community, costs and habitat quality all should be included in the design of BMPs.
- Location: The location of the BMPs should be in compliance of federal/state law. (USEPA, 2004)

Table 2-3 summarizes the types of BMPs and their effective constituents' removal.

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Table 2-3. Average Influent and Effluent Concentrations of Best Management Practices (Geosyntec Consultants &Wright Water Engineers Inc, 2008)

Constituents	Sample	Detention Pond (n=25)	Wet Pond (n=46)	Wetland Basin (n=19)	Biofilter (n=57)	Media Filter (n=38)	Hydrodynamic Devices (n=32)	Porous Pavement (n=6)
Suspended Solids (mg/L)	Influent	72.65	34.13	37.76	52.15	43.27	39.61	xx
	Effluent	31.04	13.37	17.77	23.92	15.86	37.67	16.96
Total Cadmium (µg/L)	Influent	0.71	0.49	0.36	0.54	0.25	0.74	xx
	Effluent	0.47	0.27	0.24	0.30	0.19	0.57	xx
Dissolved Cadmium (µg/L)	Influent	0.24	0.19	xx	0.25	0.16	0.33	xx
	Effluent	0.25	0.11	xx	0.21	0.13	0.31	xx
Total Copper (µg/L)	Influent	20.14	8.91	5.65	31.93	14.57	15.42	xx
	Effluent	12.1	6.36	4.23	10.66	10.25	14.17	xx
Dissolved Copper (µg/L)	Influent	6.66	7.33	xx	14.15	7.75	13.59	xx
	Effluent	7.37	4.37	xx	8.4	9.00	13.92	xx
Total Chromium (µg/L)	Influent	7.36	6.00	xx	5.63	2.18	4.07	xx
	Effluent	3.18	1.44	xx	4.64	1.48	3.52	xx
Total Lead (µg/L)	Influent	25.01	14.36	4.62	19.53	11.32	18.12	xx
	Effluent	15.77	5.32	3.26	6.7	3.76	10.56	7.88
Dissolved Lead (µg/L)	Influent	1.25	3.40	0.50	2.25	1.44	1.89	xx
	Effluent	2.06	2.48	0.87	1.96	1.18	3.34	xx
Total Zinc (µg/L)	Influent	111.56	60.75	47.07	176.71	92.34	119.08	xx
	Effluent	60.2	29.35	30.71	39.83	37.63	80.17	16.60
Dissolved Zinc (µg/L)	Influent	26.11	47.46	xx	58.31	69.27	35.93	xx
	Effluent	25.84	32.86	xx	25.40	51.25	42.46	xx
Total Phosphorus (mg/L)	Influent	0.19	0.21	0.27	0.25	0.20	0.24	xx
	Effluent	0.19	0.12	0.14	0.34	0.14	0.26	0.09
Dissolved Phosphorus (mg/L)	Influent	0.09	0.09	0.10	0.09	0.09	0.06	xx
	Effluent	0.12	0.08	0.17	0.44	0.09	0.09	xx
Total Nitrogen (mg/L)	Influent	1.25	1.64	2.12	0.94	1.31	1.25	xx
	Effluent	2.27	1.43	1.15	0.78	0.76	2.01	xx
Nitrate-Nitrogen (mg/L)	Influent	0.70	0.36	0.22	0.59	0.41	0.40	xx
	Effluent	0.58	0.23	0.13	0.60	0.82	0.51	xx
TKN (mg/L)	Influent	1.45	1.26	1.15	1.80	1.52	1.09	xx
	Effluent	1.89	1.09	1.05	1.51	1.55	1.48	1.23

n = Number of the BMPs xx = Lack of sufficient data

2.4.4. Exfiltration Trench as Best Management Practice

Ohio EPA requires all the public entities to implement post-construction BMPs in compliance with “Location and Design Manual, Volume two Drainage Design”(ODOT, 2010) Which is in compliance with Ohio EPA Construction General Permit for Storm Water Discharge (OHC000003). Changing the alignment of road during roadway improvement is not an alternative, in order to implement less complicated and cost effective BMPs, and also in highly urbanized areas stormwater management is a complicated task. ODOT in compliance with OEPA selected three BMPs which are manufactured system, vegetated biofilter; and exfiltration trench, for linear transportation projects. Among these alternatives the exfilteration trench appears more cost effective and easily manageable in view point of operation and maintenance.

According to ODOT Location and Design Manual Volume – 2 an exfiltration trench drains the roadway runoff and is located outside edge of the shoulder of the road. It has a simple structure and contains three layers of pervious concrete, gravel and sand filter. When its effective design life (is completely clogged or cannot treat the contaminant) is over, it can be replaced. (Wawszkiewicz, 2010)

Exfiltration trench also has been proposed as best management practice to control quantity and quality of stormwater runoff by many researchers. Li, Buchberger and Sansalone (1999) found that an exfiltration trench is a BMP for controlling quality and quantity of stormwater runoff. They concluded in their research that not only exfiltration trench improve the quality of runoff but it also acts as storage to mitigate the peak flow. Refer to Figure 2-2 and Figure 2-3.

Figure 2-2. Exfiltration trench, Photo by: Wawszkiewicz Hydraulic/BMP Specialist ODOT (Wawszkiewicz, 2010)

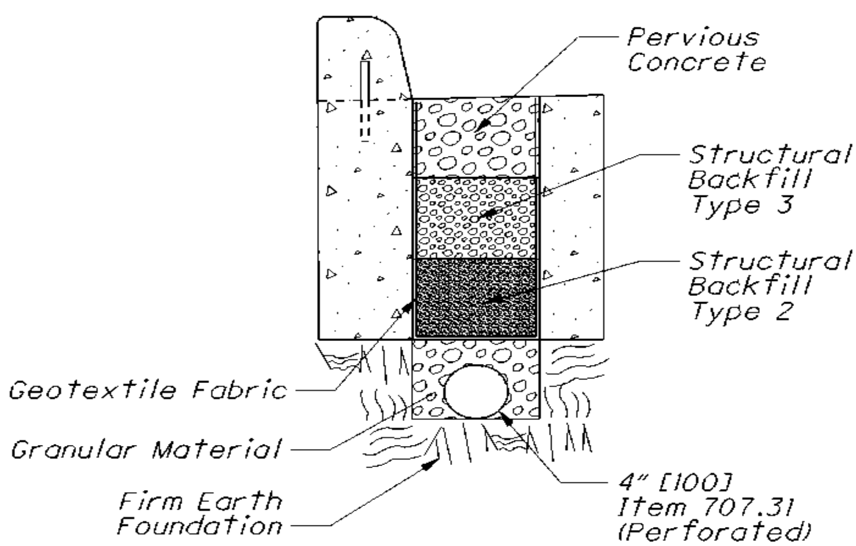

*Figure 2-3. Exfiltration trench cross section: Standard construction d*rawing: *WQ-1.3 ODOT (ODOT, 2010)*

2.5. Pervious Concrete

Pervious concrete has been used as a sustainable construction material over the last decade and strict stormwater regulations gave the pervious concrete much more important role. Pervious concrete is a construction material which contains Portland cement, aggregate, water and admixture. Due to the high porosity and permeability demand fine aggregates are rarely parts of the concrete mixture. Pervious concrete are less dense than the conventional concrete mix, and this decreased density gives the concrete high permeability beside the structural integrity and stiffness. Stormwater runoff percolates through pervious concrete to underlying layers. This leads to not only removing the runoff from the surface but also recharging the groundwater. Usually the layer underlying the pervious concrete is an appropriate porous aggregate layer which provides storage to store the runoff water for the rainfall event.

After the promulgation of Phase II regulation of USEPA, all the owners of construction sites of 1 – acre area are required to have a management system for stormwater. This regulation required a sustainable and cost effective solution to the problem. In comparison to the other large investments in stormwater treatment design, pervious concrete offers better options. Pervious concrete removes the stormwater and filters it which significantly improves the quality of stormwater runoff. Stormwater not only contains chemical elements and suspended solids, but also the temperature of the runoff is being raised by the impervious surfaces. Both the chemicals and temperature have direct impact on depletion of dissolved oxygen in receiving water body and endanger the aquatic life.

In the cold region when the pervious concrete freezes the ice formation quickly leaves the surface of the pervious concrete due to the higher porosity. Higher voids provide passage for the water upon melting and prevent re-freezing. (Huffman, 2005)

Research by Kevern, Haselbach and Schaefer (2009) shows that pervious concrete stores less energy during hot weather than the traditional concrete with the same concrete mixture and cement color. The findings of the research suggest that using the pervious concrete with high porosity is effective in lowering the effect of heat in the area and cool down the surfaces.

2.6. Greensand

Greensand has been used since 1950 and is known to be useful for removing iron, manganese and hydrogen sulfide. Greensand is processed from glauconite (iron, potassium phyllosilicate mineral). Due to the uniform effective size of 0.3 – 0.35 mm and uniformity coefficient of 1.6, greensand has excellent filtering characteristics. (Rader, 2003)

CHAPTER 3: METHODOLOGY

The exfiltration trench as recommended by the Ohio Department of Transportation (ODOT), Construction and Specification Manual (2010), contains three layers. The top layer of the trench is pervious concrete. This layer was simulated in the laboratory and tested for permeability, porosity, total suspended solids released, compression strength and freeze and thaw strength. The concrete mix was prepared according to ACI 522R-08 (ACI, 2008). Designated molds and procedures were followed accordingly for each test. Step by step procedures are discussed in the following sections. ACI 522R-08 and ORMCA have the same specification, except in ACI 522R-08 fine aggregate is avoided to improve permeability.

3.1. Concrete Mix Design

The pervious concrete mixture was mixed according to the ACI 522R – 08 (ACI, 2008). For the concrete mix only gravel # 67, Portland cement and tap water were used. Fine aggregate was avoided due to the reduction in permeability. The properties and ASTM requirements for the material are discussed in following:

3.1.1. Equipment/Materials

- Ten, 4 inches diameter acrylic cores (approximately 6” in height)
- Four freeze/thaw molds in accordance to ASTM C666-97
    - Three rectangular prism t molds that provide for a 3 by 4 by 16 inches.

- Materials in accordance with ACI 522R -08, which uses ASTM C 33 requirement for Aggregate and for Portland Cement ASTM C 150 requirement were used (ASTM C150, 2009a).

- Gilson Concrete Mixer Model Number: CT-30A

- Properties of Concrete Mixture

    - Type - I Portland Cement

    - Grading Designation: AASHTO No. 67crushed limestone

    - Water to Cement Ratio: 0.36

    - For dry density of coarse aggregate ASTM C 29 used (ASTM C29, 2009b).

3.1.2. Methodology of Preparing Specimens

Beam and Rectangular prism Molds- The beam mold used for the creation of the concrete specimens to be used in the freeze/ thaw test had a width of 4 inches, height of 3 inches, and length of 16 inches. The interior surfaces of the mold of the reusable freezing and thawing specimen molds were lightly covered with mineral oil. The mineral oil was a nonreactive releasing agent.

Cylindrical Molds- The cylindrical molds were used to form pervious concrete to be used in the permeability and porosity tests. Ten molds were prepared. The dimensions of each mold included 4 inches diameter and 6 inches height. The use of these molds were based on the requirements of ASTM C 192/ C 192 M, "the shapes and sizes of specimens for particular tests may be molded as desired following the general procedures set forth in this practice" (ASTM C192,2006).

Three extra cylindrical molds were utilized to form concrete to be used in the compression strength tests. The dimensions of these molds were 4" diameter and 8" height.

To allow for the cement paste to create open pores on the bottom end of the mold, aggregate was placed at the bottom of the cylindrical mold. The aggregate prevented the cement paste from smearing, thus closing off interconnecting pores.

Temperature-The concrete materials were cured in Room 032 Stocker Center, Ohio University, which met the requirements that the concrete be cured for 7 -10 days while using moist cover for this period in the temperature range of 68 to 87°F (20 to 30°C).

3.1.3. Procedure

The materials were measured to ensure a 10% excess of concrete after molding the test specimens. The volumes of molds are illustrated in Table 3-1. Coarse aggregate information is in Table 3-2. Table 3-3 shows the mix information. The materials needed to form the concrete were proportioned according to Table 3-4. The quantity of aggregate was measured on a scale which measured to the nearest 1 kg.; the water and Portland cement portions were measured on a scale which measured to the nearest 0.1 g. Summary of required materials for all molds are in Table 3-5.

Table 3-1. Concrete Samples

Number of samples	Sample Dimensions			Volume (in^3)
	Diameter (in)		Height (in)	
10	4		6	753.98
3	4		8	301.59
	Length (in)	Width (in)	Height (in)	
3	4	3	16	216.00
Total Volume (in^3)				1271.58

Table 3-2. Coarse Aggregate Information

Size	No.67
Dry-rodded density (lb/cft)	108.7
Specific Gravity	2.75
Absorption	1.20%

Table 3-3. Mix Information

Type	Well compacted pervious concrete
w/c Ratio	0.36
Void content	18.00%
Volume (ft^3)	1

Table 3-4. Calculations & Quantities (for one cubic foot of mix)

Wt of Aggregate (lb)	107.613
Paste Content	17.00%
Volume of paste (cft)	0.17
Cement Content (lb)	15.669
Water Content (lb)	5.641
Aggregate Volume (cft)	0.627
Cement Volume (cft)	0.080
Water Content (cft)	0.090
Total Solid Volume (cft)	0.797
Percent Voids	20.28%
Percolation rate	7.00%

Table 3-5. Summary of the Required Quantities for the Mix

Cement (lb)	15.669
Aggregate (lb)	107.613
Water (lb)	5.641

3.1.4. Preparation of Porous Concrete

1. Prior to starting the rotation of the mixer, the coarse aggregate and some of the mixing water were added. The mixer was started; the rest of the water and the cement were added into the mixer.
2. The concrete was mixed for approximately 3 minutes, followed by a 3 minute rest, and followed by a 2 minute final mixing.
3. To prevent sealing the paste on the cylindrical molds, aggregates were placed on the bottom of the cylindrical molds.

4. The concrete mix was placed into the molds using a scoop. Each scoopful of concrete from the mixer was used to guarantee that the concrete was representative of the batch. The concrete was placed first into the cylindrical molds, and then into the freeze/thaw molds.
5. The specimens were prepared outside Stocker Center room 032 and immediately stored in room for curing. It was necessary to remix the concrete in the mixer with a shovel to prevent segregation during the molding of the specimens. While placing the concrete into the molds (either cylindrical or freeze/thaw) the scoop was moved around the top edge of the mold as the concrete was placed to ensure a symmetrical distribution of the concrete and minimize segregation of the coarse aggregate within the mold. The concrete was further distributed by tamping the placed concrete with a tamper at the start of consolidation. When the final layer was placed in a mold, an additional amount of concrete was added that exactly filled the mold after compaction. When the concrete was being remixed or sampled it was covered to prevent evaporation. After filling the molds, the molds were covered with a plastic cover.

3.1.5. Curing

The cores were transported from outside to Room 032. The molds were placed on a rigid surface (concrete slab) that allowed the concrete to be free from vibrations and other disturbances. The molds were cured for 7 days: with each covered with a moist cover. The covers were changed every 12 hours. Jarring, striking, tilting, or scarring of the surface of the specimens were avoided while transporting the specimens into the storage place. The porous concrete molds are shown in Figure 3-1.

Figure 03-1. Porous concrete molds

3.2. Permeability and Porosity Test Procedure

After the concrete specimens were cured for the desired period, the first series of tests started which included the determination of tap water permeability, porosity and total suspended solids released from the specimens after each permeability test. The permeability was conducted according to Meininger (1998) which has been discussed in the test procedure in the following. Before running the permeability the flow regime in pervious concrete was checked on ODOT mix which was tested prior to the ORM mix. The aggregate which was used in the ODOT mix was aggregate #57 and the particle size analysis on 5500 g of gravel is reported in Table 3-6 and Figure 3-2.

Table 3-6. Gravel #57 Particle Size Analysis

Sieve analysis		Mass of each sieve (g)	Mass of each sieve plus retained soil (g)	Mass of soil retained (g)	Mass of soil passed (g)	Percentage passing (%)
Sieve size (mm)	19	1637.3	1864.1	226.8	5273.2	95.9
	12.5	1261	3838.3	2577.3	2695.9	49.0
	9.5	1264.1	2304.5	1040.4	1655.5	30.1
	4.75	1209.3	2031.4	822.1	833.4	15.2
	2.36	1089	1810.9	721.9	111.5	2.0

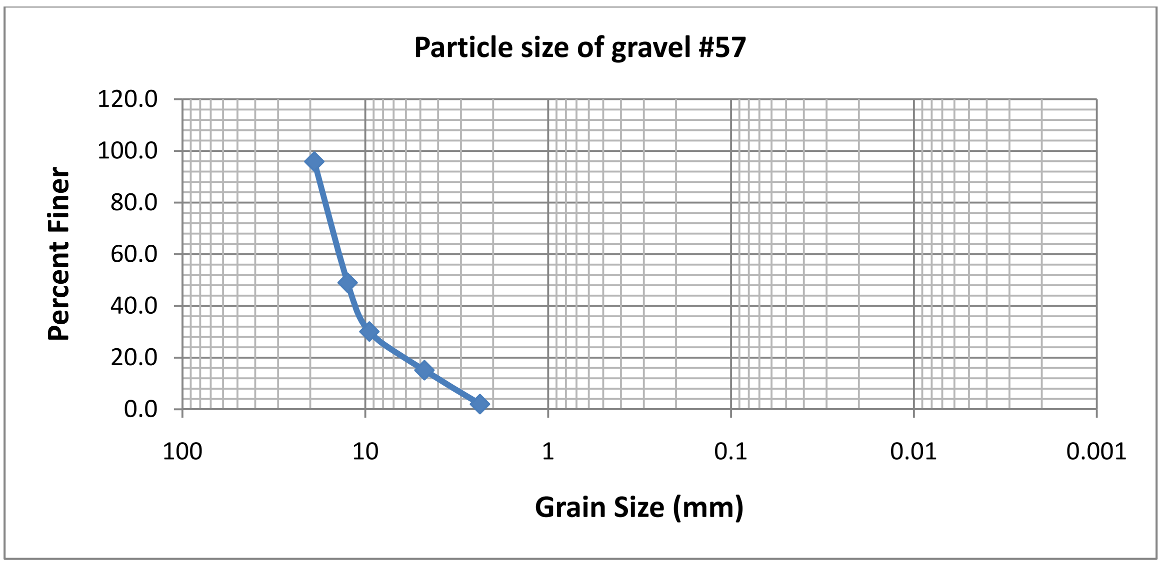

Figure 3-2. Gravel #57 particle size

The Reynold's number is expressed in Equation 3-1 as follows:

$$R = \frac{\rho V D}{\mu}$$ ……….Equation 3-1

Based on the above graph D_{10} of the gravel is 3.5 mm.

Fluid velocity, V = ki = 3.6 cm/s

Particle diameter, D = 3.5 mm = 0.35 cm, which represents the pore diameter

Water density @ 23C°, $\rho = 0.9976$ kg/L

Fluid dynamic viscosity, $\mu = 0.9408*10^{-2}$ kg/m-S

According to equation 3- 1, Reynolds number is 133 < 150 and the flow regime is transient (Bear, 1979).

The flow regime is transient in the lab due to the elevation and velocity head in the falling head permeameter but the flow regime is laminar in the field, since in the field the elevation head and velocity heads are negligible.

The permeability test was performed three times on each specimen, and the averages of all tests were calculated. Figure 3-3 shows the permeameter used for falling head permeability. The falling head permeability test procedure was as follows:

3.2.1. Determination of Initial Permeability with Tap Water

3.2.1.1. Apparatus and Materials

- Vertical Permeameter Device (consisting of acrylic standpipe, threaded 4.0 in. PVC connector, two rubber connectors)
- 4 in. rubber-bladder control plug (used to control the flow rate through the permeameter)
- Digital Scales Model: AND GP-12k (maximum mass reading of 12 kg, measures mass to the nearest 0.1 g)
- two, 5 gallon buckets
- Tape Measure
- Thermometer

Figure 30-3. Vertical I-shaped permeameter with core mounted

3.2.1.2. Procedure

1. Measurement of dry mass of the concrete specimen (mass of concrete plus mass of encasement) to the nearest 0.1 g. excluding the mass of the encasement (measured prior to pouring) from the measured mass and recorded as the "Dry Mass", M_D.
2. Measurement of the length of the concrete specimen to the nearest 0.1 mm at three representative locations, and recorded as L_1, L_2 and L_3.
3. Calculation of the average length (L_{avg}) of the specimen as the average of the three measurements in Step 2. The diameter of the concrete is the same as the inside diameter of the encasement (4.0 in.). Compute the total volume of the concrete (V_T), using the average length (L_{avg}) and diameter (D).
4. Assembling the falling head permeameter. The pervious concrete is placed with "flushed" side down, so that the jagged end (the side with protruding aggregate) is facing up (referred to as 'top side").
5. Placement of two marks 18 inches apart on the acrylic standpipe, and set the fiber optic light detectors at these marks.
6. Measurement of the distance between the bottom of the concrete specimen to the top mark (h_1) and bottom mark (h_2), and record as h_1 and h_2.
7. Pouring 2.64 gallons (10 liters) of tap water into the 5 gallon bucket.
8. Weighing the influent water.
9. Measurement of the temperature of the influent water and bucket.
10. Placing the rubber-control plug onto the bottom of the permeameter.

11. Placing a clean 5 gallon bucket underneath the permeameter. Carefully pour the influent water into the standpipe.
12. Setting the electronic timer on 2 (check that light mode is set).
13. Weighing the empty influent bucket and subtract from the mass of the influent water plus bucket, and record as M_w.
14. Determining the water volume, V_W
15. After 30 minutes the concrete specimen has been saturated, the control plug is released. Prior to releasing the plug set the electronic timer to 1.
16. Recording the time measured as *t*.
17. Transferring the effluent sample to bench top, weighing the effluent and measurement of the temperature
18. Preserving sample for TSS analysis
19. Performing steps 7-18 two more times.

The permeability determination tables are in Appendix – 1

3.2.2. Porosity Test

After finishing the tap water permeability the concrete specimen was tested for porosity. The porosity test was conducted as ASTM SEDL (Montes et al., 2005) and followed as below:

3.2.2.1. Apparatus and Material

- AND GP-12k Digital Scale (maximum mass reading of 12 kg, measures to the nearest 0.1 g)
- Ball Pen Hammer
- Tape measure
- Thermometer
- Watch
- 4.0” Diameter Concrete Specimen
- Wire Mesh Basket
- 5-gal container

3.2.2.2. Procedure

The following procedure was conducted for determination of porosity of pervious concrete samples:

1.) Attach wire mesh to the digital scales.
2.) Zero the digital scales.
3.) Place the specimen into the steel wire mesh basket.
4.) Submerge specimen completely into a 5-gal container filled with tap water, and let the specimen sit upright for 30 min underwater.
5.) After 30 min tap each of the specimen against the bottom of the tank 5 times, (Tap hard enough to allow air bubbles to be released, but not too hard as to damage the specimen or container). Invert the specimen 180°.

10) Weigh the submerged concrete specimen to the nearest 0.1 g, and record as W_{sat}.

11) Record the temperature of the water

12) Equation 3-2 was used to calculate the porosity

$$\boldsymbol{P}(\%) = \left[\mathbf{1} - \frac{\left(\frac{(\boldsymbol{M_D} - \boldsymbol{M_S})}{\rho_W} - \boldsymbol{V_A}\right)}{\boldsymbol{V_{CT}}}\right] * 100 \text{.................Equation 3-2}$$

Where:

M_D =D ry mass of the specimen (g)

M_S = Submerged mass of the specimen (g)

ρ_w = Density of water (g/cm^3)

V_A = Volume of acrylic (cm^3)

V_{CT}= Total volume of concrete (cm^3)

P = Porosity of the specimen which is the ratio of volume of voids to total volume of the specimen (V_{voids}/ V_{sol}) given in percent

The porosity determination tables are in Appendix – 2

3.3. TSS Analysis

The effluents from the falling head permeability tests were collected for total suspended solids analysis. The total suspended solids test was performed according to ASTM D3977 (ASTM D3977, 2007b) as follow:

3.3.1. Apparatus and Materials

- 5 gallon bucket with spigot
- Mechanical stirrer
- Glass fiber filter discs, 4.7 cm, Type 934-AH
- Filter holder, membrane filter funnel or Gooch crucible adapter
- Suction flask, 350 mL
- Aluminum Evaporating dishes
- 250L graduated cylinder
- Drying oven, capable of 105°C ± 2°C
- Desiccators
- Analytical balance, capable of weighing to 0.1 mg

3.3.2. Procedure

1. Pouring effluent sample into a 5 gallon bucket with spigot.
2. Placing mixer inside effluent container and mix.
3. Placing the filter disc into the aluminum weighing dish.
4. Labeling the weighing dish appropriately.
5. Placing the disc on the membrane filter.
6. Assembling the filtering apparatus and begin suction.
7. Washing the disc with three successive 20 mL volumes of ultrapure water.
8. Removing all traces of water by continuing to apply vacuum after water has passed through. Discard washings.

9. Drying in an oven at 103 to 105°C. The drying time should be long enough to ensure a constant weight. Place in desiccators, cool, and weigh to the nearest 0.1 mg.
10. Placing the oven dried dishes into the desiccators. Weigh the oven-dried weighing dish with disc and record mass as initial mass.
11. Obtaining a 250 mL sample from the spigot. Carefully pour sample into the suction flask.
12. Filtering the sample through the glass fiber filter, rinse with three 10 mL portions of distilled water and continue to apply vacuum for about 3 minutes after filtration is complete to remove as much water as possible.
13. Drying in an oven at 103 to 105°C. The drying time should be long enough to ensure a constant weight. Place in desiccators, cool, and weigh to the nearest 0.1 mg.
14. Equation 3-3 was used to calculate TSS as follows:

$$TSS, mg/L = \frac{(A-B)*1000}{C} \qquad \text{…………Equation 3-3}$$

Where:

A = weight of filter (or filter and crucible) + residue in mg

B = weight of filter (or filter and crucible)

C = L of sample filtered

The TSS determination tables are in Appendix – 3

3.4. Falling Head Permeability with Sand (Sand Clogging)

After determining the tap water permeability, porosity and total suspended solids released for all ten specimens, the clogging test with ordinary sand was performed on three specimens (specimens I,II and III). Four grams of sand were introduced per liter of tap water which is a total of 40 g of sand per 10 liters of tap water. The test was performed until the permeability of pervious concrete specimen was reduced to 15 – 20 percent of initial permeability. The number of tests performed on each specimen varied due to the porosity and aggregate bonding of each specimen. The permeability and total suspended solids analysis tests procedures were outlined previously. The tap water permeability and TSS tests procedures were followed, except in sand clogging permeability test, 4 g of sand was introduced per 1 liter of tap water.

After the clogging test, maintenance of each specimen was performed. Maintenance of specimen included three steps; sweeping of accumulated sand from the surface of the specimen, vacuuming of the sand from the specimen with vacuum machine, and pressure washing of specimen. The sand which was recovered in each of the maintenance steps was collected and weighed. Mass balances of sand were calculated as follows:

Amount Stored in Specimen = Amount Introduced – Amount collected in effluent – Amount Collected in maintenance……..…. Equation 3-4

After the maintenance and recovery of introduced sand, post maintenance permeability was determined. The permeability after the maintenance or sand recovery was compared with last test of clogging permeability to determine how much the permeability increased after the maintenance.

The data and tables of sand clogging test are in Appendix - 4

3.5. Falling Head Permeability with A6 Soil

Tests were performed on specimens IV, V and VI with A6 soil in the influent. The test procedure was the same as with the sand, except in A6 soil test the amount of soil was 8 g per liter of tap water, which is 80 g per 10 L of tap water. The soil was taken from Nelsonville bypass and it was disturb soil

After running several tests with 4 – 8 g of A6 soil per liter of tap water, the pervious concrete specimens were not clogged at all. About 90% of the introduced A6 soil was recovered in effluent from falling head permeameter.

After the tests, maintenance of each specimen was performed. Maintenance of specimen included three steps; sweeping of accumulated A-6 soil from the surface of the specimen, vacuuming of the A6 soil from the specimen with vacuum machine, and pressure washing of specimen. The A6 soil which was recovered in the maintenance steps was collected and weighed. Mass balance of A6 soil was calculated as per equation:

Amount Stored in Specimen = Amount Introduced – Amount collected in effluent – Amount Collected in maintenance……….….. Equation 3-5

After the maintenance and recovery of introduced A6, post maintenance permeability was performed. The permeability after the maintenance or A6 soil recovery was compared with last test of clogging permeability to determine how much the permeability increased after the maintenance.

The detailed data of the tests and maintenance are in the Appendix – 5

3.6. Artificial Runoff

Artificial runoff was prepared to simulate stormwater and then introduced to the laboratory specimens with different concentrations of runoff constituents. The concentrations of constituents are taken from the literature. Three different types of concentrations of constituents were made. The three specimens, VII, VIII and IX were tested with high concentration, medium concentration and low concentration, respectively.

The summary of test procedure is, 150 L of tap water was mixed with specified amount of A6 soil for one hour and then concentrated metals solution, which was prepared beforehand by the chemistry department, was mixed with the solution for one hour. The pH was adjusted to around 7 before starting the test by using NaOH. Samples were taken from the influent and effluent of the falling head permeability to analyze for total suspended solids, particle size, total metals and dissolved metals. The remaining amount of effluent from the falling head permeameter became the influent for the constant head permeameter containing green sand. Samples for total suspended solids, particle size, total metals and dissolved metals were taken from the effluent of the constant head permeameter for analysis.

Table 3-7 below shows the target concentrations of the constituents in the artificial runoff.

Table 3-7. Target Concentrations for Contaminants in Artificial Roadway Runoff (Mitchell, Riefler & Russ, 2010)

Metal	Low	Medium	High
total Cd (µg/L)	20	100	500
total Cr (µg/L)	25	125	625
total Cu (µg/L)	35	175	875
total Fe (µg/L)	250	7720	16500
total Ni (µg/L)	95	475	2375
total Pb (µg/L)	215	1075	5375
total Zn (µg/L)	25	500	2300
pH	7.0±0.1	7.0±0.1	7.0±0.1

The detailed procedure of running the artificial runoff test with different concentrations is followed as below:

3.6.1. Artificial Runoff Tests with High Concentration

A. Preparation of 150 ℓ of artificial runoff

1. Water holding tank was filled to about 75 to 100 ℓ with tap water.

   110.55 g of A-6 soil was weighed for artificial runoff. (110.55 g A-6 soil to achieve target concentration of 737 mg/ ℓ.)

$$737\frac{mg}{\ell}\ (150\ell)\left(\frac{g}{1000mg}\right) = 110.55g$$

2. While mixing, A-6 soil was added to the water in the tank. The container was well rinsed to transfer all soil to the tank.
3. After about 15 minutes, while mixing, concentrated solutions containing the metals supplied by the chemistry department to the tank, was added. The mix was thoroughly mixed about 5-10 min.

4. The tank was filled near to the 150 ℓ mark with tap water (a graduated cylinder was used to top off at the 150 liter mark to prevent over filling); stirring resumed
5. Before starting experiments the mix was stirred almost for 2 hours.
6. pH was adjusted to around 7. Both pH and temperature were measured.
7. Mixing of tank contents was continued throughout the experiments.

B. Falling Head Test for Pervious Concrete Specimen

1. Pump with tubing from holding tank spigot to the top of the falling head permeameter was set up.
2. The weight of the effluent sample container to be placed under permeameter was obtained.
3. Pump was started and influent was supplied to the permeameter until fluid is at the 10 liter mark.
4. Temperature of fluid in holding tank was obtained.
5. 1.5 liters of influent sample from the spigot of the holding tank via the pump and tubing was obtained into a container.
6. Influent sample container transferred to bench top, and mixed with mixer; after the pH and temperature measurement, extracted samples were as following:

Total Suspended Solids	3 samples each 250 mℓ =	750 mℓ
Totals Metals	3 samples each 15 mℓ =	45 mℓ

(These were acid digested by CE and given to Chemistry for analyses.)

Dissolved Metals 3 samples filtered through 0.45µm filter, each 15 mℓ = 45 mℓ

Particle size 2 samples each 250 ml= 500 mℓ

TOTAL = 1340 mℓ

7. After water reached steady state in permeameter (at least 15 min elapsed or no more bubbles emanated from specimen) the valve at the bottom of the permeameter was opened. The falling head time was measured as the influent passed through the specimen.
8. The effluent was collected in the effluent sample container.
9. Effluent sample was moved to the bench top, the weight and temperature was recorded. The mixer was inserted in the container and the mixing started. The pH, and samples as per above (Step 6) for TSS, total metals, dissolved metals, particle size analysis, were obtained.
10. The volume of remaining sample, after extracting samples for analysis, was reweighed and prepared as influent for the green sand constant head permeability test.
11. The same procedure from 1 to 10 was followed for the next run and was repeated for a total of 10 times.

C. Constant Head Test for Filter Medium Greensand

1. The greensand was poured in the constant head permeameter and clean water permeability measured three times and the average was obtained in advance of the artificial runoff test.
2. The effluent remaining from the falling head test was used as the influent for the constant head device. The sample was added as per the instructions and standard method for the permeameter, and permeability was determined.
3. Effluent of sample was moved to the bench top, the weight and temperature was recorded. The mixer was inserted in the container and the mixing started. The pH, and samples as per above (Step 6 of part B) for TSS, total metals, dissolved metals, particle size analysis, were obtained.

D. Particle size analysis

The analysis of the particles in both influent and effluent of falling head permeability and effluent of constant head permeability was done in Coulter Beckman machine, which uses laser diffraction and polarization intensity differential scattering (PIDS) to recognizes the size of particles. The range that the machine was able to detect was 0.375 μm to 2000 μm. Coulter Beckman machine needs certain range of concentration of the particles in samples. If the concentration is below the certain ranges the machine could not detect the particles in sample and data that was provided was not accurate. The step by step instruction of the test is given by the software of machine.

Particle size analysis has been run on influent of falling head permeability, effluent of falling head permeability and effluent of constant head permeability samples. Only the particles in influent falling head permeability and effluent falling head permeability samples were detectable by Coulter Beckman machine.

E. Metals

The total metal and dissolved metal samples were sent to chemistry department for analysis. The result of analyses is discussed in Chapter 4.

The detailed data of artificial runoff, high concentration are in Appendix – 6

3.6.2. Artificial Runoff Tests with Medium Concentration

Medium concentration artificial runoff testing was performed similarly as high concentration artificial runoff on specimen number VIII except the amount of A6 soil was 31.05 g (31.05 g A-6 soil to achieve target concentration of 207 mg/ ℓ.) and chemical constituents were as per mentioned in Table 3-6. The detail data of artificial runoff, medium concentration are in Appendix - 7

3.6.3. Artificial Runoff Tests with Low Concentration

Low concentration artificial runoff performed on specimen number IX similarly as high and medium concentration artificial runoff. The amount of A6 soil was 1.36 (1.35 g A-6 soil to achieve target concentration of 9 mg/ ℓ.) g and chemical constituents were as per mentioned in Table 3-7.

The detailed data of low concentration runoff are in Appendix – 8

After the artificial run off tests, maintenance of specimens was performed. The maintenance procedure was similar as that described in sand clogging test. Only in pressure washing negligible amounts of suspended solids were recovered from specimen number VII. The recovered amount of the suspended solids did not change the post maintenance permeability of specimen number VII. The maintenance was only performed on the specimen which was exposed to high concentration artificial run off.

3.7. Compressive Strength of Pervious Concrete

The compression test was performed on the specimens XI, XII and XIII. These specimens had diameter of 4 inches and height of 8 inches. The test was performed according to ASTM C39 standard (ASTM, 2009c). Peak load and unconfined compressive strength of each specimen was determined. The details of the test procedure were followed as below:

3.7.1. Unconfined Compressive Strength Test Procedure

Before starting the test all concrete cylinders were weighed and dimensions were measured and data were recorded.

3.7.2. Capping the Specimens (ASTM C617,2010)

Apparatus

a. Capping mold
b. Melting pot
c. Aluminum foil

Materials

a. Sulfur mortar
b. Concrete cylinders

Procedure

a. The sulfur was heated in heating pot until it melted then concrete specimen was placed in the capping molds. Since the concrete cylinder did not have smooth surface to be capped properly the molten sulfur mortar overflowed from the capping mold.
b. Molds were made from the aluminum foil exactly the same size as the concrete cylinder.
c. The aluminum molds were oiled
d. Molten sulfur mortar was poured in the aluminum mold and concrete cylinder was placed inside of that.
e. Similar procedure was followed for both sides of the concrete cylinders. All the concrete cylinders were capped.

3.7.3 Compressive Strength of Concrete Cylinders test procedure

Apparatus

a. MTS Compression test machine

Material

a. Capped concrete cylinders

Procedure

a. The concrete cylinder was centered in the lower and upper platen of the machine the lower platen was raised until the upper platen touched the surface of the concrete and concrete specimen was seated completely.

b. The load display and dial gage both were made zero.

c. The load was applied at the rate of 30 psi/s

d. The dial gage was read for every 5 divisions (each division is 0.001 inches) and the applied load was recorded.

e. The load was recorded until it reached to the peak load and the concrete cylinder was damaged

For all three concrete cylinders the same procedure was followed and the detail data are in appendix 9.

The Figure 3-4 shows the concrete specimen under testing.

Figure 3-4. Concrete specimen under the test

3.8. Freeze and Thaw Test

Three pervious concrete specimens were tested for freeze and thaw. The ASTM C 666 standard test method for resistance of concrete to rapid freezing and thawing (ASTM C666, 1997), was as follow:

3.8.1. Procedure

1. Specimens are removed from molds.
2. The edges of the specimens were trimmed by mechanical saw to fit exactly in the freeze and thaw mold.

3. The mass of the specimen were measured and recorded to the nearest 0.1g.
4. Specimens were placed into freeze thaw container.
5. The specimen were surrounded by not less than 1/32 in, [1 mm] nor more than 1/8 in. [3 mm]of water at all times while it is being subjected to freezing and thawing cycles
6. Freezing and thawing tests started by placing the specimens in the thawing phase of the cycle.
    a. The machine is started.
    b. The specimens removed from the apparatus, in thawed conditions, at intervals not exceeding 36 cycles of exposure to the freezing and thawing cycles and determine the mass of each specimen.
    c. To ensure that the specimen is completely thawed and at the specified temperature, hold the specimens at the end of the thaw cycle in the freezing and thawing apparatus for a sufficient time for this condition to be attained throughout each specimen to be tested.
7. The specimen removed from the freeze thaw container and measured the mass of the specimen.
8. The appearances of the specimen were checked, after the 22 cycle of freeze and thaw the specimens lost from 18% to 20.3% of the initial mass. The mass loss was the edge of the specimen.

The detail result of freeze and thaw are in Appendix 10.

3.9. Type 3 Aggregate

The second layer of the exfiltration trench is type 3 aggregate. Type 3 aggregate is crushed stone that meets item 703.11 of ODOT 2008 C&MS. The thickness of this layer in the trench is 6 inches and is located under the pervious concrete layer. For this study Type 3 aggregate is a No. 67 graduated crushed limestone obtained from a rock quarry in Albany, Ohio. In order to determine the characteristics of the type 3 material falling head permeability tests and total suspended solids (TSS) analysis were performed on washed and unwashed Type 3 aggregate. Three permeability and TSS tests were performed on six Type 3 samples (three washed and three unwashed samples). The test consisted of running 10L of water through each aggregate sample, which was totally 30L of water for washed specimen and 30L of water for unwashed specimen. The permeability and total suspended solids (TSS) values from the washed and unwashed type 3 aggregate are compared to one another in the result chapter.

3.9.1 Preparation of Aggregates

A sieve analysis, according to ASTM D 422, was performed on a representative 5 kg of the Type 3 gravel prior to the permeability test. Any particles larger than 19 mm (3/4 in.) were separated out by sieving (ASTM D422, 2007a). This oversize material was not used for the permeability test, but the percentage of the oversized was recorded. The sieve analysis is tabulated in Table 3-8:

Table 3-8.Sieve Analysis of the Aggregate

Sieve Analysis		Sieve Weight	Sieve & Gravel Weight	Percent Retained (%)	Percent Passing (%)
Sieve Size (mm)	50	0.55	0.55	0	100
	37.5	0.56	0.56	0	100
	25	0.574	0.574	0	100
	19	0.67	2.4655	35.91	64.09
	12.5	0.642	3.3675	54.51	9.58
	9.5	0.628	1.071	8.86	0.72
	4.75	0.509	0.544	0.7	0.02
	2	0.607	0.607	0	0.02
	Pan			0.02	

3.9.2. Washing of Aggregate

For the falling head permeability test there were 3 washed and 3 unwashed Type 3 materials were tested. The following is a description of the procedure used to prepare the washed aggregate:

A. The aggregate was weighed before washing in order to have initial mass and mass after the washing

B. Three large metal containers were selected and the mass of each container was measured. (Each container is marked, so that the containers could be identified.)

C. The air-dried Type 3 sample was equally distributed into the containers.

D. The samples were placed into a No. 10 sieve (the No. 10 sieve which has opening of 2 mm, is smallest sized sieve used to determine Type 3 materials). To prevent overloading of the sieve approximately 500 g of aggregate was placed into the sieve at a time.

E. The aggregate in the sieve was placed under a faucet. Then the aggregate was washed with lukewarm tap water. The sieve was rotated accordingly, so that each side could be washed.

F. After washing the aggregate for approximately a minute, the aggregate was placed into a clean metal container. (As with step 1 the mass of each container predetermined).

G. Steps 6-7 were repeated until all the aggregates had been washed.

H. After washing the aggregates, the retained materials were placed into a large metal container and allowed to air-dry for several days. The aggregate was rotated in the metal container once every 24 hours.

I. After a day period a sample of the washed aggregate was taken and placed into a small metal container.

J. The mass of the aggregate in the container was weighed.

K. Step 9 was repeated every 24 hours. After the container had retained a constant mass the aggregate was considered to be air-dried.

3.9.3. Tap Water Permeability of Type 3

The procedure for tap water permeability of the type 3 is exactly similar to the pervious concrete, mentioned in pervious concrete section, except a mold was designed to hold the type 3 aggregated in the falling head permeameter. The mold had a mesh at the bottom small enough to hold the gravel from falling. Falling head permeability was performed on both washed (3 samples) and unwashed (3 samples) type 3 gravel. The effluent of the falling head permeability was preserved for total suspended solids (TSS) analysis.

3.9.4. Total Suspended Solids Analysis of Type 3

The effluents of falling permeability tests of both washed and unwashed type 3 gravel, were analyzed for total suspended solids (TSS) and the difference between the results of the washed and unwashed type 3 gravel were compared. The total suspended solids analysis test procedure is similar to total suspended solids analysis of pervious concrete discussed in pervious concrete section.

The detail test data are in Appendix 11

3.10. Filter Media Greensand

Filter media is the third or bottom layer in the exfiltration trench. The depth of the layer is 6 inches and this layer function s as the filter media for the exfiltration trench. In this stage of laboratory work greensand was used as filter media and all the properties of the greensand was closely monitored during the laboratory tests. There are distinguished differences between the ordinary sand and greensand. Greensand usually is used for the purposes of cleaning the iron, manganese and hydrogen sulfide in the water that has been passed through. The other property which is important for this project is the uniformity in size of the greensand grain. The effective size of the greensand is 0.3 – 0.35 mm and the uniformity coefficient is smaller than 1.6. This homogenounity in grain size gives the greensand a good property of filtering.

The greensand was also subjected to tapwater permeability and total suspended solids analysis, then the A6 soil was introduced and total suspended solids analysis was performed.

3.10.1. Constant Head Permeability

Scope

This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through greensand. The procedure is to establish representative values of the coefficient of permeability of greensand.

Apparatus

In accordance to ASTM Practice D 2434-68, cylinders with specimen should have minimum diameters approximately 8 to 12 times the maximum particle size. The permeameter was fitted with stainless steel mesh at the top and bottom of specimen with permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10% finer size) to prevent movement of particles.

Manometer outlets are needed for measuring the loss of head, *h*, over a length, *l*, equivalent to at least the diameter of the cylinder.

Constant Head Filter Tank

Water was supplied and was fitted with suitable control valves to maintain steady conditions (flow through the soil voids saturated the specimen until and no air bubbles remained in the soil).

Manometer Tubes, with metric scales for measuring head of water, *Balance*, of 2-kg (4.4 lb) capacity, sensitive to 1 g (0.002 lb).

Scoop, with a capacity of about 100 g (0.25 lb) of soil.

Miscellaneous Apparatus

Thermometers, clock with sweep second hand, 250-mL graduated cylinder, quart jar, mixing pan, etc.

Sample

The specific amount of greensand was weighed and poured in the constant head permeameter.

3.10.2. Preparation of Specimens

The following initial measurement was made in centimeters or square centimeters ; inside diameter of permeameter, *D*; the length *L*, between manometer outlets; the depth H_1, measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous plate or screen. All the data were recorded.

The cross sectional area *A*, volume and height of specimens were determined and recorded.

Preparation of Specimen for Permeability Test

The upper surface of the soil was leveled by placing the upper stainless steel mesh or screen in position and by rotating it gently back and forth. The greensand was weighed and poured in the permeameter to the top and then the permeameter was assembled.

Ten liters of water ware prepared in a plastic bucket and the bucket was placed at an elevation to have potential head. The tubes from the bucket to permeameter top and manometer tube to permeameter were connected. One tube was connected from the bottom of permeameter to the effluent bucket. The water were supplied to the 10 liter bucket to maintain the constant height in the bucket (10 liter level was marked in the bucket and the level of water was maintained in marked level during the test). The system was assembled completely and made ready for the test.

Procedure

The valve of the bucket was opened and water run through the greensand for awhile till the bubble in the monometer tube dissipated and the flow came to steady state.

When the flow became steady the following measurement and recording were done as follows:

The final height difference of specimen (H_1–H_2) was recorded.

A specific time *t* (60 sec) was set and during this time the amount of flow of effluent *Q* was recorded.

The temperature *T* of the water was recorded.

Note: The measurement units must be consistent.

Calculation:

The coefficient of permeability, k, was calculated as Equation 3-6:

$$k = QL/Ath \quad \text{……….. Equation 3-6}$$

where:

k = Coefficient of permeability (cm/s)

Q = Water discharge (cm3)

L = Distance between manometers (cm)

A = Cross – sectional area of specimen (cm2)

t = Total time of discharge (s)

h = Difference in head on manometer (cm)

The permeability was corrected to that at 20°C by multiplying k by the ratio of the viscosity of water at the temperature to the viscosity of water at 20°C.

The total suspended solids analysis is similar to pervious concrete total suspended solids analysis discussed in pervious concrete section.

The detail data of the test is in Appendix 12.

3.10.3. Constant Head Permeability Test Procedure with A6 Soil (A6 Soil Clogging)

The constant head permeability test procedure with A6 soil (A6 soil clogging) is similar to tap water constant head permeability test of greensand. The volume of water used in tap water constant head permeability was 10 liter, but for A6 clogging test it was 5 liter. Since the filter media is the third layer in the exfiltration trench, filter media is subjected to the solids that come from the previous concrete layer and type 3 gravel layers. For A6 soil clogging test of the filter media the amount of A6 soil was taken from effluent of A6 soil test for the pervious concrete. Thirty grams of A6 soil that was the maximum amount which was recovered in 10 liters effluent of the falling head permeability of A6 soil test of pervious concrete.

Total suspended solids analysis test procedure with A6 soil (A6 soil clogging) is similar to tap water total suspended analysis test of pervious concrete. The detailed data of the test is in Appendix 12.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Concrete Mix Design

The pervious concrete mixture was mixed according to the ACI 522R – 08 (ACI, 2008). For the concrete mix only gravel # 67, Portland cement and tap water were used. Fine aggregate was avoided due to the reduction in permeability. The standard followed for this concrete mix, similar to Ohio Ready Mix Concrete Association (ORMCA) except in this mix fine aggregate is avoided due to permeability purposes. In this document the mix is abbreviated as ORM.

4.1.1. Tap Water Permeability and Total Suspended Solids Analysis

The test procedure of tap water permeability, total suspended solids analysis and porosity determination are discussed in details in the Chapter 3 Methodology. The overall results for the tap water permeability and total suspended solids analysis of ten specimens are summarized in Table 4-1.

Table 4-1. Summary of Permeability, Porosity and Effluents for Ohio Ready Mix (ORM) Concrete Specimens

Final test results of Ohio Ready Concrete Mix											
Specimen	Test	$k_{@20°C}$	*Average* $k_{@20°C}$	Porosity, n	Mean TSS	Min μ-2σ	Stdev	Max μ+2σ	Cumulative Amount of Water Passing per Test	Volume of Concrete Specimen	Total Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	(cm/s)	%	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(L)	Cm^3	(gr/cm^3)
I	1	4.1	4.0	37.48	98.96	86.5	6.21	111.4	10	1228.69	0.000112
	2	4.0			37.00	30.6	3.2	43.4	20		
	3	4.0			2.00	0.3	0.9	3.8	30		
II	1	4.7	5.0	42.43	113.30	81.4	16.0	145.2	10	1269.88	0.000098
	2	4.9			6.50	-4.3	5.4	17.3	20		
	3	5.4			4.90	3.7	0.6	6.1	30		
III	1	4.0	4.1	34.69	65.30	43.9	10.7	86.7	10	1231.27	0.000056
	2	4.1			2.40	1.4	0.5	3.5	20		
	3	4.1			1.20	-0.3	0.8	2.7	30		
IV	1	4.4	4.3	30.14	97.80	87.6	5.1	108.0	10	1226.98	0.000093
	2	4.3			14.00	10.9	1.6	17.2	20		
	3	4.4			1.70	1.0	0.4	2.4	30		
V	1	3.9	3.9	31.22	78.60	67.3	5.6	89.8	10	1265.59	0.000072
	2	3.9			10.00	7.5	1.2	12.5	20		
	3	4.0			2.60	1.1	0.7	4.0	30		
VI	1	4.5	4.5	34.39	79.70	43.6	18.1	115.8	10	1187.51	0.000076
	2	4.5			9.60	4.4	2.6	14.7	20		
	3	4.5			0.70	-0.1	0.4	1.6	30		
VII	1	4.5	4.7	42.87	87.80	60.3	13.7	115.2	10	1214.96	0.000086
	2	4.7			12.10	8.6	1.8	15.7	20		
	3	5.0			4.60	3.4	0.6	5.8	30		
VIII	1	4.1	4.0	40.37	103.90	95.5	4.2	112.3	10	1201.23	0.000108
	2	3.9			22.50	17.0	2.8	28.0	20		
	3	4.0			3.60	0.5	1.6	6.8	30		
IX	1	5.2	5.5	39.65	69.00	56.6	6.2	81.5	10	1208.10	0.000059
	2	5.5			1.70	-0.3	1.0	3.7	20		
	3	5.8			0.30	-0.1	0.2	0.8	30		
X	1	5.6	5.7	42.31	53.60	34.3	9.6	72.8	10	1187.51	0.000050
	2	5.7			3.60	2.0	0.8	5.2	20		
	3	5.8			1.70	-3.8	2.7	7.2	30		
		Average	4.6	37.5	99.10					Average	0.000081

Based on the summarized data in the Table 4-1, the tap water average permeability of the pervious concrete mix (ORM) at 20C° is 4.6 cm/s. The average total suspended solids are 99 mg/L. The average amount of total suspended solids per cubic centimeter of the concrete mix is 8.1×10^{-4} gr/cm^3. All the values for permeability, total suspended solids vary according to the porosity of each specimen. Porosity is dominant factor in the analysis of the pervious concrete mix. The average porosity of the above specimens is 37.5%.

4.1.2. Falling head Permeability with Sand (Sand Clogging)

After determining the tap water permeability, total suspended solids and porosity of all 10 specimens, sand was introduced to specimens I,II and III.

Specimen – I sand clogging test

Ten sand clogging tests were performed on specimen – I. Forty grams of sand was introduced in 10 L of tap water in each test. After test # 10 the permeability reduced to 55.4% of its original value. Total amount of sand introduced at the end of the test was 400 g. Total amount of sand recovered in effluent was 277.4 g, 42 g recovered in maintenance (6.2 g in surface brushing, 19.5 g in vacuuming and 16 g in pressure washing) and 123 g of sand remained in the specimen. After the maintenance the permeability of the specimen was tested again, and the specimen showed 58.2% permeability recovery in post maintenance permeability test. The summary of maintenance is in Table 4-2 and Table 4-3.

Table 4-2. Specimen – I Sand Clogging Test Result

ORM - I					
Tests	**$k_{@20°C}$**	**Percent Permeability Reduction**	**TSS Passing**	**TSS Retained**	**Maintenance**
	(cm/s)	**(%)**	**(g)**	**(g)**	**g**
1	4.44	0.00	23.25	16.75	0.00
2	4.02	9.44	30.10	26.65	0.00
3	3.64	17.89	30.90	35.75	0.00
4	3.25	26.88	32.67	43.08	0.00
5	3.09	30.49	28.79	54.28	0.00
6	2.95	33.65	22.21	72.08	0.00
7	2.60	41.53	25.95	86.12	0.00
8	2.40	45.96	30.07	96.05	0.00
9	2.28	48.53	26.58	109.46	0.00
10	1.98	55.43	26.82	122.64	41.67
Total			**277.36**	**123**	**42**

Table 4-3. Specimen – I Maintenance Summary

Maintenance and permeability	
Surface brushing =	6.2 g
Vacuuming =	19.5 g
Pressure washing =	15.97 g
Permeability Recovery =	58.2 %
Initial permeability =	3.978 cm/s
Recovered permeability =	2.3 cm/s
Porosity =	38.46 %

Specimen – II sand clogging test

Fifteen sand clogging tests were performed on specimen – II. The total amount of the sand which was introduced, was 600 g, 40 g in each test. After test #15 the permeability of the specimen decreased by 75.1%. From 600 g of sand which was introduced in 15 tests, 369.3 g was recovered in effluent, 154 g recovered in maintenance (78.3 g in surface brushing, 69.3 g in vacuuming and 6.5 g in pressure washing) and 77 g retained in the specimen. After the maintenance the permeability of the specimen was tested again and the specimen showed 69.7% permeability recovery in post maintenance permeability test. The data are in Tables 4-4 and Table 4-5.

Table 4-4. Specimen – II Sand Clogging Test Result

ORM - II					
Tests	**$k_{@20°C}$**	**Percent Permeability Reduction**	**TSS Passing**	**TSS Retained**	**Maintenance**
	(cm/s)	**(%)**	**(g)**	**(g)**	**g**
1	4.25	0.00	18.90	21.10	0.00
2	3.61	15.04	24.91	36.19	0.00
3	3.32	21.92	28.96	47.23	0.00
4	2.91	31.62	25.55	61.69	0.00
5	2.84	33.22	27.48	74.21	0.00
6	2.31	45.57	19.29	94.92	0.00
7	1.82	57.30	13.95	120.97	0.00
8	1.35	68.33	25.48	135.49	0.00
9	1.26	70.46	26.87	148.62	0.00
10	1.14	73.12	12.94	175.68	0.00
11	1.12	73.68	31.99	183.69	0.00
12	1.10	74.04	37.97	185.71	0.00
13	1.00	76.43	19.01	206.70	0.00
14	1.04	75.64	39.39	207.31	0.00
15	1.06	75.07	16.61	230.70	154.00
Total			**369.30333**	**77**	**154**

Table 4-5. Specimen II Maintenance Summary

Maintenance and permeability	
Surface brushing =	78.3 g
Vacuuming =	69.3 g
Pressure washing =	6.5 g
Permeability recovery =	69.7%
Initial permeability =	4.99 cm/s
Permeability recovery =	3.5 cm/s
Porosity =	42.43 %

The porosity of the specimen has a great affect on the maintenance, sand retainage inside of the specimen and permeability recovery. As shown for specimen – II the sand recovered maintenance, sand retainage inside of the specimen and permeability recovery all are much greater compare to the specimen – I, since specimen – II has greater porosity.

Specimen – III sand clogging test result

Sixteen sand clogging tests were performed on specimen – III. The total amount of the sand which was introduced, was 640 g, 40 g in each test. After test #16 the permeability of the specimen decreased by 92.6%. From 640 g of sand which was introduced in 15 tests, 343.4 g was recovered in effluent, 197.4 g recovered in maintenance (98 g in surface brushing, 81.5 g in vacuuming and 17.9 g in pressure washing) and 99.2 g retained in the specimen. After the maintenance the permeability of the specimen was tested again, and the specimen showed 59.1% permeability recovery in post maintenance permeability test. The porosity of specimen – III is the smallest compared to the first and second specimens. This is one of the reasons that the specimen – III clogged more compared to the first and second specimen. The summary of results is in Tables 4-6 and Table 4-7

Table 4-6. Specimen III Sand Clogging Test

ORM - III					
Tests	**$k_{@20°C}$**	**Percent Permeability Reduction**	**TSS Passing**	**TSS Retained**	**Maintenance**
	(cm/s)	**(%)**	**(g)**	**(g)**	**g**
1	3.34	17.85	20.28	19.72	0.00
2	3.12	23.03	27.62	32.10	0.00
3	2.98	26.55	26.83	45.27	0.00
4	2.70	33.58	28.14	57.13	0.00
5	2.39	41.06	23.60	73.53	0.00
6	2.16	46.74	29.26	84.28	0.00
7	2.10	48.34	22.78	101.50	0.00
8	2.04	49.88	29.47	112.03	0.00
9	1.83	54.95	25.83	126.20	0.00
10	1.62	60.07	23.89	142.31	0.00
11	1.11	72.65	21.13	161.18	0.00
12	1.07	73.53	28.99	172.19	0.00
13	0.81	80.04	22.16	190.03	0.00
14	0.49	87.96	7.87	222.16	0.00
15	0.34	91.57	3.43	258.73	0.00
16	0.30	92.55	2.15	296.58	197.40
Total			**343.42**	**99.2**	**197.40**

Table 4-7. Specimen III Maintenance Summary

Maintenance and permeability	
Surface brushing =	98 g
Vacuuming =	81.5 g
Pressure washing =	17.9 g
Permeability Recovery =	59.14 %
Initial permeability =	4.06 cm/s
Permeability recovery =	2.4 cm/s
Porosity =	34.7 %

The overall reduction in permeability for all three specimens is summarized in Figure 4-1.

Overall results

The average removal of suspended solids of three specimens were 153.8 g which was 38.5% of the introduced mass. The average suspended solids recovered in maintenance of the three specimens were 89.3 g which was 22.3% of the introduced mass. The overall peremeability recovery after the maintenance was 62.3%.

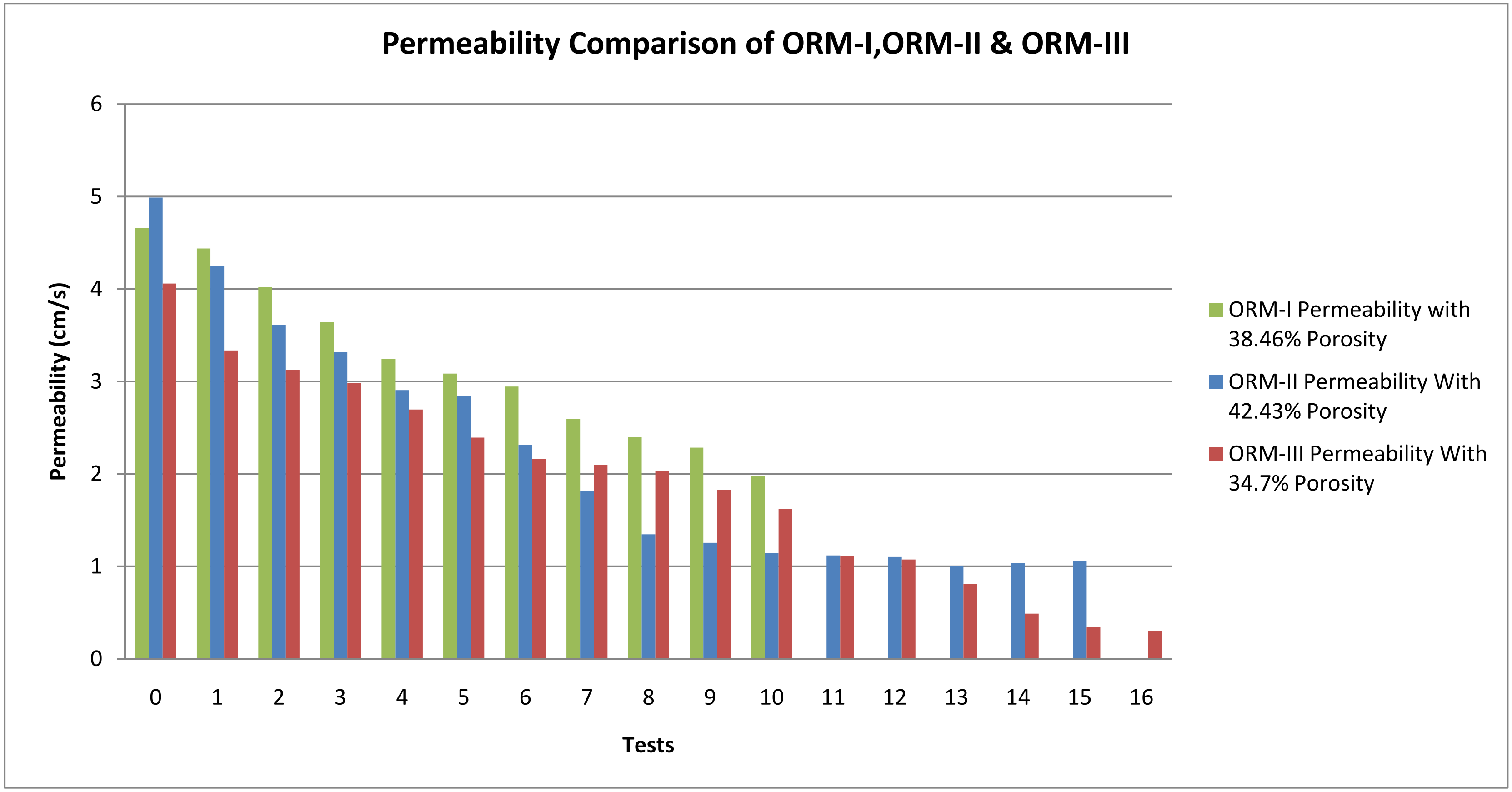

Figure 4-1. Clogged permeability of specimen I, II and III

4.1.3. Falling Head Permeability with A6 Soil

Specimens IV, V and VI were tested with A6 soil. A6 soil procedure is discussed in detail the Methodology chapter 3.

Specimen –IV A6 soil test result

Fifteen tests were performed on specimen – IV. In the first six tests 40 g of A6 soil were introduced in each test. Since there was not significant decrease in permeability of the specimen, from test #7 to test #15the amount of A6 soil was increased to 80 g per test. After 15 tests the permeability of the specimen did not have significant reduction. The second indicator that confirmed that the permeability of the specimen did not reduce is the total suspended solids. From 960 g of A6 soil which was introduced 907.1 g were recovered in the effluent. Sixteen grams were recovered in maintenance. It shows that very small amount of A6 soil was retained inside of the specimen. The summary of the data are shown in Table 4-8 and Figure 4-2.

In the post maintenance permeability test the permeability of the specimen recovered to 94% or 4.1 cm/s the maintenance data is shown in Table 4-9.

Table 4-8. Specimen IV A6 Soil Test Result

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	A6 soil Added	Accumulated Amount of A6 added	Amount of A6 Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.3	1.3428	35.7159	4.28	4	0	4	40.0	40.0	0.0035
2	4.1	4.5107	38.91	1.09	5	0	4	40.0	80.0	0.0009
3	4.3	0.6072	36.03	3.97	9	0	4	40.0	120.0	0.0032
4	4.3	0	37.88	2.12	11	0	4	40.0	160.0	0.0017
5	4.3	0	37.69	2.31	14	0	4	40.0	200.0	0.0019
6	4.3	0	38.13	1.87	16	0	4	40.0	240.0	0.0015
7	3.7	13.6238	84.30	0	11	0	8	80.0	320.0	0
8	3.5	19.4192	77.01	2.99	14	0	8	80.0	400.0	0.0024
9	2.9	33.7356	75.31	4.69	19	0	8	80.0	480.0	0.0038
10	3.4	20.5493	77.82	2.18	21	0	8	80.0	560.0	0.0018
11	3.91	12.4579	73.35	6.65	28	0	8	80.0	640.0	0.0054
12	3.9	10.4761	74.76	5.24	33	0	8	80.0	720.0	0.0043
13	3.7	15.2720	75.80	4.20	37	0	8	80.0	800.0	0.0034
14	4.0	7.1308	70.69	9.31	47	0	8	80.0	880.0	0.0076
15	4 .0	6.9249	73.74	6.26	53	16	8	80.0	960.0	0.0051
Total			**907.14**		**36.8**	**16**		**960**		**0.0431**

Table 4-9. Specimen IV Maintenance Result

Initial permeability =	**4.33 cm/s**
Porosity =	**31.14 %**
Amount of A6 soil recovered in maintenance	
Surface brushing =	**1 g**
Vacuuming =	**6.7 g**
Pressure washing =	**8.35 g**
Permeability recovery =	**94.0 %**
Permeability recovery =	**4.1 cm/s**

Note: The maintenance has been done after test# 15

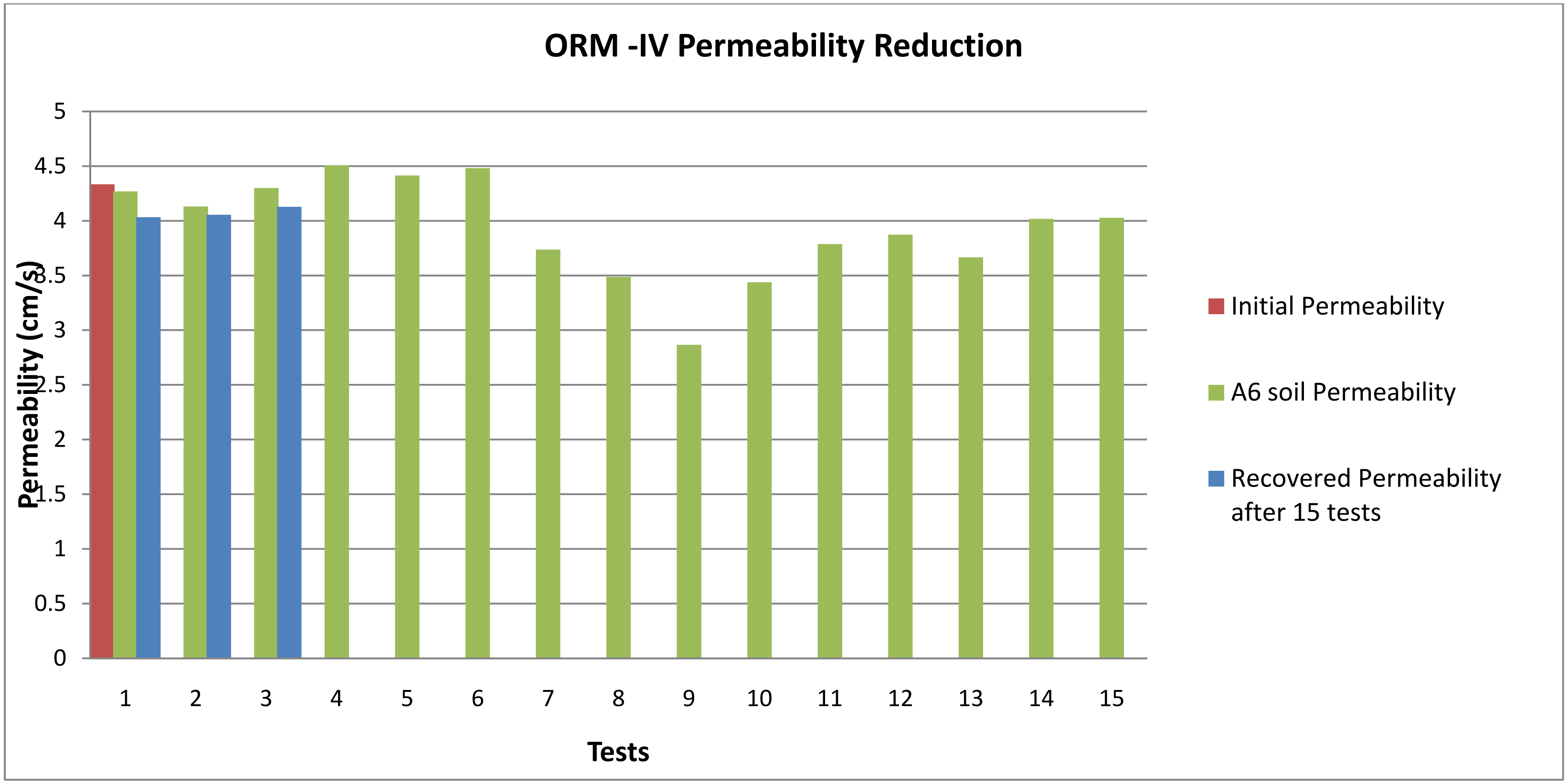

Figure 4-2. Specimen IV A6 soil test results

Specimen –V A6 soil test result

After the observation of the specimen – IV results, six A6 tests were performed on the specimen – V. The permeability of the specimen did not decrease significantly. From 480g of A6 soil introduced 417 g were recovered in the effluent. Nineteen grams of A6 soil were recovered in maintenance and 44 g of A6 soil remained in the specimen. The summary of the tests are in the Table 4-10 and shown in Figure 4-3. The permeability recovery after the maintenance was 98.1% or 3.84 cm/s since there was not significant reduction in the permeability of the specimen from the initial value. The result is summarized in the Table 4-11.

Table 4-10. Specimen V A6 Soil Test Result

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	A6 Soil Added	Accumulated Amount of added (A6)	Amount of A6 Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	3.6	8.3544	67.14003	12.86	13	0	8	80.0	80.0	0.0102
2	3.42	12.5359	71.94041	8.06	21	0	8	80.0	160.0	0.0064
3	3.3	15.0881	74.84852	5.15	26	0	8	80.0	240.0	0.0041
4	3.3	15.2396	68.89791	11.10	37	0	8	80.0	320.0	0.0088
5	3.4	13.2706	56.62696	23.37	61	0	8	80.0	400.0	0.0185
6	3.3	15.5086	77.54363	2.46	63	19	8	80.0	480.0	0.0019
Total			**417.00**		**44**	**19**		**480**	**Total**	**0.0498**

Table 4-11. Specimen V Maintenance Result

Initial permeability =	**3.9 cm/s**
Porosity =	**31.22%**
Amount of A6 recovered in maintenance	
Surface brushing =	**2.5 g**
Vacuuming =	**6.4 g**
Pressure washing =	**10.2 g**
Permeability recovery =	**98.10%**
Permeability recovery =	**3.84**

Note: The maintenance has been don after test# 6

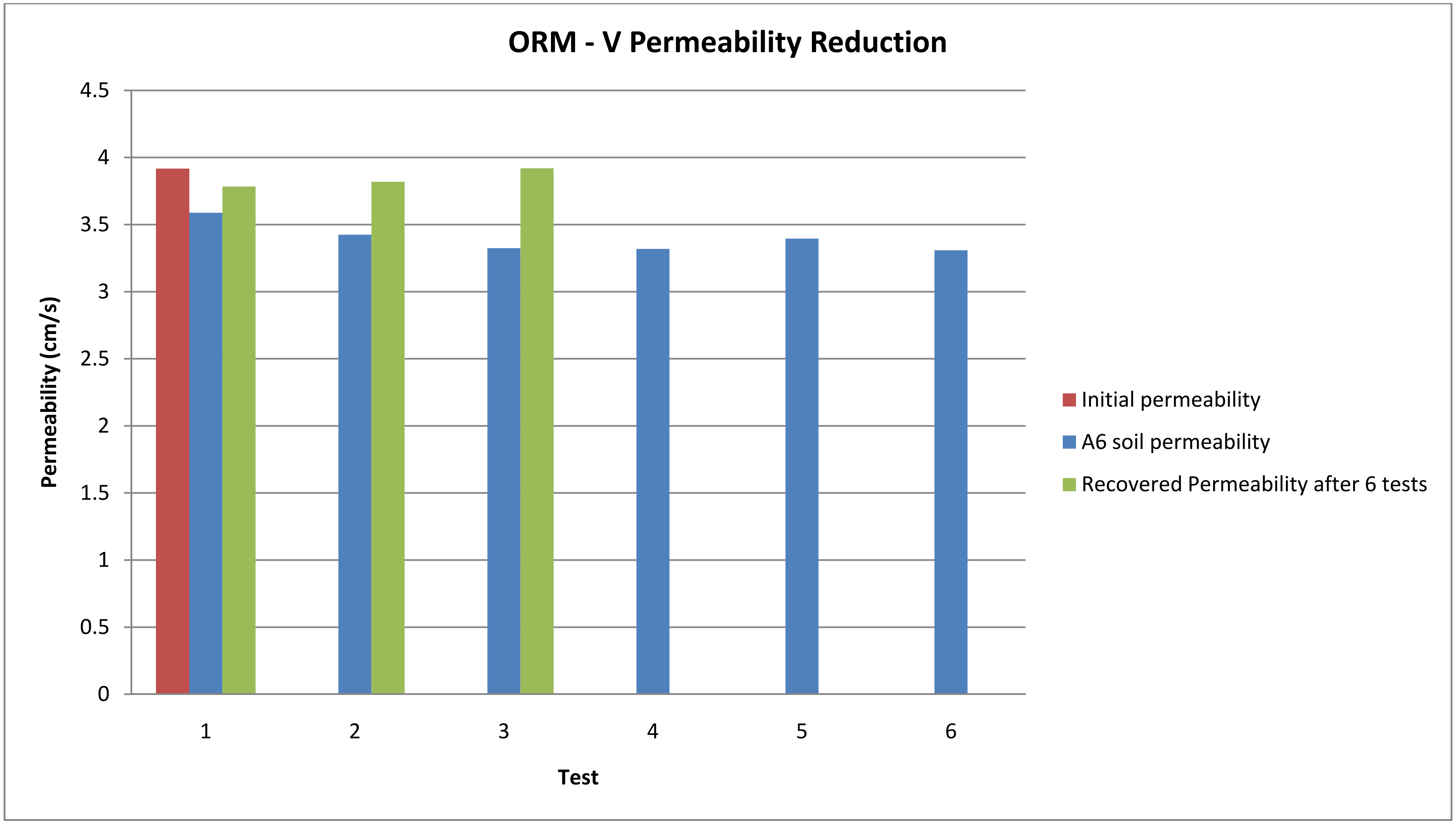

Figure 4-3. Specimen V A6 soil test result

Specimen –VI A6 soil test result

Six A6 soil clogging tests were performed on specimen – VI. Similar to specimen – IV and V the permeability of this specimen did not reduce. From 480 g of A6 that was introduced, 450.6 g were recovered in the effluent, 5 g were recovered in maintenance (1 g in surface brushing, 1.2 g in vacuuming and 2.9 g in pressure washing) and 24.4 g were retained inside of the specimen – VI. Since there was not significant reduction in the permeability the post maintenance permeability recovery was 94.5% (the average of the post maintenance permeability compared to the initial permeability) or 4.3cm/s. The summary of the result is shown is Table 4-12 and Figure 4-4.

Overall results

The overall results of the three specimens that were tested for A6 soil showed that the specimens did not clog at all and there were not significant reduction in the permeability of all three specimens. The second indicator was more than 90% of the introduced A6 soil was recovered in the effluent; it showed only very small percentage of the A6 soil remained inside the specimens. Maintenance of the specimens was not effective since only one to two percent of the A6 soil recovered since little A6 soil was retained.

The average removal of suspended solids of three specimens was 37.7 g which was 8% of the introduced mass. The average suspended solids recovered in maintenance of the three specimens were 13.4 g which was 3% of the introduced mass. The overall permeability recovery after the maintenance was 95.8%.

. The summary of maintenance is shown in Table 4-13.

Table 4-12. Specimen VI A6 Soil Test Result

Tests	$k_{@20^\circ C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	A6 Soil Added	Accumulated Amount A6 added	Amount of A6 Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.3	4.4055	73.51068	6.49	6	0	8	80.0	80.0	0.0055
2	4.2	7.4750	73.50502	6.49	13	0	8	80.0	160.0	0.0055
3	3.99	10.8405	77.24939	2.75	16	0	8	80.0	240.0	0.0023
4	4.1	10.0022	76.01497	3.99	20	0	8	80.0	320.0	0.0034
5	4.1	8.7172	76.53009	3.47	23	0	8	80.0	400.0	0.0029
6	3.98	11.3534	73.80888	6.19	29	5	8	80.0	480.0	0.0052
Total			**450.62**		**24**	**5**			**Total**	**0.0247**

Table 4-13. Specimen VI A6 Soil Maintenance Result

Initial permeability =	**4.49 cm/s**
Porosity =	**34.39 %**
Amount of A6 recovered in maintenance	
Surface brushing =	**1 g**
Vacuuming =	**1.2 g**
Pressure washing =	**2.9 g**
Permeability recovery =	**95.4 %**
Permeability recovery =	**4.3 cm/s**

Note: The maintenance was performed after test# 15.

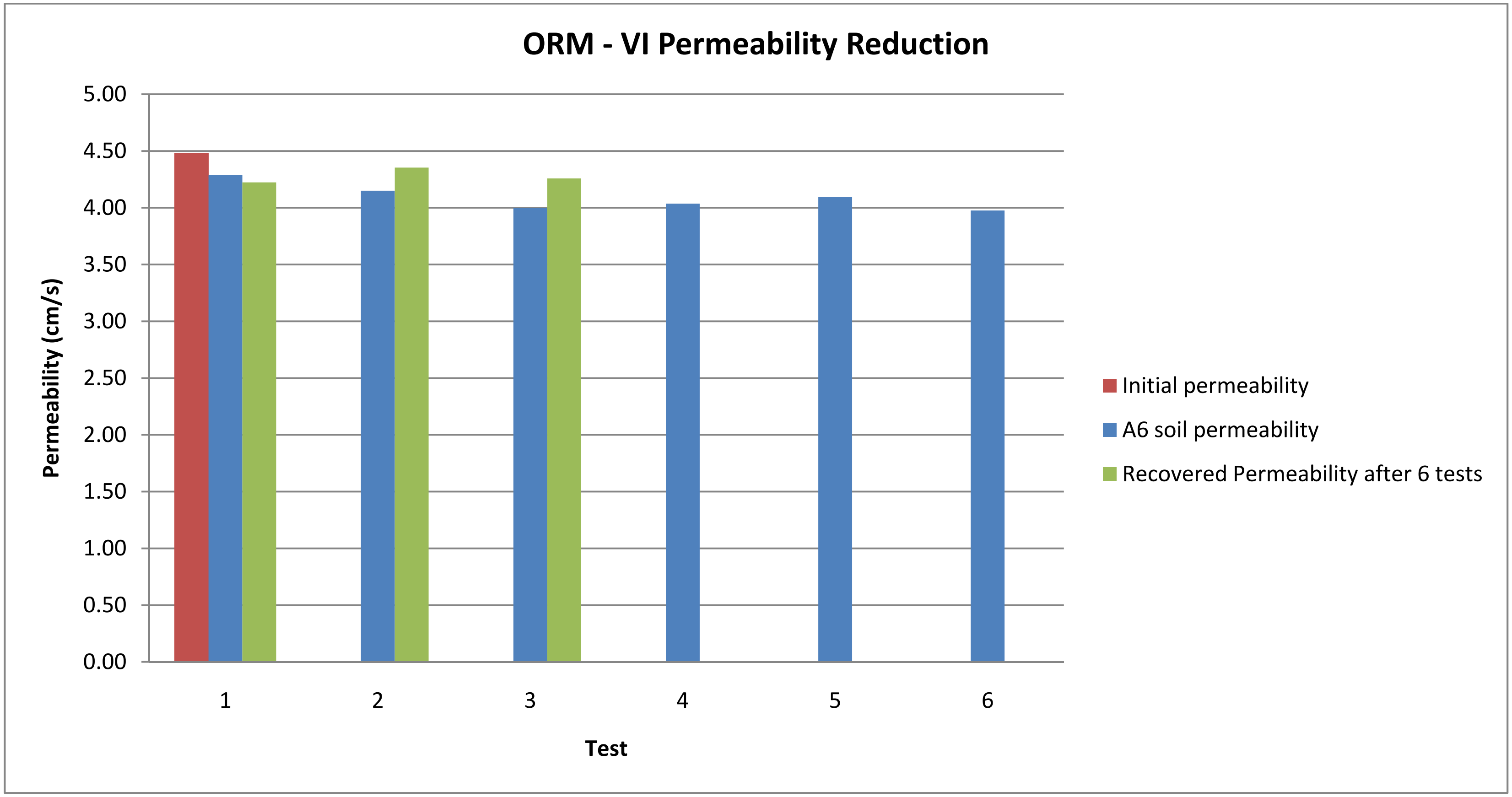

Figure 4-4. Specimen VI A6 soil test result

4.1.4. Artificial Runoff

As discussed in the methodology the artificial runoff was prepared to simulate storm runoff and then introduced to the laboratory specimens at different concentrations of runoff constituents.

4.1.4.1. Artificial Runoff High Concentration Test Results

A. Falling head permeability

Nine falling head permeability tests were performed on specimen – VII using the artificial runoff high concentration solution. The permeability of the specimen was only reduced by 18%. Refer to the Table 4-14 and Figure 4-5. The suspended solids recovered from the influent of falling head permeameter were 1021.2 mg/L which was 7658.2 mg in 7.5 liter of cumulative influent. The suspended solids recovered from the effluent of the falling head permeability were 815.4 mg/L which was 6115.4 mg in 7.5 liter of cumulative effluent. The difference between influent and effluent showed that 20.2% of the suspended solids were caught inside the specimen. Refer to the Table 4-15. The maintenance of the specimen was not so effective by all three methods (surface brushing, vacuuming and pressure washing) discussed in maintenance; only 1.8 mg of the particles were recovered. Post maintenance permeability did not show any change in the permeability. After obtaining the maintenance result for the high concentration artificial runoff, maintenance of specimens – VIII and IX were not performed since they were exposed to lesser concentrations of constituents in artificial runoff. The Table 4-16 and Figure 4-6 shows the relationship between influent and effluent falling head TSS.

Table 4-14. Falling Head Permeability Artificial Runoff, High Concentration

Test No.	Manometer H_1	Manometer H_2	Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	2.11	14.99	1.94	22.02	4.5	4.7	10000	9927.7
2	94.6	48.9	45.7	2.13	14.99	1.94	22.64	4.4	4.6	10000	9964.5
3	94.6	48.9	45.7	2.13	14.99	1.94	23.92	4.2	4.6	10000	9947.2
4	94.6	48.9	45.7	2.19	14.99	1.94	23.61	4.1	4.5	10000	9877.5
5	94.6	48.9	45.7	2.15	14.99	1.94	23.37	4.2	4.6	10000	9857.9
6	94.6	48.9	45.7	2.28	14.99	1.94	23.75	4.0	4.3	10000	9935.8
7	94.6	48.9	45.7	2.24	14.99	1.94	23.36	4.1	4.4	10000	9853.8
8	94.6	48.9	45.7	2.32	14.99	1.94	23.42	3.9	4.3	10000	9939.9
9	94.6	48.9	45.7	2.46	14.99	1.94	23.61	3.7	4.0	10000	9467.4

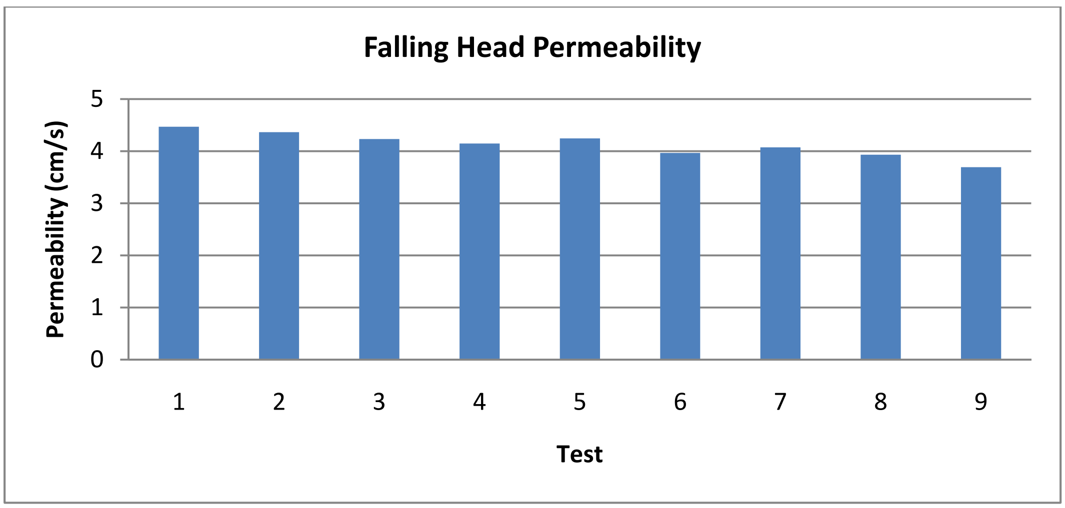

Figure 4-5. Falling head permeability artificial runoff high concentration

Table 4-15. TSS Difference between Influent and Effluent

ORM TSS Influent Falling Head High Concentration	
Average TSS collected per Vol:	**1021.149 mg/L**
Total TSS collected:	**7658.62 mg**
Cumulative Vwater =	**7.5 L**
ORM TSS effluent Falling Head High Concentration	
Average TSS collected per Vol:	**815.4 mg/L**
Total TSS collected:	**6115.4 mg**
Cumulative Vwater =	**7.5 L**

Table 4-16. Influent versus Effluent Suspended Solids in High Concentration

Tests	Influent TSS	Cumulative Influent TSS	Effluent TSS	Cumulative influent TSS	Effluent TSS	Cumulative TSS
	Falling head	Falling head	Falling head	Falling head	Constant head	Constant head
0	0	0	0	0	0	0
1	1058.2	1058.2	1401.3	1401.3	68.4	68.4
2	1390.1	2448.3	826.4	2227.7	33.24	101.64
3	1085.9	3534.2	798.5	3026.2	10.4	112.04
4	975	4509.2	764.7	3790.9	-	-
5	1039.6	5548.8	793.8	4584.7	-	-
6	1083.5	6632.3	640.4	5225.1	-	-
7	1049.4	7681.7	674.6	5899.7	-	-
8	878.6	8560.3	443.4	6343.1	-	-
9	537.1	9097.4	905.4	7248.5	-	-
10	1114.1	10211.5	905.3	8153.8	-	-

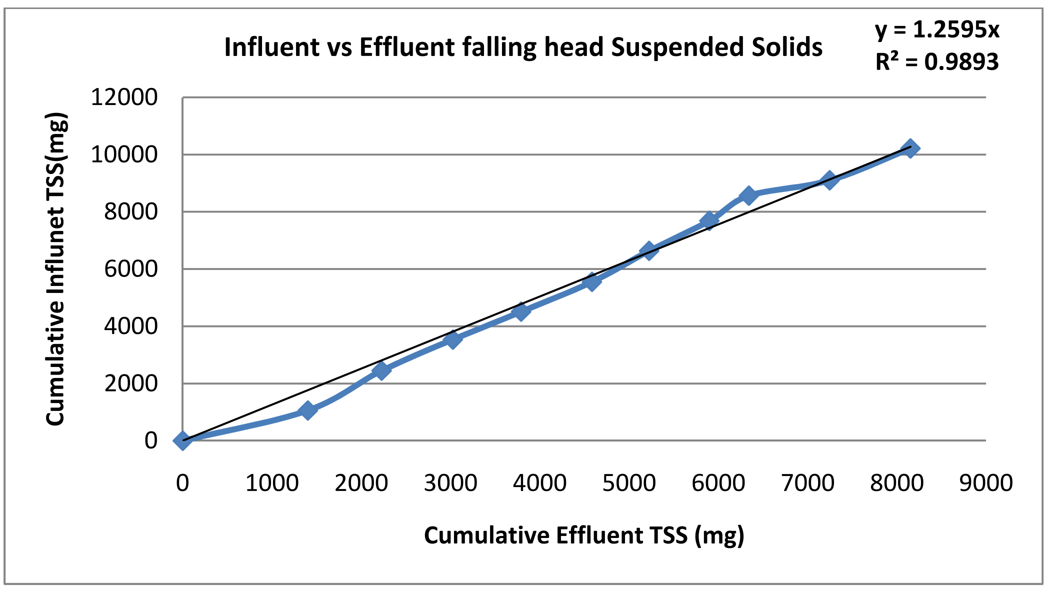

Figure 4-6. Influent and effluent falling head suspended solids comparison

B. Constant head permeability

Two constant head permeability tests were performed on greensand; the greensand specimen clogged completely after the second test. The permeability reduction between first test and second was 74.1%. Refer to the Table 4-17 and Table 4-18. The average suspended solids recovered from the effluent of the constant head permeability were 37.4 mg/L which was 84.03mg in 2.25 liter of cumulative effluent. The summary is show in Table 4-19. Since the greensand layer functions as a filter media the difference between concentration of suspended solids in effluent of falling head and effluent of constant head is [1 -(37.4/815.4)] *100 = 95.4%. The greensand layer caught 95.4 % of the suspended solids or in other words the greensand layer cleaned the high suspended solids by 95.4% of high concentration of artificial runoff (this percentage may differ for the ordinary sand, since greensand has uniform particle size).

C. Results for the composite pervious concrete and greensand

The average removal of suspended solids as a composite system (pervious concrete and greensand) was [1-(37.4/1021.1)]*100 = 96.3%. As a result the permeability of pervious concrete dropped by 18% after the introduction of 92 g of suspended solids and the permeability of the greensand dropped by 74.1% after the introduction of 12.2 g of suspended solids.

Table 4-17. 1st Constant Head Permeability Results with Artificial Runoff, High Concentration

Run No.	Manometer		ΔH	Q	Time	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	64	49.5	14.5	830	60	0.170628	0.7	23.8	0.109275
2	36	23	13	550	60	0.113067	0.78	23.8	0.080766
3	26	12	14	460	60	0.094565	0.73	23.8	0.062725
								Average =	0.084256

Table 4-18. 2nd Constant Head Permeability Results with Artificial Runoff, High Concentration

Run No.	Manometer		ΔH	Q	Time	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	11.5	6.5	5	75	60	0.015418	2.0	23.5	0.028836
2	17	9	8	65	60	0.013362	1.3	23.5	0.015619
3	12	5.5	6.5	71	60	0.014596	1.6	23.5	0.020998
								Average =	0.021818

Permeability Reduction 74.11% from test # 1 to test # 2

Table 4-19 TSS Recovered from the Effluent of Constant Head Permeability

ORM TSS Effluent Constant Head High Concentration	
Average TSS collected per Vol:	**37.4mg/L**
Total TSS collected:	**84.03mg**
Cumulative Vwater =	**2.25L**

D. Particle size

The particle size was performed only on the influent and effluent of the falling head permeameter. The average size of 90% of the particles in the influent of falling head permeability test was 8.3 μm and 10% of the particles in the influent of falling head permeability test were 0.75 μm. Refer to the Figure 4-7 and Table 4-20. The concentration of the effluent of the constant head permeability was below the certain detectable range of the Coulter Backman machine and data which was obtained in this range was not accurate.

The average size of the 90% of the particles in the effluent of falling head permeability test was 8.0 μm and 10% of the particles in the influent of falling head permeability test were 0.8 μm. Refer to the Figure 4-8 and Table 4-21. No significant difference between particle size of influent of falling head permeability and effluent falling head permeability were observed. They were almost in the same range.

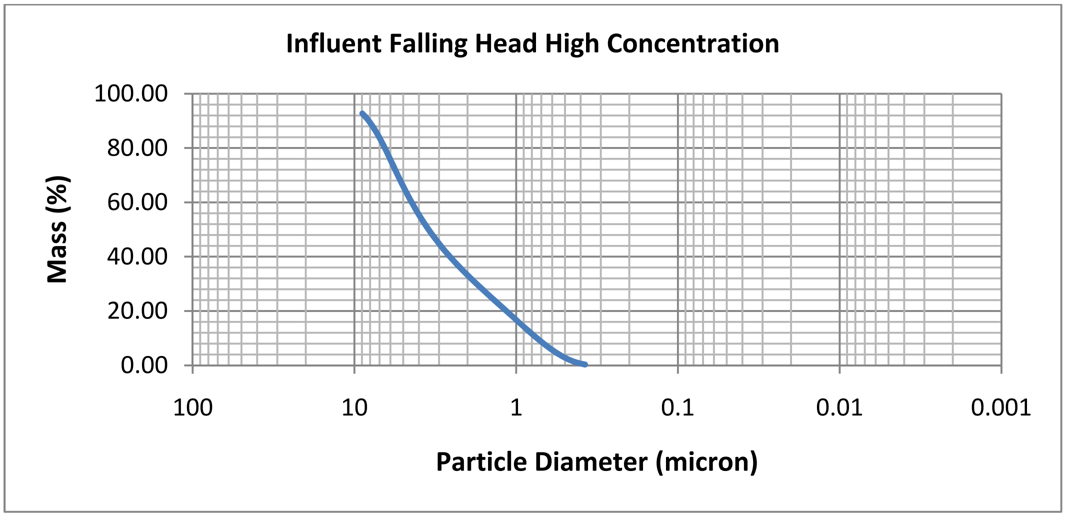

Figure 4-7. Particle size distribution in influent of falling head permeability

Table 4-20. Summary of Figure 4-7

D_{90}	**8.3**	**µm**
D_{60}	**4.5**	**µm**
D_{50}	**3.5**	**µm**
D_{10}	**0.75**	**µm**

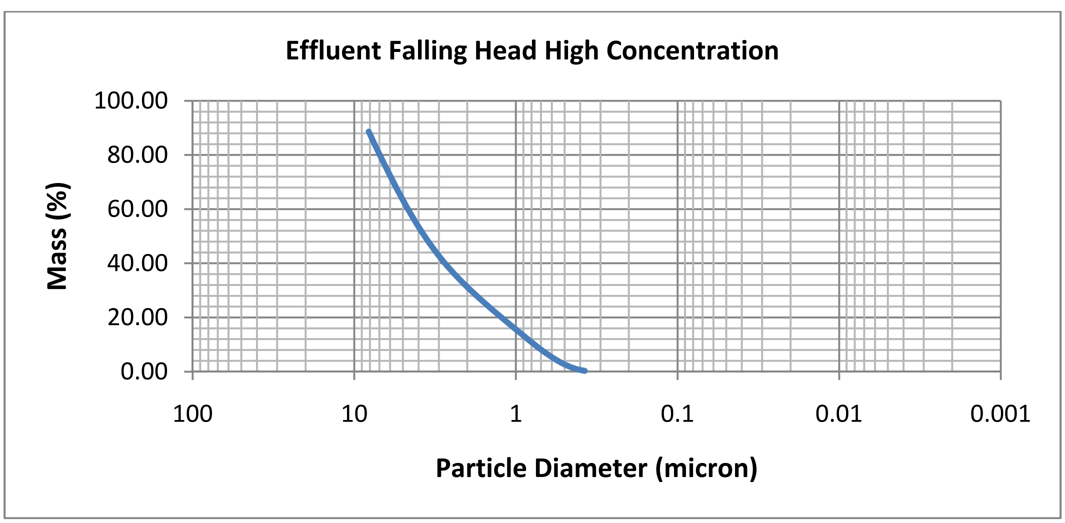

Figure 4-8. Particle size distribution in effluent of falling head permeability

Table 4-21. Summary of Figure 4-8

D_{90}	8	µm
D_{60}	4.6	µm
D_{50}	3.6	µm
D_{10}	0.8	µm

E. Metals

The total metals and dissolved metals samples were sent to chemistry department for analysis. Statistical analysis was conducted on the metals data. T-test was performed to show the difference between average mean of total and dissolved metals of influent and effluent falling head permeability. The t-test summary for high concentration artificial runoff is in Table 4-22. Total metals reduction by pervious concrete was generally low for all total metals. Pervious concrete only reduced the total cadmium by 8%, total copper by 8%, total chromium by 12%, total nickel by 3% and total lead by 2.75%. Nickel and iron were somewhat more predominant in dissolved form than the other metals. Pervious concrete reduced the dissolved iron by 12% and Nickel by 25%. Total metals were reduced to a great percentage by filter media. The reduction range was 85 – 97%. Dissolved iron was not reduced by the filter media and dissolved nickel was reduced by 86% by filter media. Some of dissolved metals did not reduce and even there were some increase in dissolved iron and dissolved zinc. It is concluded that filter media (greensand) is a good agent in filtering the total metal or suspended form of total metals. The summary of analysis of total metal and dissolved metal is in Table 4-23.

Table 4-22. T-Test Result for Influent and Effluent Falling Head Permeability

Metals	Sample	High Concentration Artificial Runoff		T-test Confidence Interval (%)
		Introduced (µg/L)	Average (µg/L)	
Total Cadmium	Influent Pervious Concrete	500	324.3	
	Effluent Pervious Concrete		295.9	97.3
	Effluent Filter Media		16.8	
Dissolved Cadmium	Influent Pervious Concrete		78	
	Effluent Pervious Concrete		62	99.99
	Effluent Filter Media		12	
Total Copper	Influent Pervious Concrete	875	775.4	
	Effluent Pervious Concrete		711.7	99.3
	Effluent Filter Media		17.3	
Dissolved Copper	Influent Pervious Concrete		0	
	Effluent Pervious Concrete		0	99.99
	Effluent Filter Media		0	
Total Chromium	Influent Pervious Concrete	625	629.6	
	Effluent Pervious Concrete		548.3	99.99
	Effluent Filter Media		20.7	
Dissolved Chromium	Influent Pervious Concrete		7	
	Effluent Pervious Concrete		7	74.9
	Effluent Filter Media		6	
Total Iron	Influent Pervious Concrete	16500	48280.6	
	Effluent Pervious Concrete		49249.0	27.9
	Effluent Filter Media		7276.5	
Dissolved Iron	Influent Pervious Concrete		391	
	Effluent Pervious Concrete		342	99.99
	Effluent Filter Media		4134	
Total Nickel	Influent Pervious Concrete	2375	2748.4	
	Effluent Pervious Concrete		2665.0	71.8
	Effluent Filter Media		84.3	
Dissolved Nickel	Influent Pervious Concrete		659	
	Effluent Pervious Concrete		493	99.99
	Effluent Filter Media		69	
Total Lead	Influent Pervious Concrete	5375	5535.6	
	Effluent Pervious Concrete		5383.3	63.7
	Effluent Filter Media		177.6	
Dissolved Lead	Influent Pervious Concrete		0	
	Effluent Pervious Concrete		0	92.8
	Effluent Filter Media		0	
Total Zinc	Influent Pervious Concrete	2300	2760.4	
	Effluent Pervious Concrete		3028.1	60.6
	Effluent Filter Media		151.3	
Dissolved Zinc	Influent Pervious Concrete		29	
	Effluent Pervious Concrete		8	99.8
	Effluent Filter Media		74	

Table 4-23. Total and Dissolved Metal Analysis

Metals	Sample	High Concentration Artificial Runoff				
		Introduced (µg/L)	Maximum (µg/L)	Minimum (µg/L)	Average (µg/L)	Reduction (%)
Total Cadmium	Influent Pervious Concrete	**500**	348.7	275.8	324.3	0.00
	Effluent Pervious Concrete		327.2	272.6	295.9	8.76
	Effluent Filter Media		29.2	9.3	16.8	94.32
Dissolved Cadmium	Influent Pervious Concrete		103.7	63.8	78	0.00
	Effluent Pervious Concrete		87.5	52.6	62	20.51
	Effluent Filter Media		21.4	6.5	12	80.65
Total Copper	Influent Pervious Concrete	**875**	828.7	666.6	775.4	0.00
	Effluent Pervious Concrete		801.1	635.8	711.7	8.22
	Effluent Filter Media		36.9	0.4	17.3	97.57
Dissolved Copper	Influent Pervious Concrete		0.174	0.174	0	0.00
	Effluent Pervious Concrete		0.174	0.174	0	0.00
	Effluent Filter Media		0.174	0.174	0	0.00
Total Chromium	Influent Pervious Concrete	**625**	678.9	541.0	629.6	0.00
	Effluent Pervious Concrete		611.9	479.6	548.3	12.91
	Effluent Filter Media		37.3	5.5	20.7	96.22
Dissolved Chromium	Influent Pervious Concrete		7.9	6.7	7	0.00
	Effluent Pervious Concrete		7.8	5.9	7	0.00
	Effluent Filter Media		6.1	5.3	6	14.29
Total Iron	Influent Pervious Concrete	**16500**	59874.2	35632.2	48280.6	0.00
	Effluent Pervious Concrete		62088.0	33617.4	49249.0	-2.01
	Effluent Filter Media		19187.5	566.2	7276.5	85.23
Dissolved Iron	Influent Pervious Concrete		401.2	381.4	391	0.00
	Effluent Pervious Concrete		352.7	324.5	342	12.53
	Effluent Filter Media		11114.2	540.0	4134	-1108.77
Total Nickel	Influent Pervious Concrete	**2375**	3234.8	2177.1	2748.4	0.00
	Effluent Pervious Concrete		3294.3	2116.3	2665.0	3.03
	Effluent Filter Media		180.1	22.6	84.3	96.84
Dissolved Nickel	Influent Pervious Concrete		885.4	514.1	659	0.00
	Effluent Pervious Concrete		683.3	389.3	493	25.19
	Effluent Filter Media		152.1	20.1	69	86.00
Total Lead	Influent Pervious Concrete	**5375**	6035.0	4618.1	5535.6	0.00
	Effluent Pervious Concrete		6209.4	4560.0	5383.3	2.75
	Effluent Filter Media		385.2	6.2	177.6	96.70
Dissolved Lead	Influent Pervious Concrete		0.4	0.1	0	0.00
	Effluent Pervious Concrete		0.3	0.1	0	0.00
	Effluent Filter Media		3	0.1	0	0.00
Total Zinc	Influent Pervious Concrete	**2300**	5122.5	1660.8	2760.4	0.00
	Effluent Pervious Concrete		7665.5	1692.6	3028.1	-9.70
	Effluent Filter Media		349.4	18.1	151.3	95.00
Dissolved Zinc	Influent Pervious Concrete		89.4	3.7	29	0.00
	Effluent Pervious Concrete		40.3	0.2	8	72.41
	Effluent Filter Media		221.0	0.3	74	-825.00

4.1.4.2. Artificial Runoff Medium Concentration Test Results

A. Falling head permeability

Ten falling head permeability tests were performed on specimen – VIII. The permeability of the specimen did not decrease at all. The procedure of the medium concentration artificial runoff tests is discussed in the methodology chapter in detail. Refer to Table 4-24 and Figure 4-9. The amount of the suspended solids recovered from the influent of the falling head permeability was 265.3 mg/L which was 1990.1 mg in 7.5 L of cumulative influent. The amount of suspended solids recovered from the effluent of the falling head permeability was 238.2 mg/L which was 1786.5 mg in 7.5 L of cumulative effluent. The difference between influent falling head suspended solids and effluent falling head suspended solids was 10.2%. Refer to the Table 4-25. This difference in the mass showed that 10.2% of the suspended solids were caught inside the concrete specimen. The Table 4-26 and Figure 4-10 shows the relationship between influent and effluent falling head TSS.

Table 4-24. Falling Head Permeability Artificial Runoff, Medium Concentration

Test No.	Manometer H_1	Manometer H_2	Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	2.2	14.8	1.94	21.4	4.2	4.4	10000	9931.3
2	94.6	48.9	45.7	2.3	14.8	1.94	20.43	4.3	4.3	10000	9967.2
3	94.6	48.9	45.7	2.3	14.8	1.94	20.13	4.3	4.3	10000	9958.7
4	94.6	48.9	45.7	2.2	14.8	1.94	21.02	4.3	4.4	10000	9967.6
5	94.6	48.9	45.7	2.3	14.8	1.94	20.62	4.3	4.3	10000	9934.4
6	94.6	48.9	45.7	2.3	14.8	1.94	21.19	4.2	4.3	10000	9996.6
7	94.6	48.9	45.7	2.2	14.8	1.94	21.07	4.3	4.4	10000	9975.7
8	94.6	48.9	45.7	2.3	14.8	1.94	21.31	4.2	4.3	10000	9970.3
9	94.6	48.9	45.7	2.2	14.8	1.94	22.26	4.1	4.4	10000	9968.4
10	94.6	48.9	45.7	2.3	14.8	1.94	22.14	4.1	4.3	10000	9971.2

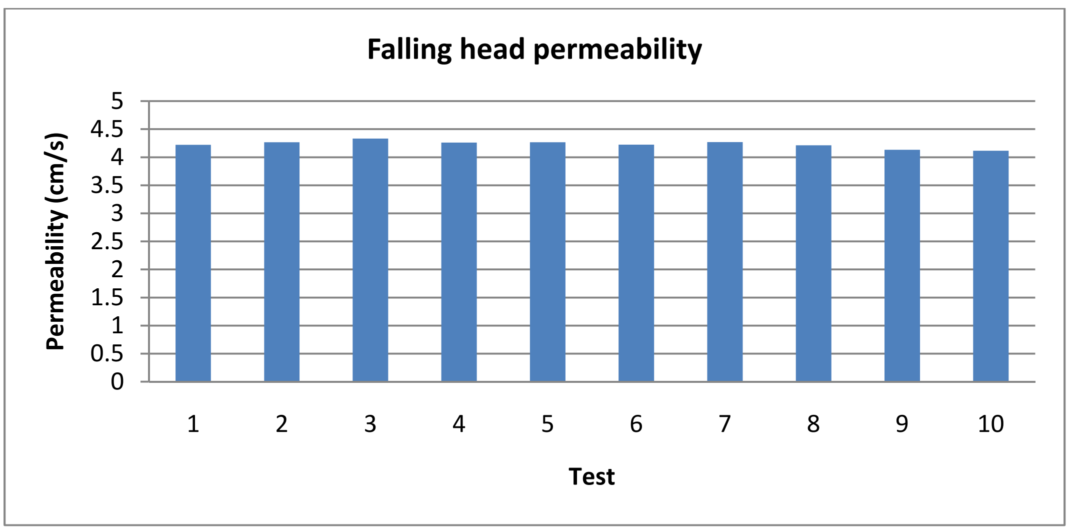

Figure 4-9. Falling head permeability

B. Constant head permeability

Nine tests were performed on the greensand, using the medium concentration artificial runoff. Figure 4-11 shows relationship between influent and effluent TSS from constant head test. The average suspended solids recovered in the effluent of constant head permeability were 26.9 mg/L which was 202 mg in 7.5 L of cumulative effluent. Refer to Table 4-25. After test #9 the permeability of the greensand was reduced by 79.4%. Refer to Table 4-27 and Figure 4-12. The difference between the effluent of the falling head permeability and constant head permeability gave the amount of suspended solids filtered by the greensand, which was [1 – (26.9/238.2)]*100 = 88.7%.

Table 4-25. TSS Difference Influent and Effluent

ORM TSS Influent Falling Head Medium Concentration	
Average TSS collected per Vol:	**265.3mg/L**
Total TSS collected:	**1990.1mg**
Cumulative Vwater =	**7.5L**
ORM TSS Effluent Falling Head Medium Concentration	
Average TSS collected per Vol:	**238.2mg/L**
Total TSS collected:	**1786.5mg**
Cumulative Vwater =	**7.5L**
ORM TSS Effluent Constant Head Medium Concentration	
Average TSS collected per Vol:	**26.9mg/L**
Total TSS collected:	**202mg**
Cumulative Vwater =	**7.5L**

Table 4-26. Influent and Effluent Falling Head TSS and Effluent Constant Head

Tests	Influent TSS (mg)	Cumulative TSS (mg)	Effluent TSS (mg)	Cumulative TSS (mg)	Effluent TSS (mg)	Cumulative TSS (mg)
	Falling head	Falling head	Falling head	Falling head	Constant head	Constant head
0	0	0	0	0	0	0
1	236.5	236.5	207.2	207.2	21.4	21.4
2	239.4	475.9	236.4	443.6	20.3	41.7
3	266.4	742.3	222	665.6	27.2	68.9
4	203.3	945.6	235.9	901.5	22	90.9
5	295.1	1240.7	242.1	1143.6	23.9	114.8
6	312.6	1553.3	257.8	1401.4	23.3	138.1
7	316.1	1869.4	253.3	1654.7	19	157.1
8	339.6	2209	216.5	1871.2	19	176.1
9	290.2	2499.2	229.3	2100.5	17.8	193.9
10	154.1	2653.3	281.3	2381.8	74.4	268.3

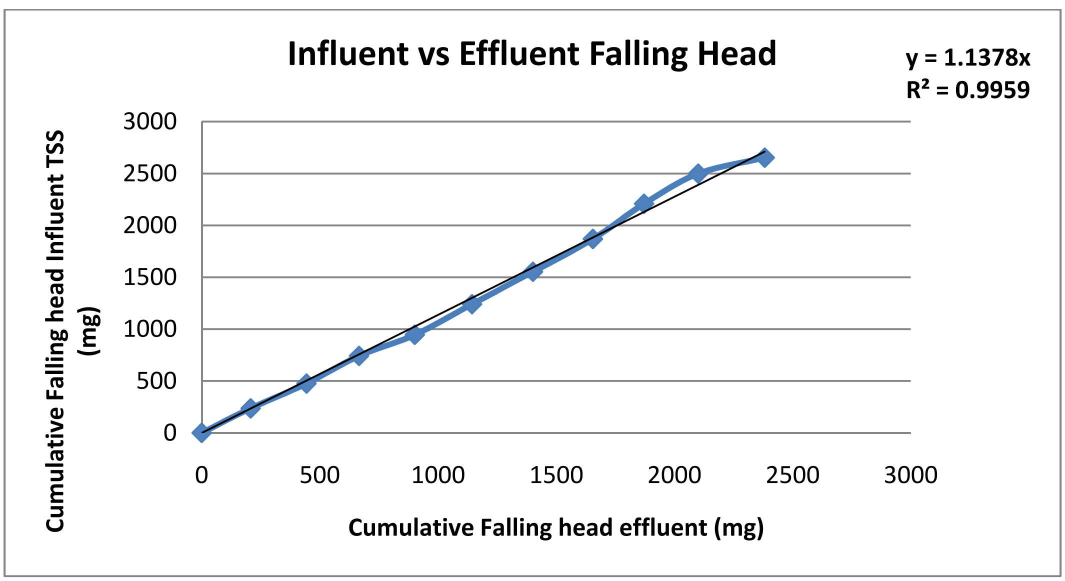

Figure 4-10. Influent and effluent falling head

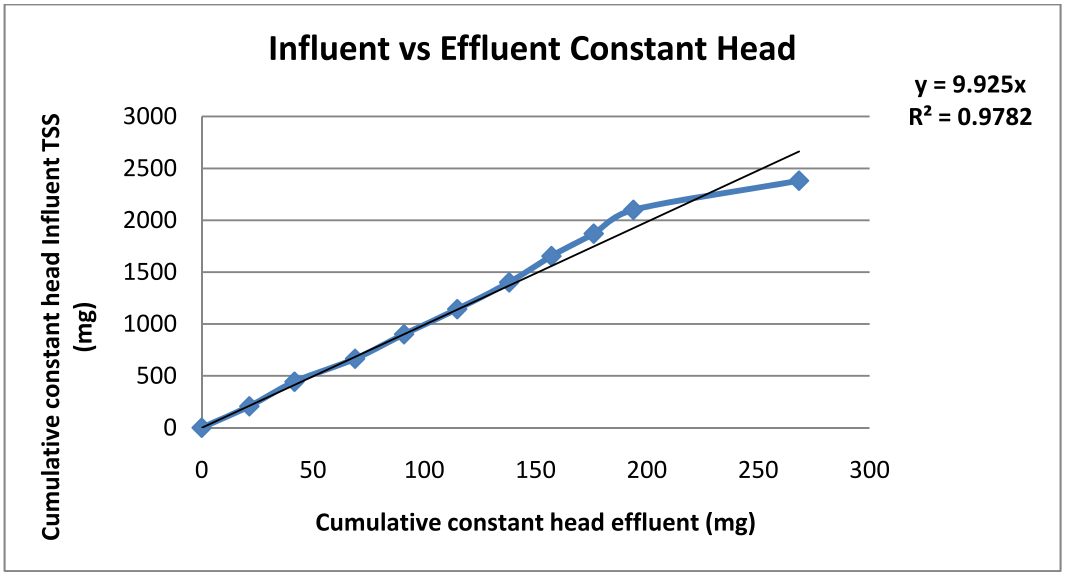

Figure 4-11. Influent and effluent constant head

Table 4-27. Constant Head Permeability

Medium Concentration Artificial Runoff	
Tests	Average constant head Permeability of Greensand (cm/s)
1	0.15
2	0.08
3	0.06
4	0.09
5	0.05
6	0.05
7	0.04
8	0.04
9	0.03

After test #9 the permeability of the greensand was reduced by 79.4%

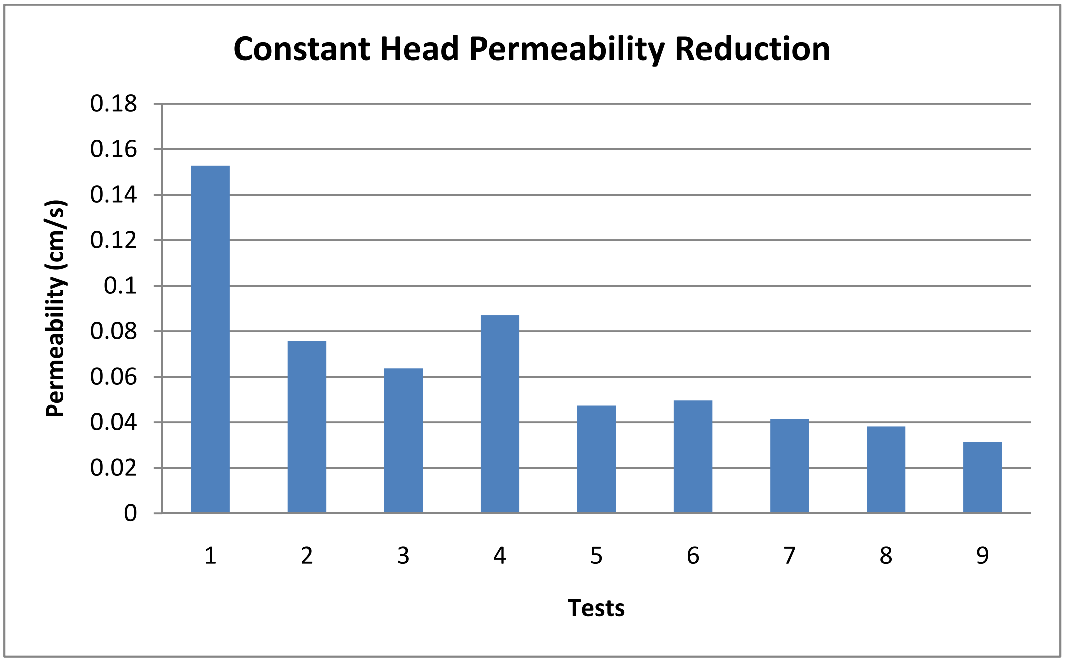

Figure 4-12. Constant head permeability reduction medium concentration

C. Results for the composite pervious concrete and greensand

The average removal of suspended solids as a composite system (pervious concrete and greensand) was [1-(26.9/265.3)]*100 = 90%. As a result the permeability of pervious concrete did not drop but the permeability of the greensand dropped by 79.4% after the introduction of 16.1g of suspended solids.

D. Particle size

The concentration of the samples for particle size analysis was less than the detectable range for the particle size analyzer, Coulter Beckman machine. The characteristics of the particle size analyzer machine are discussed in detail in the methodology chapter 3.

E. Metals

The total metals and dissolved metals samples were sent to chemistry department for analysis. Statistical analysis was conducted on the metals data. T-test was performed to show the difference between average mean of total and dissolved metals of influent and effluent falling head and effluent of constant head permeabilities. The t-test summary for medium concentration artificial runoff is in Table 4-28. Total metals were not reduced by pervious concrete for the medium concentration of artificial runoff. For the medium concentration, the dissolved iron and dissolved nickel were predominant as found for as high concentration of artificial runoff. Dissolved iron decreased by 46.8% by pervious concrete. Dissolved nickel was reduced by 2.5% by pervious concrete. Total metals were reduced in filter media. The reduction range was 52 – 87%. Filter media reduced the dissolved nickel by 86%. Some of dissolved metals did not reduce even there are some increase in the amount of dissolved iron. It is concluded that filter media (greensand) is a good agent in filtering the total metal rather than dissolved metal. The efficiency of pervious concrete and filter media decrease by reduction in concentration of influent. The result of analysis of total metal and dissolved metal is in Table 4-29.

Table 4-28. T-Test Result for Influent and Effluent Falling Head Permeability Medium Concentration

Metals	Sample	Medium Concentration Artificial Runoff		T-test Confidence Interval (%)
		Introduced (µg/L)	Average (µg/L)	
Total Cadmium	Influent Pervious Concrete	100	79	
	Effluent Pervious Concrete		81	98.5
	Effluent Filter Media		10	99.99
Dissolved Cadmium	Influent Pervious Concrete		33	
	Effluent Pervious Concrete		31	71.6
	Effluent Filter Media		3	99.9
Total Copper	Influent Pervious Concrete	175	126	
	Effluent Pervious Concrete		133	96.7
	Effluent Filter Media		47	99.99
Dissolved Copper	Influent Pervious Concrete		8	
	Effluent Pervious Concrete		7	48.2
	Effluent Filter Media		7	94.7
Total Chromium	Influent Pervious Concrete	125	91	
	Effluent Pervious Concrete		91	11.2
	Effluent Filter Media		29	99.99
Dissolved Chromium	Influent Pervious Concrete		14	
	Effluent Pervious Concrete		13	59.3
	Effluent Filter Media		11	99.9
Total l Iron	Influent Pervious Concrete	7720	12113	
	Effluent Pervious Concrete		11993	22.7
	Effluent Filter Media		4584	99.98
Dissolved Iron	Influent Pervious Concrete		525	
	Effluent Pervious Concrete		279	65.0
	Effluent Filter Media		1347	82.8
Total Nickel	Influent Pervious Concrete	475	393	
	Effluent Pervious Concrete		399	76.4
	Effluent Filter Media		78	99.99
Dissolved Nickel	Influent Pervious Concrete		281	
	Effluent Pervious Concrete		274	79.0
	Effluent Filter Media		38	99.99
Total Lead	Influent Pervious Concrete	1075	909	
	Effluent Pervious Concrete		909	0
	Effluent Filter Media		261	99.99
Dissolved Lead	Influent Pervious Concrete		25	
	Effluent Pervious Concrete		5	63.6
	Effluent Filter Media		5	99.99
Total Zinc	Influent Pervious Concrete	500	428	
	Effluent Pervious Concrete		442	62.2
	Effluent Filter Media		211	30.4
Dissolved Zinc	Influent Pervious Concrete		55	
	Effluent Pervious Concrete		66	46.1
	Effluent Filter Media		20	92.1

Table 4-29. Summary of Total and Dissolved Metal Medium Concentration

Metals	Sample	Medium Concentration Artificial Runoff				
		Introduced (µg/L)	Maximum (µg/L)	Minimum (µg/L)	Average (µg/L)	Reduction (%)
Total Cadmium	Influent Pervious Concrete	**100**	81.3	76.0	79	0.00
	Effluent Pervious Concrete		83.2	78.3	81	-2.53
	Effluent Filter Media		33.1	4.2	10	87.65
Dissolved Cadmium	Influent Pervious Concrete		52.2	16.8	33	0.00
	Effluent Pervious Concrete		52.0	15.6	31	6.06
	Effluent Filter Media		19.9	0.4	3	90.32
Total Copper	Influent Pervious Concrete	**175**	131.7	118.7	126	0.00
	Effluent Pervious Concrete		156.2	126.3	133	-5.56
	Effluent Filter Media		87.9	24.8	47	64.66
Dissolved Copper	Influent Pervious Concrete		33.3	5.3	8	0.00
	Effluent Pervious Concrete		8.6	5.8	7	12.50
	Effluent Filter Media		7.9	6.9	7	0.00
Total Chromium	Influent Pervious Concrete	**125**	98.7	85.6	91	0.00
	Effluent Pervious Concrete		93.4	88.0	91	0.00
	Effluent Filter Media		63.4	12.7	29	68.13
Dissolved Chromium	Influent Pervious Concrete		32.5	12.3	14	0.00
	Effluent Pervious Concrete		15.1	11.8	13	7.14
	Effluent Filter Media		11.7	10.4	11	15.38
Total Iron	Influent Pervious Concrete	**7720**	13528.9	10193.2	12113	0.00
	Effluent Pervious Concrete		14221.4	10975.3	11993	0.99
	Effluent Filter Media		13970.1	2425.6	4584	61.78
Dissolved Iron	Influent Pervious Concrete		2762.8	268.4	525	0.00
	Effluent Pervious Concrete		301.5	272.5	279	46.86
	Effluent Filter Media		7220.9	319.6	1347	-382.80
Total Nickel	Influent Pervious Concrete	**475**	409.7	365.1	393	0.00
	Effluent Pervious Concrete		407.5	389.5	399	-1.53
	Effluent Filter Media		193.1	45.2	78	80.45
Dissolved Nickel	Influent Pervious Concrete		326.3	231.9	281	0.00
	Effluent Pervious Concrete		328.4	219.8	274	2.49
	Effluent Filter Media		73.7	18.8	38	86.13
Total Lead	Influent Pervious Concrete	**1075**	935.3	869.2	909	0.00
	Effluent Pervious Concrete		928.9	886.9	909	0.00
	Effluent Filter Media		655.6	46.2	261	71.29
Dissolved Lead	Influent Pervious Concrete		219.8	3.5	25	0.00
	Effluent Pervious Concrete		5.1	4.3	5	80.00
	Effluent Filter Media		5.9	5.3	5	0.00
Total Zinc	Influent Pervious Concrete	**500**	505.0	388.7	428	0.00
	Effluent Pervious Concrete		491.7	409.4	442	-3.27
	Effluent Filter Media		475.1	89.4	211	52.26
Dissolved Zinc	Influent Pervious Concrete		135.8	0.3	55	0.00
	Effluent Pervious Concrete		170.2	0.7	66	-20.00
	Effluent Filter Media		127.4	1.2	20	69.70

4.1.4.3. Artificial Runoff Low Concentration Test Results

A. Falling head permeability

The low concentration artificial runoff tests were performed on specimen – IX. The results were similar to medium concentration; there was no reduction in the permeability at all. Refer to Table 4-30 and Figure 4-13. The suspended solids recovered in the influent of falling head permeability were 13.2 mg/L which was 98.9 mg in 7.5 L of cumulative influent. The effluent suspended solids were 10.8 mg/L which was 81.1 mg in 7.5 L of cumulative effluent. Refer to Table 4-31

Table 4-30. Falling Head Permeability Artificial Runoff, Low Concentration

Test No.			Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	H_1	H_2									
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	1.88	14.9	1.94	23.61	4.8	5.2	10000	9959.3
2	94.6	48.9	45.7	1.87	14.9	1.94	23.2	4.9	5.3	10000	10004.8
3	94.6	48.9	45.7	1.89	14.9	1.94	23.3	4.8	5.2	10000	9992.8
4	94.6	48.9	45.7	1.91	14.9	1.94	23.6	4.75	5.2	10000	9944.8
5	94.6	48.9	45.7	1.9	14.9	1.94	23.7	4.7	5.2	10000	9956.6
6	94.6	48.9	45.7	1.9	14.9	1.94	23.1	4.8	5.2	10000	9920
7	94.6	48.9	45.7	1.9	14.9	1.94	23.1	4.8	5.2	10000	9944.7
8	94.6	48.9	45.7	1.89	14.9	1.94	23.2	4.8	5.2	10000	9976.5
9	94.6	48.9	45.7	1.88	14.9	1.94	23.8	4.9	5.2	10000	9976.5
10	94.6	48.9	45.7	1.87	14.9	1.94	23.7	4.8	5.3	10000	9951.9

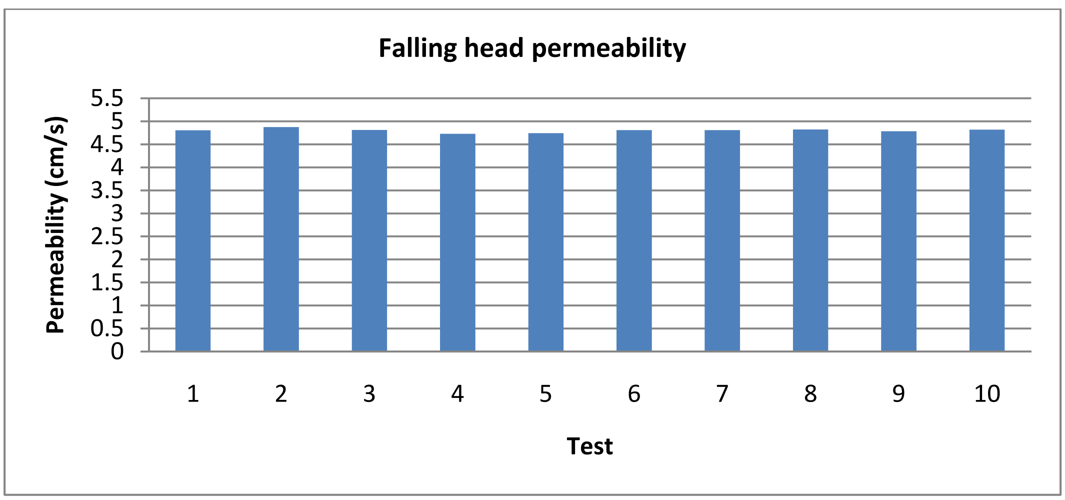

Figure 4-13. Falling permeability low concentration

Table 4-31. TSS Difference Influent and Effluent Low Concentration

ORM TSS Influent Falling Head Low Concentration	
Average TSS collected per Vol:	**13.18mg/L**
Total TSS collected:	**98.87mg**
Cumulative V_{water} =	**7.50L**
ORM TSS Effluent Falling Head Low Concentration	
Average TSS collected per Vol:	**10.8mg/L**
Total TSS collected:	**81.1mg**
Cumulative V_{water} =	**7.50L**
ORM TSS Effluent Constant Head Low Concentration	
Average TSS collected per Vol:	**1.91mg/L**
Total TSS collected:	**7.25mg**
Cumulative V_{water} =	**7.50L**

B. Constant head permeability

Nine constant head permeability tests were performed on greensand by using the low concentration of artificial runoff. The permeability of greensand did not reduce at all. Refer to the Table 4-32 and Figure 4-14. The suspended solids recovered in the effluent of the constant head permeability were 1.9 mg/L which was 7.25 mg in 7.5L of cumulative effluent. The difference between suspended solids in the effluent of falling head permeability and effluent of constant head permeability showed the amount of suspended solids filtered by the greensand which was [1- (1.9/10.8)]*100 = 82.4%. The concrete specimen removed on average 18% percent of the influent suspended solids. Table 4-33 and Figure 4-15 and Figure 4-16 shows relationship between influent and effluent of falling head permeability influent and effluent constant head permeability.

C. Results for the composite pervious concrete and greensand

The average removal of suspended solids as a composite system (pervious concrete and greensand) was [1-(1.91/13.18)]*100 = 85.5%. As a result the permeability of pervious concrete greensand did not drop.

Table 4-32. Constant Head Permeability Low Concentration

Low Concentration Artificial Runoff	
Tests	**Average constant head Permeability of Greensand (cm/s)**
1	0.074
2	0.075
3	0.08
4	0.08
5	0.083
6	0.084
7	0.086
8	0.086
9	0.085

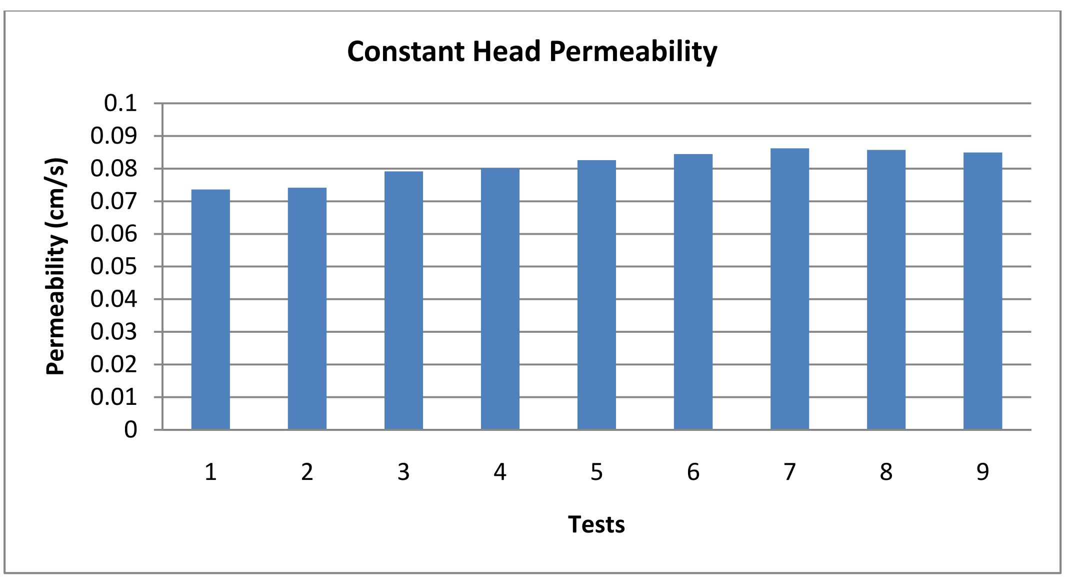

Figure 4-14. Constant head permeability low concentration

Table 4-33. Influent and Effluent Falling Head TSS and Effluent Constant Head Low Concentration

Tests	Influent TSS Falling head	Cumulative TSS Falling head	Effluent TSS Falling head	Cumulative TSS Falling head	Effluent TSS Constant head	Cumulative TSS Constant head
0	0	0	0	0	0	0
1	10.8	10.8	12.4	12.4	9.5	9.5
2	14.4	25.2	13.7	26.1	1.5	11
3	17.9	43.1	9.5	35.6	1.1	12.1
4	10.9	54	10.3	45.9	0.97	13.07
5	12.3	66.3	11.2	57.1	3.32	16.39
6	11.8	78.1	9.9	67	0.7	17.09
7	16.1	94.2	11.3	78.3	0.82	17.91
8	11.7	105.9	10.9	89.2	0.1	18.01
9	14.6	120.5	10.7	99.9	0	18.01
10	11.3	131.8	8.2	108.1	1.12	19.13

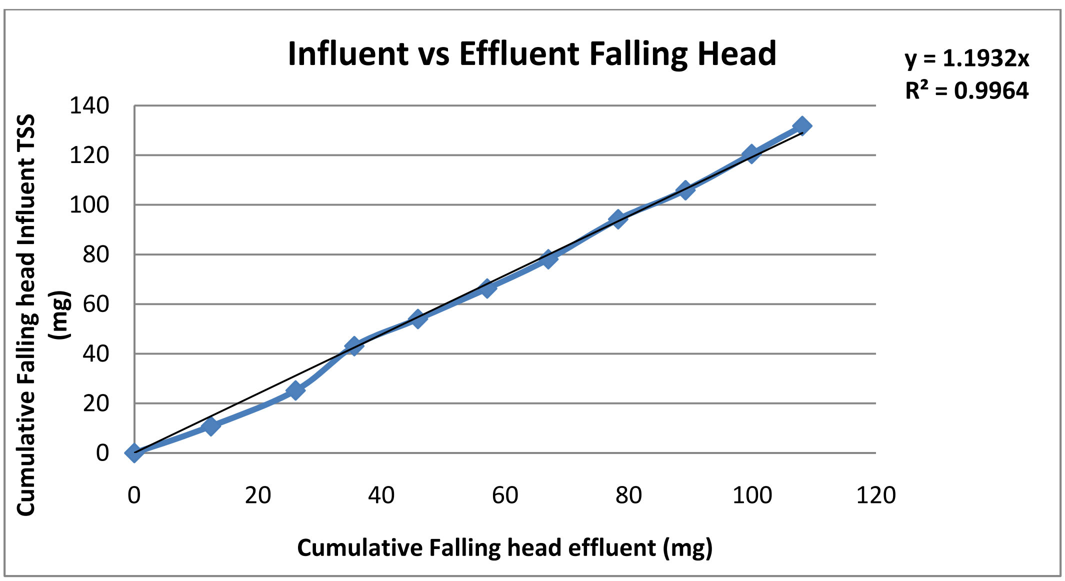

Figure 4-15. Influent and effluent falling head low concentration

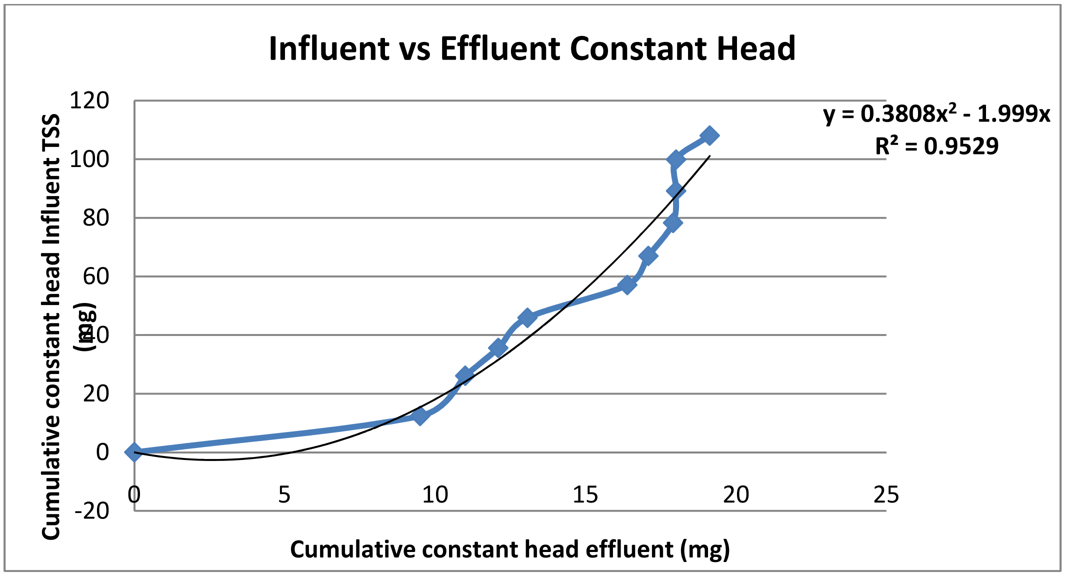

Figure 4-16. Influent and effluent constant head concentration

D. *Particle Size*

The concentration of the samples for particle size analysis was less than the certain detectable range for the particle size analyzer, Coulter Beckman machine. The characteristics of the particle size analyzer machine are discussed in detail in the methodology chapter.

E. *Metals*

The total metals and dissolved metals samples were sent to chemistry department for analysis. Statistical analysis was conducted on the metals data. T-test was performed to show the difference between average mean of total and dissolved metals of influent and effluent falling head and effluent of constant head permeabilities. The t-test summary for low concentration artificial runoff is in Table 4-34. Pervious concrete reduced total nickel by 26.3%, total lead by 27.4% and total zinc by 16%. Dissolved nickel and dissolved iron were predominant. Dissolved iron was reduced by 10% by pervious concrete. Total metals were reduced by filter media. The reduction range was 12 – 92%. Total iron did not reduce for low concentration of artificial runoff. Dissolved nickel reduced by 41.4% by filter media. Some of dissolved metal reduced and some did not and there are some increases in dissolved iron and dissolved zinc in filter media. The efficiency of pervious concrete and filter media decreased by reduction in concentration of influent. The result of analysis of total metal and dissolved metal is in Table 4-35.

Table 4-34. T-Test Result of Influent and Effluent Falling Head and Effluent Constant Head Permeability Low Concentration

Metals	Sample	Low Concentration Artificial Runoff		T-test Confidence Interval (%)
		Introduced (µg/L)	Average (µg/L)	
Total Cadmium	Influent Pervious Concrete	**`20**	13	
	Effluent Pervious Concrete		14	77.4
	Effluent Filter Media		1	99.99
Dissolved Cadmium	Influent Pervious Concrete		15	
	Effluent Pervious Concrete		14	99.8
	Effluent Filter Media		1	99.99
Total Copper	Influent Pervious Concrete	**35**	29	
	Effluent Pervious Concrete		60	99.9
	Effluent Filter Media		25	99.5
Dissolved Copper	Influent Pervious Concrete		29	
	Effluent Pervious Concrete		29	34.7
	Effluent Filter Media		17	99.99
Total Chromium	Influent Pervious Concrete	**25**	18	
	Effluent Pervious Concrete		21	98.6
	Effluent Filter Media		8	99.99
Dissolved Chromium	Influent Pervious Concrete		7	
	Effluent Pervious Concrete		8	78.5
	Effluent Filter Media		8	56.4
Total Iron	Influent Pervious Concrete	**250**	798	
	Effluent Pervious Concrete		1250	95.9
	Effluent Filter Media		1275	2.3
Dissolved Iron	Influent Pervious Concrete		251	
	Effluent Pervious Concrete		225	99.99
	Effluent Filter Media		1100	68.9
Total Nickel	Influent Pervious Concrete	**95**	99	
	Effluent Pervious Concrete		73	99.6
	Effluent Filter Media		13	99.99
Dissolved Nickel	Influent Pervious Concrete		77	
	Effluent Pervious Concrete		76	93.4
	Effluent Filter Media		7	99.99
Total Lead	Influent Pervious Concrete	**215**	175	
	Effluent Pervious Concrete		127	97.1
	Effluent Filter Media		17	99.9
Dissolved Lead	Influent Pervious Concrete		17	
	Effluent Pervious Concrete		17	6.8
	Effluent Filter Media		9	99.99
Total Zinc	Influent Pervious Concrete	**25**	125	
	Effluent Pervious Concrete		105	62.2
	Effluent Filter Media		92	30.4
Dissolved Zinc	Influent Pervious Concrete		16	
	Effluent Pervious Concrete		15	99.4
	Effluent Filter Media		27	34.7

Table 4-35. Summary of Total and Dissolved Metals Low Concentration

Metals	Sample	Low Concentration Artificial Runoff				
		Introduced (µg/L)	Maximum (µg/L)	Minimum (µg/L)	Average (µg/L)	Reduction (%)
Total Cadmium	Influent Pervious Concrete	20	16.2	8.7	13	0.00
	Effluent Pervious Concrete		19.6	11.1	14	-7.69
	Effluent Filter Media		7.5	0.0	1	92.86
Dissolved Cadmium	Influent Pervious Concrete		17	13	15	0.00
	Effluent Pervious Concrete		16	12	14	6.67
	Effluent Filter Media		9	0	1	92.86
Total Cupper	Influent Pervious Concrete	35	41.2	20.1	29	0.00
	Effluent Pervious Concrete		118.7	47.5	60	-106.90
	Effluent Filter Media		70.7	17.0	25	58.33
Dissolved Copper	Influent Pervious Concrete		33	24	29	0.00
	Effluent Pervious Concrete		36	24	29	0.00
	Effluent Filter Media		17	16	17	41.38
Total Chromium	Influent Pervious Concrete	25	23.4	11.8	18	0.00
	Effluent Pervious Concrete		27.2	17.9	21	-16.67
	Effluent Filter Media		9.2	6.7	8	61.90
Dissolved Chromium	Influent Pervious Concrete		8	7	7	0.00
	Effluent Pervious Concrete		9	7	8	-14.29
	Effluent Filter Media		8	7	8	0.00
Total Iron	Influent Pervious Concrete	250	943.9	644.8	798	0.00
	Effluent Pervious Concrete		2175.5	589.5	1250	-56.64
	Effluent Filter Media		9199.2	280.5	1275	-2.00
Dissolved Iron	Influent Pervious Concrete		254	246	251	0.00
	Effluent Pervious Concrete		235	214	225	10.36
	Effluent Filter Media		8431	257	1100	-388.89
Total Nickel	Influent Pervious Concrete	95	172.5	70.1	99	0.00
	Effluent Pervious Concrete		101.4	60.0	73	26.26
	Effluent Filter Media		31.9	4.2	13	82.19
Dissolved Nickel	Influent Pervious Concrete		80	75	77	0.00
	Effluent Pervious Concrete		78	70	76	1.30
	Effluent Filter Media		36	1	7	90.79
Total Lead	Influent Pervious Concrete	215	182.1	157.0	175	0.00
	Effluent Pervious Concrete		249.2	70.4	127	27.43
	Effluent Filter Media		35.7	11.2	17	86.61
Dissolved Lead	Influent Pervious Concrete		20	15	17	0.00
	Effluent Pervious Concrete		22	14	17	0.00
	Effluent Filter Media		9	9	9	47.06
Total Zinc	Influent Pervious Concrete	25	181.5	66.8	125	0.00
	Effluent Pervious Concrete		248.5	35.1	105	16.00
	Effluent Filter Media		275.3	38.5	92	12.38
Dissolved Zinc	Influent Pervious Concrete		23	10	16	0.00
	Effluent Pervious Concrete		22	8	15	6.25
	Effluent Filter Media		268	0	27	-80.00

4.2. Result of Compressive Strength Test of Pervious Concrete

Three specimens, specimen – XI, XII and XIII, were tested for compressive strength. The specimens had diameter of 4 inches and height of 8 inches. The peak load each specimen resisted was between 2600 to 3000 lbs which was 210 to 240 psi. Refer to Table 4-36. Specimen – XI showed unexpected compressive strength; the reason for the increased strength was the penetration of the capping mortar to voids of the porous concrete specimen, which filled the gaps inside the specimen and increased the compressive strength. The compressive strength test procedure is discussed in the methodology chapter 3.

Table 4-36**.** Compressive Strength of Pervious Concrete Specimens

Specimen	**Specimen Diameter**	**Specimen Height**	**Specimen Weight**	**Specimen Unit Weight**	**Peak Load**	**Unconfined Compressive Strength**
No	**in**	**in**	**lb**	**lb/ft3**	**lb**	**psi**
11	4	8.17	5.324	91.57	6040	480.65
12	4	8.25	5.346	91.95	2940	233.96
13	4	8.25	5.478	94.22	2620	208.49

4.3. Freeze and Thaw Test Result

Pervious concrete has poor freeze and thaw resistance if it is fully saturated. Since pervious concrete has high drainage capacity it rarely would be fully saturated. The full saturation of the pervious concrete happens when:

a. The pervious concrete clogged completely
b. The average daily temperature stays under zero for a long period of time
c. The underground water table raises to the depth of 3 ft form the surface of the pervious concrete.

The specimen which was tested according to ASTM C 666 was exposed to extreme condition of freeze and thaw due to the following reasons:

a. ASTM C 666 recommend fully saturated specimen for test of freeze and thaw
b. The temperature variation in freeze and thaw machine is faster than the actual variation in natural environment

Therefore, ASTM C 666 is not the actual representative of field condition.

The freeze and thaw tests of ORM specimens the specimens were fully saturation and temperature variation was approximately 1 F° per 1.2 min.

In the freeze thaw test the pervious concrete specimens' mass loss was from 18 – 20.3 % in 22 cycles of freeze and thaw. Refer to table 4-37 and 4-38.

Table 4-37. Freeze and Thaw Specimens' Specification

Specimen - I					Specimen - II					Specimen - III				
Initial Mass =	**4639.3**	**g**			**Initial Mass =**	**4639.3**	**g**			**Initial Mass =**	**4639.3**	**g**		
Length =	16	in			**Length =**	16	in			**Length =**	16	in		
	15.7	in				15.8	in				15.8	in		
	15.9	in				15.9	in				15.9	in		
Average =	**15.9**	**in**	**40.3**	**cm**	**Average =**	**15.9**	**in**	**40.4**	**cm**	**Average =**	**15.9**	**in**	**40.4**	**cm**
Width =	4	in			**Width =**	4	in			**Width =**	4	in		
	3.8	in				3.8	in				3.8	in		
	3.9	in				3.8	in				3.8	in		
Average =	**3.9**	**in**	**9.8**	**cm**	**Average =**	**3.8**	**in**	**9.7**	**cm**	**Average =**	**3.8**	**in**	**9.7**	**cm**
Thickness =	2.8	in			**Thickness =**	2.9	in			**Thickness =**	2.9	in		
	3	in				3	in				3	in		
	3.1	in				3.1	in				3.1	in		
Average =	**3.1**	**in**	**7.7**	**cm**	**Average =**	**3.1**	**in**	**7.7**	**cm**	**Average =**	**3.1**	**in**	**7.7**	**cm**

Table 4-38. Pervious Concrete Mass Loss in Freeze and Thaw

Specimen	Initial Mass	Final Mass	Mass Loss	Mass Loss (%)	Number of Cycle
1	4639.3	3696.1	943.2	20.3	22
2	4480.5	3877.7	829	18.5	22
3	4702.7	3783.6	919.1	19.5	22

4.4. Type 3 Gravel

Type 3 gravel is a graduated crushed lime stone. Type 3 is used in the second layer of the exfiltration trench. Type 3 gravel was tested for the permeability and total suspended solids analysis. Permeability test and total suspended solids analysis were conducted on 3 washed and 3 unwashed specimens. The average permeability for the unwashed type 3 gravel was 4.18 cm/s and overall suspended solids collected from three permeability tests' effluents which was 30 liter cumulative water, was 5568.1 mg. The average permeability for the washed type 3 gravel was 4.4 cm/s. and overall suspended solids collected from three permeability tests' effluents which was 30 liter cumulative water, was 1442.3 mg. Refer to Table 4-39. The difference between permeability test of washed and unwashed type 3 gravel was [1 – (4.18/4.4)]*100 = 5%. The difference between total suspended solids of washed and unwashed type 3 gravel was almost four times greater. The large difference between suspended solids from washed and unwashed type 3 gravel must be considered in designing the second layer of the exfiltration trench. The procedure of type 3 gravel tests is discussed in methodology chapter. See Figure 4-17 and 4-18.

Table 4-39. Permeability and TSS between Washed and Unwashed Type 3 Gravel

Specimen	Tests	Washed Type 3 Gravel					Unwashed Type 3 Gravel				
		$k_{@°20}$	Average $k_{@°20}$	Volume of Concrete Specimen (cm^3)	TSS per Liter (mg/L)	TSS in 3 Tests (mg)	$k_{@°20}$	Average $k_{@°20}$	Volume of Concrete Specimen (cm^3)	TSS per Liter (mg/L)	TSS in 3 Tests (mg)
1	1	4.25	4.23	1235.6	1263.7	1394.1	3.66	3.66	1132.6	4877.1	5240.4
	2	4.19		1235.6	83		3.66		1132.6	296.2	
	3	4.25		1235.6	47.4		3.66		1132.6	67.1	
2	1	4.5	4.57	1235.5	1562.1	1684.6	4.4	4.33	1132.6	4765.6	5003.4
	2	4.6		1235.5	85.8		4.3		1132.6	164.9	
	3	4.6		1235.5	36.7		4.3		1132.6	72.9	
3	1	4.4	4.40	1184.7	1175.5	1248.3	4.52	4.54	1192.7	5961.1	6460.4
	2	4.4		1184.7	53.1		4.54		1192.7	391.3	
	3	4.4		1184.7	19.7		4.56		1192.7	108	
	Average Values =		**4.40**			**1442.33**		**4.18**			**5568.07**

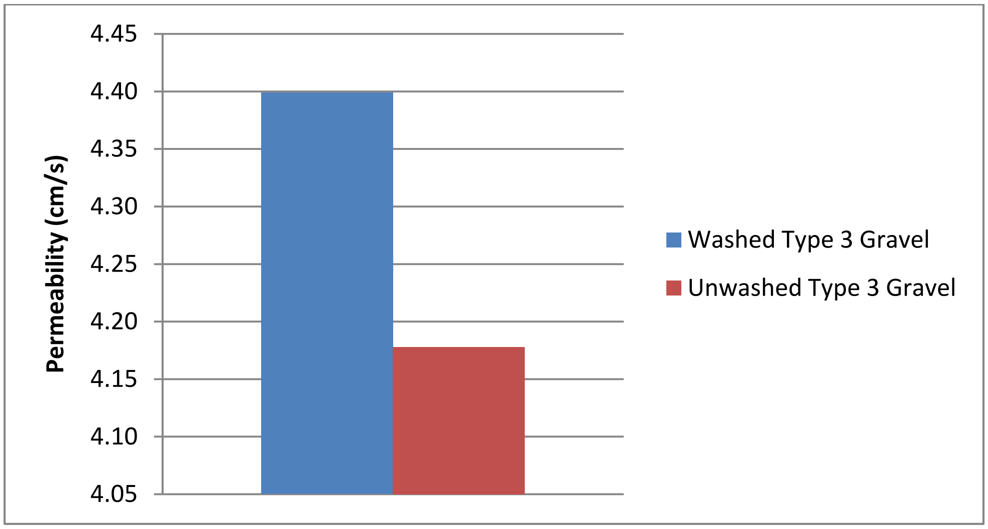

Figure 4-17. Permeability of washed and unwashed type 3 gravel

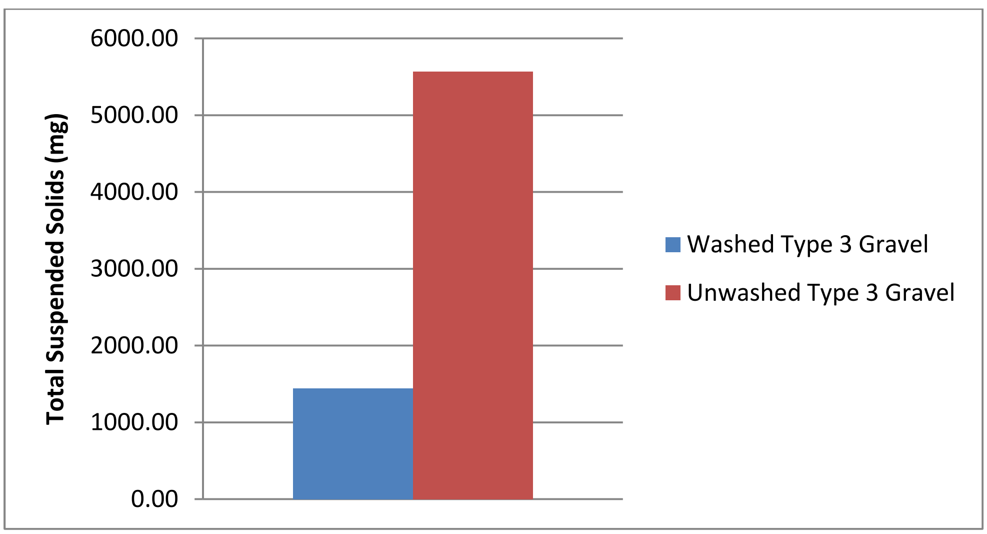

Figure 4-18. Total suspended solids of washed and unwashed type 3 gravel

4.5. Greensand

Greensand was tested for the constant head permeability, total suspended solids analysis and removal of A6 soil. The tap water permeability of greensand was 0.12 cm/s. After determining the tap water permeability, A6 soil clogging test was conducted on the greensand. Fifteen grams of A6 soil were introduced in 5 liter of tap water; in first clogging test the permeability of the greensand reduced by 25%, and the amount of the suspended solids recovered in the effluent of first clogging permeability test was 52.3 mg/L which was 261.5 mg in 5 liter of effluent. In second A6 soil clogging test the permeability of the greensand reduced by 45% and the amount of suspended solids recovered in the effluent of second clogging test was 13.34 mg/L which was 66.7 mg in 5 liter of the effluent. In third A6 soil clogging test the permeability of the greensand reduced by 47% which was close to second A6 soil clogging test. The amount of suspended solids recovered in the effluent of the third A6 soil clogging test was 4.14 mg/L which was 20.7 mg in 5 liters of the effluent. Refer to Table 4-40, Figure 4-19 and Table 4-41, Figure 4-20. The clogging test was stopped after the third clogging test since the permeability of second and third clogging tests were almost similar. The total amount of the particles recovered in total suspended solids analysis was 349 mg. The amount of introduced A6 soil was 45g. The difference between introduced soil and recovered soil gave efficiency of the greensand filtering media, which was [1 – (0.349/45)]*100 = 99%. Totally 2.97g/l retained in the greensand.

Table 4-40**.** Greensand Tapwater and Clogging Permeability

Green Sand Permeability (cm/s)			
Tapwater	**Clogging - 1**	**Clogging - 2**	**Clogging - 3**
0.12134504	**0.09129168**	**0.067154514**	**0.06457819**
100.00%	**75.23%**	**55.34%**	**53.22%**

Table 4-41. Total Suspended Solids Recovered in Clogging Test

Total Suspended Solids in effluent of clogging test		
TSS After Clogging- 1	**TSS After Clogging- 2**	**TSS After Clogging- 3**
261.5mg	**66.7mg**	**20.7mg**

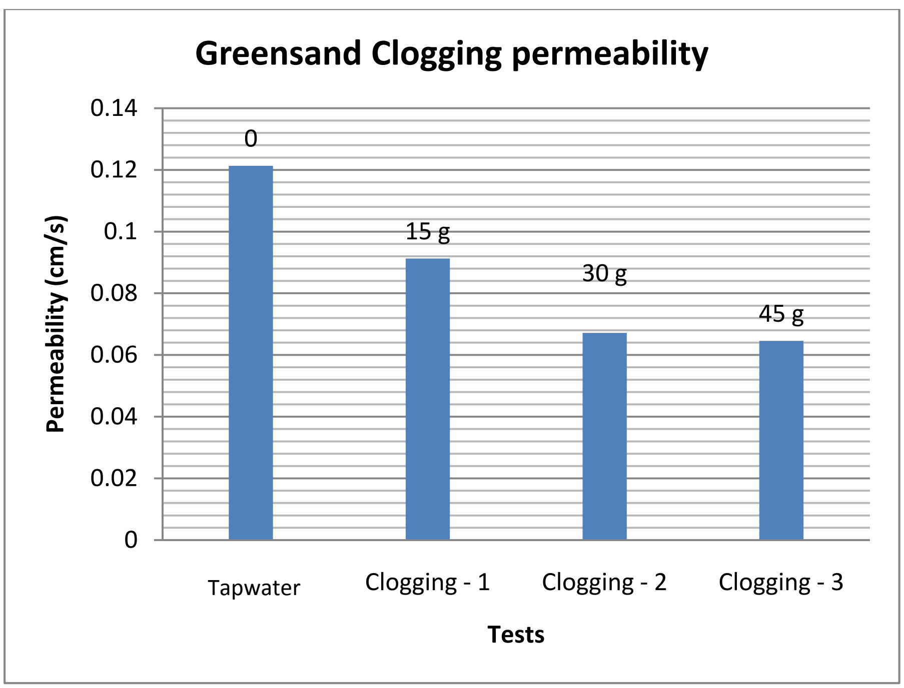

Figure 4-19. Greensand permeability after clogging

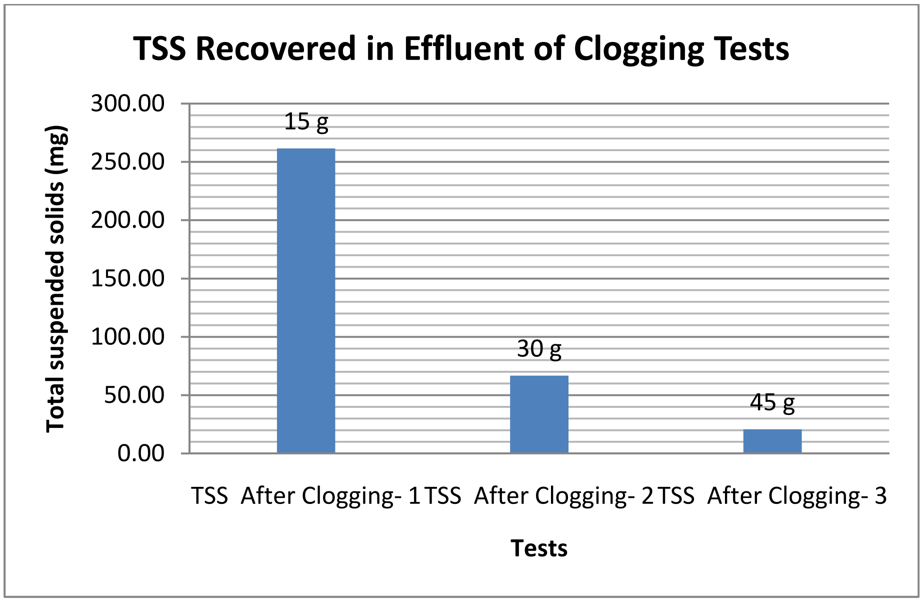

Figure 4-20. TSS in effluent of clogging test of greensand

4.6. Comparison of ODOT Mix and ORM Mix

The ODOT mix and test results are taken from the previous study in this project. The ODOT concrete mix had the same material and molds as ORM except the aggregate # 57 was used in the mix which had smaller size than the aggregate in ORM mix. The ODOT data is compared with ORM data and summarized in the following Table 4-42.

4.6.1. Permeability

The average permeability of ORM specimen was higher than ODOT specimens. Since ORM mix had bigger size aggregates. Refer to Figure 4-21.

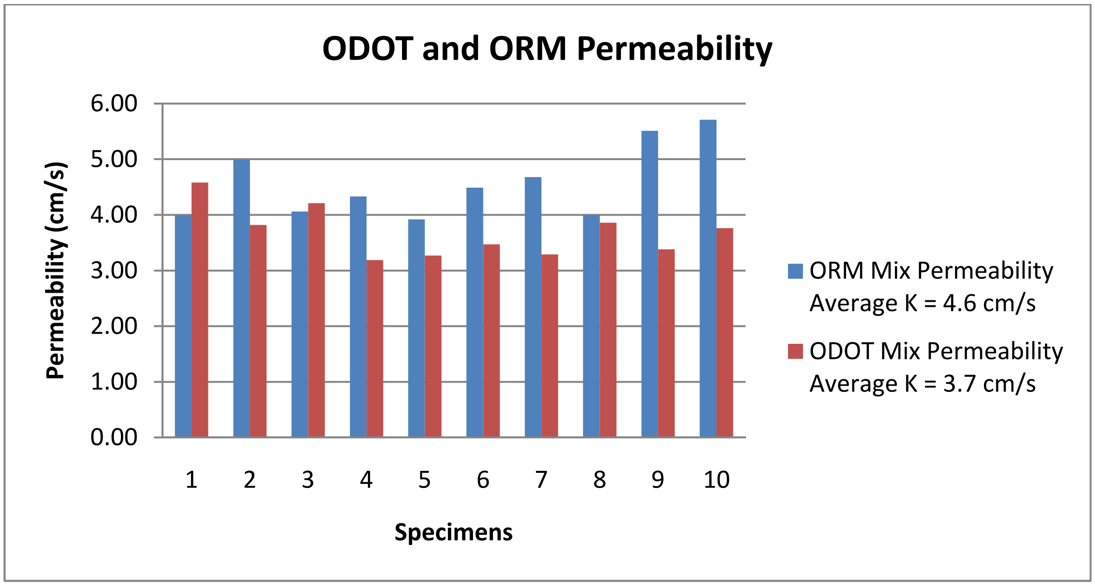

Figure 4-21. Average permeability of ODOT and ORM specimen

4.6.2. Porosity

Porosity of ODOT and ORM specimens were almost the same. See Figure 4-22.

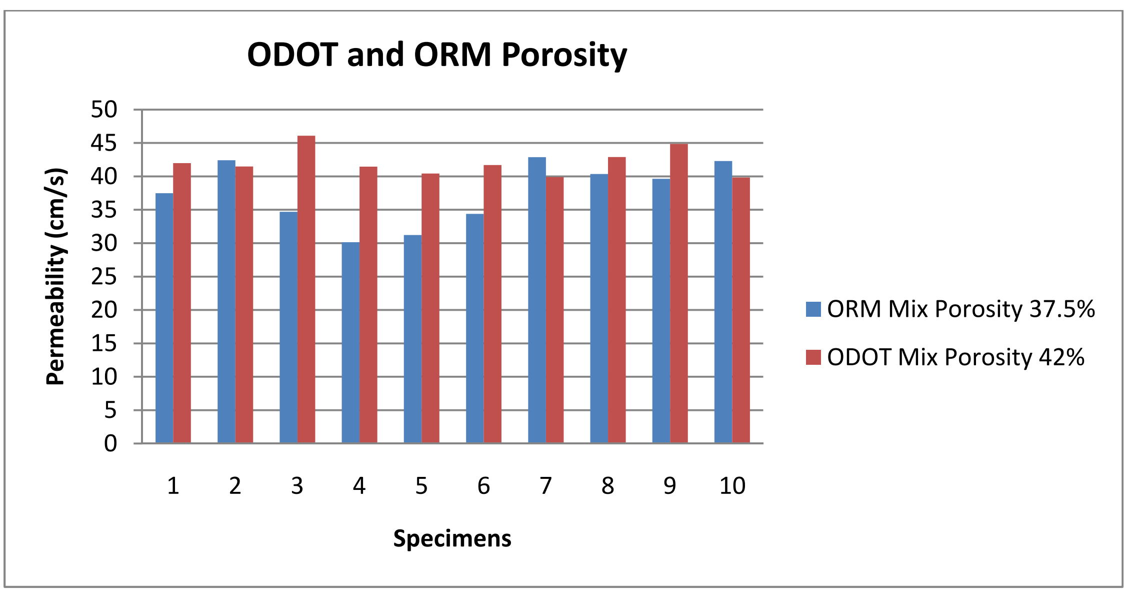

Figure 4-22. Average porosity of ODOT and ORM specimens

4.6.3. Total Suspended Solids

The average suspended solids recovered in the effluent of tapwater permeability were much higher in the ODOT specimens than ORM specimens. Perhaps the reason could be unwashed aggregate concrete mix. Refer to Figure 4-23.

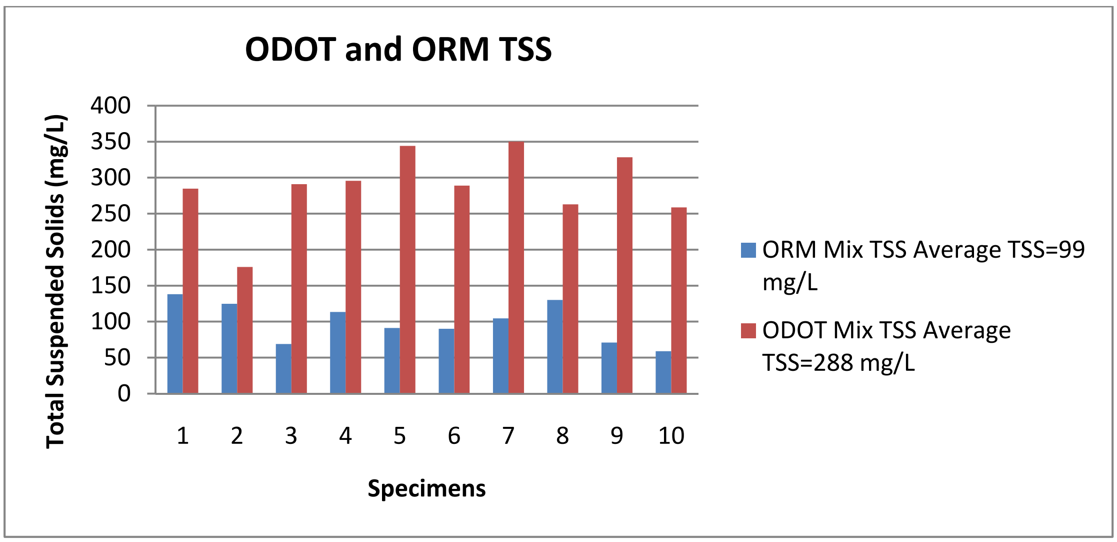

Figure 4-23. ODOT and ORM recovered total suspended solids

Table 4-42. ODOT and ORM Data Summary

No	Ohio Ready Concrete Mix Test Results			ODOT Concrete Mix Test Results		
	Average $k_{@20°C}$	Porosity, n	Mean TSS	*Average $k_{@20°C}$*	Porosity, n	Mean TSS
	(cm/s)	%	(mg/L)	(cm/s)	%	(mg/L)
1	3.99	37.48	99.0	4.58	42.00	148.5
			37.0			105.0
			2.0			31.3
	Summation		138.0	Summation		284.8
2	4.99	42.43	113.3	3.82	41.48	73.0
			6.5			71.5
			4.9			31.4
	Summation		124.7	Summation		175.9
3	4.06	34.69	65.3	4.21	46.09	154.0
			2.4			101.0
			1.3			35.9
	Summation		69.0	Summation		290.9
4	4.33	30.14	97.8	3.19	41.74	151.6
			14.0			83.6
			1.7			60.4
	Summation		113.5	Summation		295.6
5	3.92	31.22	78.6	3.27	40.43	165.1
			10.0			86.6
			2.6			92.4
	Summation		91.1	Summation		344.1
6	4.49	34.39	79.7	3.47	41.69	160.8
			9.6			89.7
			0.7			38.5
	Summation		90.0	Summation		289.0
7	4.68	42.87	87.8	3.29	39.90	166.7
			12.1			115.7
			4.6			67.8
	Summation		104.5	Summation		350.2
8	4.00	40.37	103.9	3.86	42.91	146.7
			22.5			92.1
			3.6			24.1
	Summation		130.0	Summation		262.9
9	5.51	39.65	69.0	3.38	44.87	185.0
			1.7			102.8
			0.3			40.5
	Summation		71.0	Summation		328.3
10	5.71	42.31	53.6	3.76	39.83	200.6
			3.6			46.7
			1.7			11.3
	Summation		58.8	Summation		258.6

4.6.4. Sand Clogging Comparison of ORM Mix and ODOT Mix

The average initial permeability of the three ORM specimens was 4.3 cm/s before clogging, and 16 sand clogging tests were conducted on each of the three specimens. In each clogging test 40 g of sand was introduced in 10 liters of tapwater. After 16 tests the average permeability of the specimen was reduced by about 94%. Same procedure was conducted on ODOT specimens. The average initial permeability of ODOT specimens was 4.2 cm/s. After 16 tests on each three specimens the average permeability of ODOT specimens was reduced by 82%. The aggregate in the ODOT mix were smaller in size than ORM mix, but the average porosity of ODOT specimens was 43.2% and the average porosity of ORM specimens was 38.5%. The summary of clogging test and maintenance are in the Figure 4-24 and Table 4-43, Table 4-44 and Table 4-45. The summary of average total suspended solids removal by ODOT mix and ORM mix is in the Table 4-46.

Table 4-43. Sand Clogging Summary of ODOT and ORM Mixes

ORM Average Sand Clogging			ODOT Average Sand Clogging	
Tests	***k*@20°C (cm/s)**	**Permeability Reduction (%)**	k @20°C (cm/s)	Permeability Reduction (%)
0	4.3	0.0	4.2	0.0
1	4.0	6.8	3.6	13.9
2	3.6	16.6	2.9	30.4
3	3.3	22.9	2.8	32.4
4	2.9	31.4	2.6	37.6
5	2.8	35.5	2.3	45.4
6	2.5	42.5	2.1	49.5
7	2.2	49.5	1.9	55.6
8	1.9	55.2	1.6	62.8
9	1.8	58.4	1.3	68.0
10	1.6	63.2	1.3	68.9
11	1.1	74.1	0.7	83.0
12	1.1	74.7	0.8	81.6
13	0.9	78.9	0.6	85.6
14	0.8	82.3	0.7	83.9
15	0.7	83.7	0.7	84.5
16	0.3	93.0	0.8	82.0

Table 4-44. ORM Average Maintenance Summary (Specimen 1, 2 & 3)

Maintenance Summary ORM Specimens	
Amount of sand introduced	640
Total Maintenance =	197.4 g
TSS passed the specimen =	343.4 g
TSS retained in specimen =	99.2 g
Permeability recovery =	62.3 %
Permeability recovery =	2.7 cm/s
Initial permeability =	4.3 cm/s
Porosity =	38.5 %

Table 4-45. ODOT Average Maintenance Summary (Specimen 1, 2 & 3)

Maintenance Summary ODOT Specimens	
Amount of sand introduced	640 g
Total Maintenance =	98.1 g
TSS passed the specimen =	269.7 g
TSS retained in specimen =	275.7 g
Permeability Recovery =	
Initial permeability =	4.2 cm/s
Porosity =	43.2 %

Table 4-46. Average Total Suspended Solids (Sand) Removal by ODOT and ORM Mixes (Specimen 1, 2 & 3)

Average removal of TSS by ODOT and ORM Specimens	
Amount of sand introduced	640g
Average removal by ODOT mix =	373.8 g
Average percent removal by ODOT mix =	58.4%
Average removal by ORM mix =	296.6 g
Average percent removal by ORM mix =	46.3%

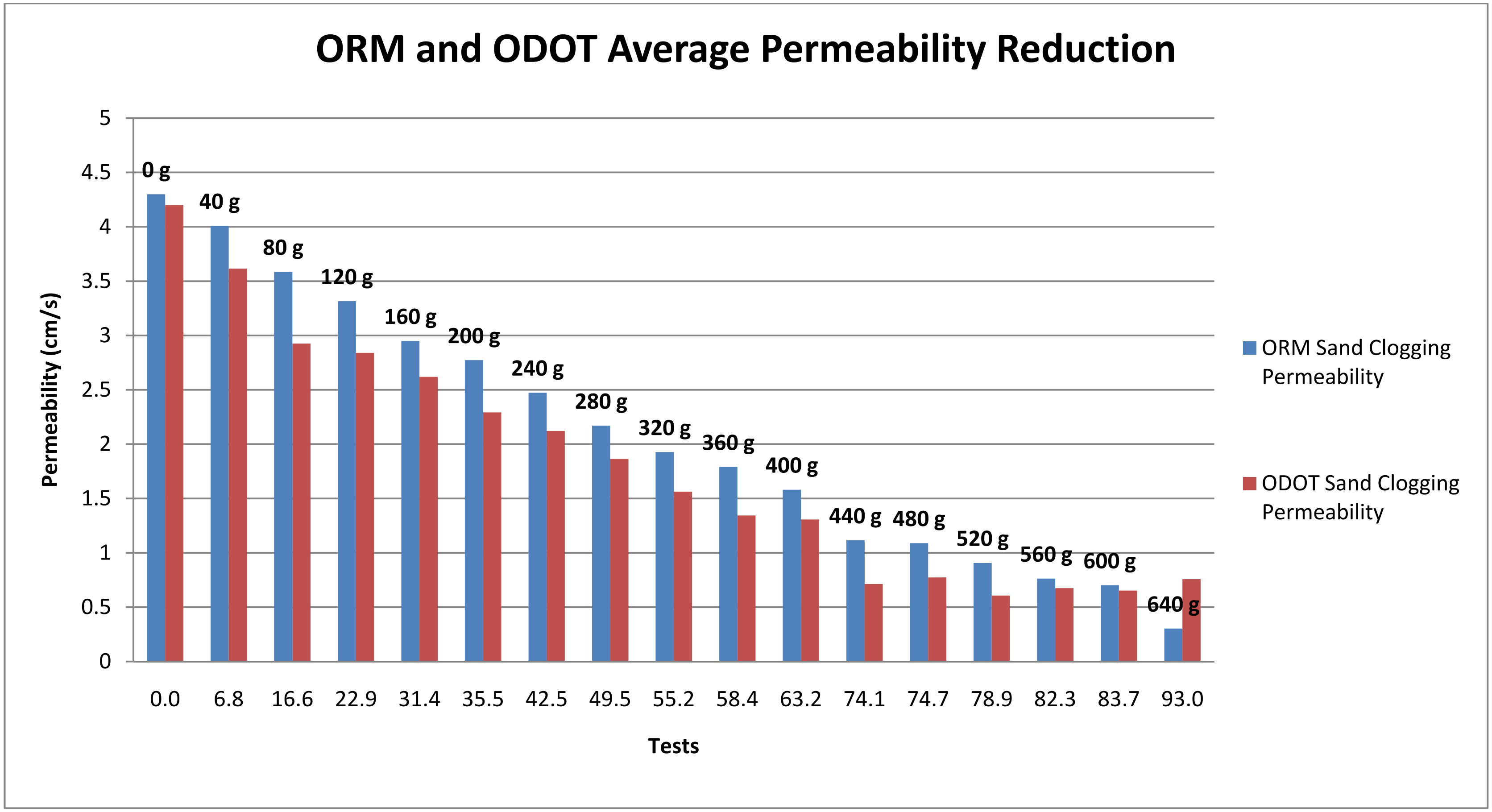

Figure 4-24. ODOT and ORM sand clogging permeability

4.7. Sand and Greensand

There are distinct differences between the greensand and ordinary sand. Greensand is mainly used for treatment of iron, manganese and hydrogen sulfide in water. Particle size of greensand are uniform than the ordinary sand. Some of the differences are as follows:

4.7.1. Permeability

Greensand particle size is uniform (0.35 – 0.3 mm); this uniformity increases the permeability of the greensand than ordinary sand. The average permeability of three specimens of sand was 0.064 cm/s and average permeability of three specimens of greensand was 0.12 cm/s by using tapwater. Three greensand and three sand specimens exposed to 18 A6 soil clogging tests (each specimen exposed to three A6 clogging tests); in every test 15 g of A6 soil were introduced in 5 liters of tapwater. After three tests and cumulative introduction of 45 g of A6 soil in the influent of a constant head permeameters the greensand permeability was reduced by 53% in average for all three specimens and the ordinary sand permeability was reduced by 11.6% in average for all three specimens. See Table 4-47, Table4-48 and Figure 4-25.

Table 4-47**.** Greensand A6 Soil Clogging

Green Sand Permeability (cm/s) average of three specimens			
Tapwater	**Clogging - 1**	**Clogging - 2**	**Clogging - 3**
0.12134504	**0.09129168**	**0.067154514**	**0.06457819**

Table 4-48**.** Sand A6 Soil Clogging

Sand Permeability (cm/s) average of three specimens			
Tapwater	Clogging - 1	Clogging - 2	Clogging - 3
0.0641365	0.031443765	0.01681657	0.00748147

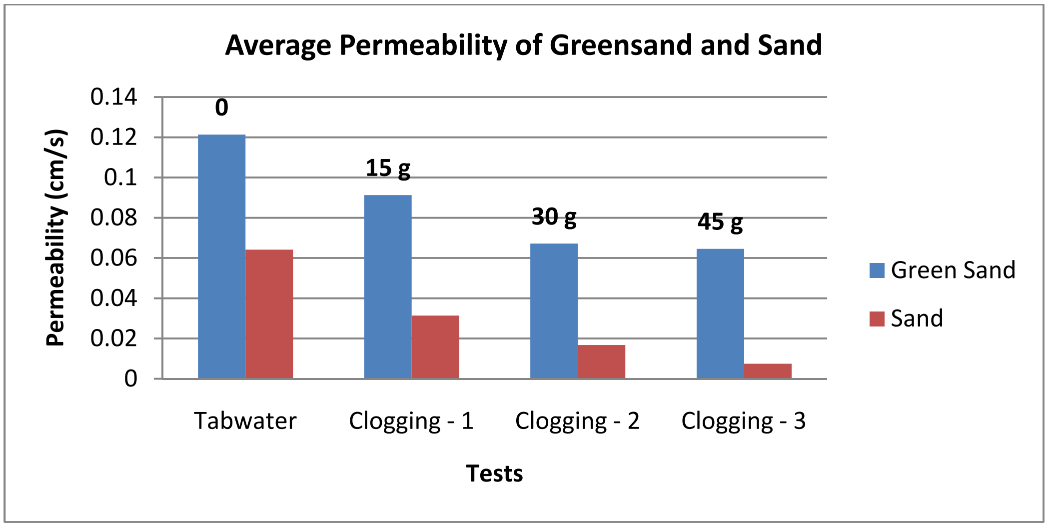

Figure 4-25. Greensand and sand A6 soil clogging permeability comparison

4.7.2. Total Suspended Solids

The total suspended solids recovery in the effluent from the greensand A6 soil clogging test was less than the ordinary sand for all specimens. Greensand was clean from dirt and particles compare to ordinary sand when exposed to the tests. Uniformity in particle size of greensand creates gaps among the particles and A6 soil particles were retained inside of the gaps. Refer to Figure 4-26 and Table 4-49 and Table 4-50. The summary of average total suspended solids removal by the ordinary sand and greensand are in the Table 4-51. Since pervious concrete did not clog in the A6 soil tests, and more than 90% of the suspended solids were in effluent in this case the controlling media for removing the particles smaller than 75 μm (A6 soil were sieved before using in A6 soil test, the opening of the sieve was 75μm) is the filter media, but if the particles are bigger than 75 μm pervious concrete also removes some parts. Refer to Table 4-52.

Table 4-49. Greensand A6 Soil Clogging TSS

Greensand Average TSS (A6 soil) in the Effluent (mg/L)		
Average TSS After Clogging- 1	Average TSS After Clogging- 2	Average TSS After Clogging- 3
52.30	13.34	4.14

Table 4-50. Sand A6 Soil Clogging TSS

Sand Average TSS (A6 soil) in the Effluent (mg/L)		
TSS After Clogging- 1	TSS After Clogging- 2	TSS After Clogging- 3
458.80	297.20	249.90

Table 4-51. Average Total Suspended Solids (A6 Soil) Removal by Sand and Greensand

Average removal of TSS (A6 soil)by ordinary sand and greensand	
Amount of sand introduced	45g
Average removal by ordinary sand =	30g
Average percent removal by ordinary sand =	66.7%
Average removal by greensand =	43.9g
Average percent removal by greensand =	97.8%

Table 4-52. Average TSS (A6 Soil) Removal by Pervious Concrete and Sand

Average removal of the TSS (A6 soil) by the system	
Average percent removal by ODOT mix and ordinary sand =	66.7% if particle size < 75 μm
Average percent removal by ODOT mix and ordinary sand =	Above 80% if particle size > 75μm
Average percent removal by ORM mix and greensand =	97.8% particle size < 75 μm

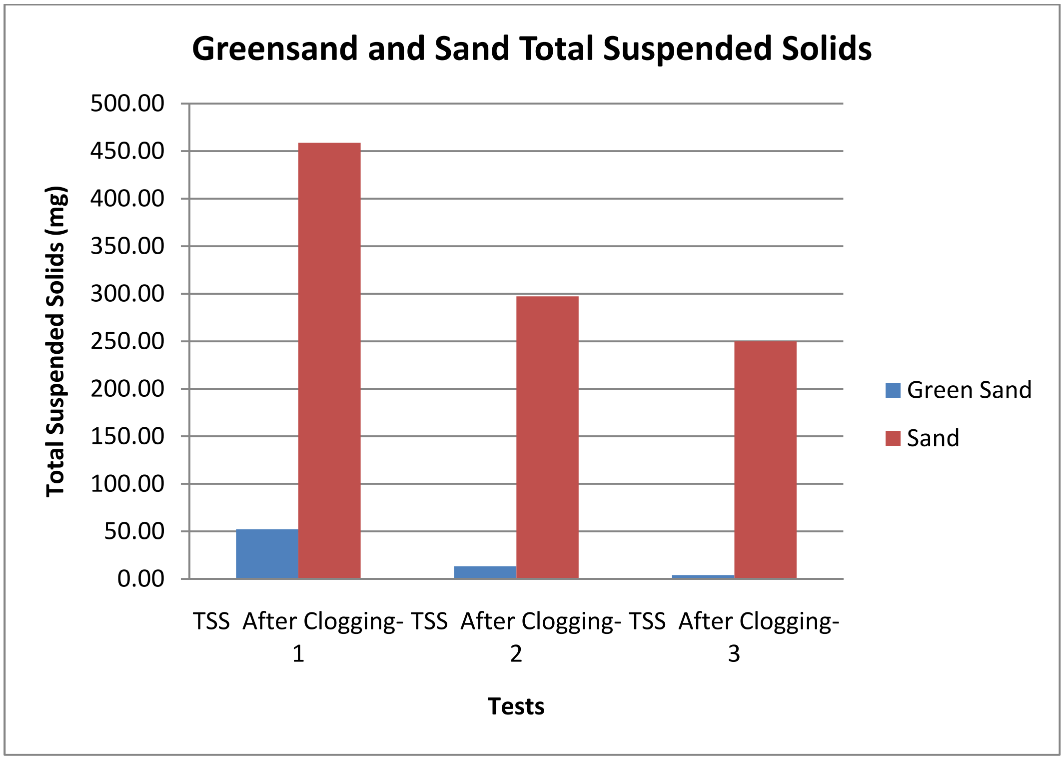

Figure 4-26. Greensand and sand A6 soil clogging suspended solids recovered in effluent

4.8. Analysis of the Media Using the Continuity Equation

4.8.1. Continuity Equation

The head loss in each layer is calculated according to total head loss (total head loss can be found by the piezometer pipes which will be installed in trenches in the field). Only pressure head would exist since there will not be considerable velocity and elevation in the field. Since backfill gravel has almost the same permeability as pervious concrete in this calculation, both layers are assumed as one layer. The head loss in each layer and equivalent permeability are calculated as below:

Continuity Equation

Total head loss in the trench

$$hc = \frac{\Delta H}{1+\frac{kc}{ks}\left(\frac{Ls}{Lc}\right)}$$ ……………Equation 4-1

$$hs = \frac{\Delta H}{1+\frac{ks}{kc}\left(\frac{Lc}{Ls}\right)}$$ ……………Equation 4-2

Where:

ΔH = Total head loss

hc = Head loss in pervious concrete

hs = Head loss in greensand

kc = Pervious concrete permeability

ks = Greensand permeability

Ls = Depth of the greensand

Lc = Depth of concrete and type 3 gravel

In this study we found:

kc = 4.4 cm/s

ks = 0.12 cm/s

Ls = 6 inches = 15.24 cm

Lc = 12 inches = 30.48 cm

$$hc = \frac{\Delta H}{1+\frac{kc}{ks}\left(\frac{Ls}{Lc}\right)} = \frac{\Delta H}{1+\frac{4.4}{0.12}\left(\frac{15.24}{30.48}\right)} = 0.05\Delta H$$

$$\text{hs} = \frac{\Delta H}{1+\frac{ks}{kc}\left(\frac{Lc}{Ls}\right)} = \frac{\Delta H}{1+\frac{0.12}{4.4}\left(\frac{30.48}{15.24}\right)} = 0.95\Delta H$$

As indicated in the above solution 95% of the head loss is occurring in the greensand. In order to prove the above equation one can check that the flowrate is equal for both layers.

$\text{qc} = kc\left(\frac{hc}{Lc}\right)A = 4.4\left(\frac{0.05\,\Delta H}{30.48}\right)A = 0.0072\,\Delta H\,A$ ....*OK* (flowrate in concrete and gravel)

$\text{qs} = ks\left(\frac{hs}{Ls}\right)A = 0.12\left(\frac{0.95\Delta H}{15.24}\right)A = 0.0072\Delta H$ ....*OK* (flowrate in greensand)

4.8.2. Equivalent Permeability of Combined Media

One can calculate the overall permeability of the three media. The equivalent permeability of the combined media is an important indicator of overall permeability in the field.

The permeability of combined media can be calculated by the following equation:

$$kv = \frac{dc+ds}{\frac{dc}{kc}+\frac{ds}{ks}}$$ …….Equation 4-3

Where:

kv = Equivalent permeability of pervious concrete and greensand

dc = Depth of pervious concrete and type 3 gravel

ds = Depth of greensand

kc = Permeability of pervious concrete

ks = Permeability of greensand

dc = 12 inches = 30.48 cm

ds = 6 inches = 15.24 cm

kc = 4.2 cm/s

ks = 0.12 cm/s

$$kv = \frac{30.48+15.24}{\frac{30.48}{4.4}+\frac{15.24}{0.12}} = 0.341 \text{ cm/s}$$

The overall permeability of the system (pervious concrete, type 3 gravel and greensand) is 0.341 cm/s.

4.9. Comparison of Pervious Concrete Permeability in Transient and Laminar Flow Regimes

It has been mentioned in the methodology Chapter 3 that the flow regime in permeameter is transient and it is also mentioned that the flow regime in the field will be laminar due the negligible amount of elevation and velocity heads in the field. The average permeability of all concrete specimens was calculated by using the Darcy's law which is only valid for laminar flow.

In this section permeability of specimen – X is calculated for both flow regimes and the difference is reported as follows:

For the Re > 150 – 300 the flow regime become turbulent and the relation between velocity of flow and hydraulic gradient is not linear anymore (Bear, 1979).

Since in transient and turbulent flow the relationship between the flow velocity and hydraulic gradient is not linear they have polynomial relationship according to Bear (1979):

$i = Av + Bv^m + C$ Equation 4-4

Where:

$1.6 \leq m \leq 2$ (Bear, 1979)

v = Velocity of flow

i = Hydraulic gradient

A, B and C = Experimental constants

The specimen – X of pervious concrete was tested for 5 different elevations of water above the specimen in the falling head permeameter. In each elevation the velocity and hydraulic gradient were recorded. The data is reported in Table 4-53 and graphed in Figure 4-27. From the Figure 4-27 the relationship between hydraulic gradient and flow velocity is:

$i = -0.0398v^2+2.25v-27.759$……Equation 4-5

From the above equation the values of experimental constant are:

A = - 0.0398

B = 2.25

C = - 27.759

Now the permeability for the transient flow is:

$k = v/i$ …. Equation 4-6

Using the above equation for hydraulic gradient we have:

$k= v/(-0.0398v^2+2.25v-27.759)$

The average initial permeability of specimen – X was 5.7 cm/s by passing 10 liters of tapwater through the specimen this 10 liters of tap water exactly creates 33 inches of elevation above the specimen in 4 inches diameter permeameter which is equal to the first elevation of the water in Table 4-53. In this elevation the flow velocity is 25 cm/s. If we plug this value in the permeability equation we have:

$k= v/ (-0.0398v^2+2.25v-27.759) = 6.9$ cm/s

The temperature for the first elevation was 25.5 C°

If we calculate the k for the 20C° we have

k = 6.9 cm/s *0.8794 = 6.1 cm/s

If we compare the two permeabilities for both regimes we have:

Difference % = [1-(5.7/6.1)]*100 = 6 %

The permeability difference by using the Darcy law and turbulent flow equation is only 6%. If we concentrate on R^2 value is equal to 0.94 which means only 6% chance of inaccuracy. If take this into account there is negligible difference between the permeabilities using Darcy and turbulent equations. It is concluded that it is accurate to use Darcy's equation for transient flow to find the permeability in this study.

Table 4-53. Velocity and Hydraulic Gradient for Different Elevation of Water in Falling Head Permeameter

Water level above the specimen	**33**	**in**	**83.82**	**cm**
h_1	39.0	in	99.1	cm
h_2	17.0	in	43.2	cm
Δh	22.0	in	55.9	cm
Time	0.6	sec	0.6	sec
L	6.0	in	15.2	cm
v_1	9.8	in/s	25.0	cm/s
i_1	3.7	cm/s	3.7	cm/s
Temperature	25.5	C°	25.5	C°
Water level above the specimen	**29.0**	**in**	**73.7**	**cm**
h_1	35.0	in	88.9	cm
h_2	17.0	in	43.2	cm
Δh	18.0	in	45.7	cm
Time	0.7	sec	0.7	sec
L	6.0	in	15.2	cm
v_2	9.2	in/s	23.4	cm/s
i_2	3.0	cm/s	3.0	cm/s
Temperature	25.4	C°	25.4	C°
Water level above the specimen	**25.0**	**in**	**63.5**	**cm**
h_1	31.0	in	78.7	cm
h_2	17.0	in	43.2	cm
Δh	14.0	in	35.6	cm
Time	0.7	sec	0.7	sec
L	6.0	in	15.2	cm
v_3	8.5	in/s	21.5	cm/s
i_3	2.3	cm/s	2.3	cm/s
Temperature	24.7	C°	24.7	C°
Water level above the specimen	**21.0**	**in**	**53.3**	**cm**
h_1	27.0	in	68.6	cm
h_2	17.0	in	43.2	cm
Δh	10.0	in	25.4	cm
Time	0.8	sec	0.8	sec
L	6.0	in	15.2	cm
v_4	7.9	in/s	20.1	cm/s
i_4	1.7	cm/s	1.7	cm/s
Temperature	23.7	C°	23.7	C°
Water level above the specimen	**17.0**	**in**	**43.2**	**cm**
h_1	23.0	in	58.4	cm
h_2	17.0	in	43.2	cm
Δh	6.0	in	15.2	cm
Time	0.8	sec	0.8	sec
L	6.0	in	15.2	cm
v_5	7.9	in/s	20.1	cm/s
i_5	1.0	cm/s	1.0	cm/s
Temperature	22.0	C°	22.0	C°

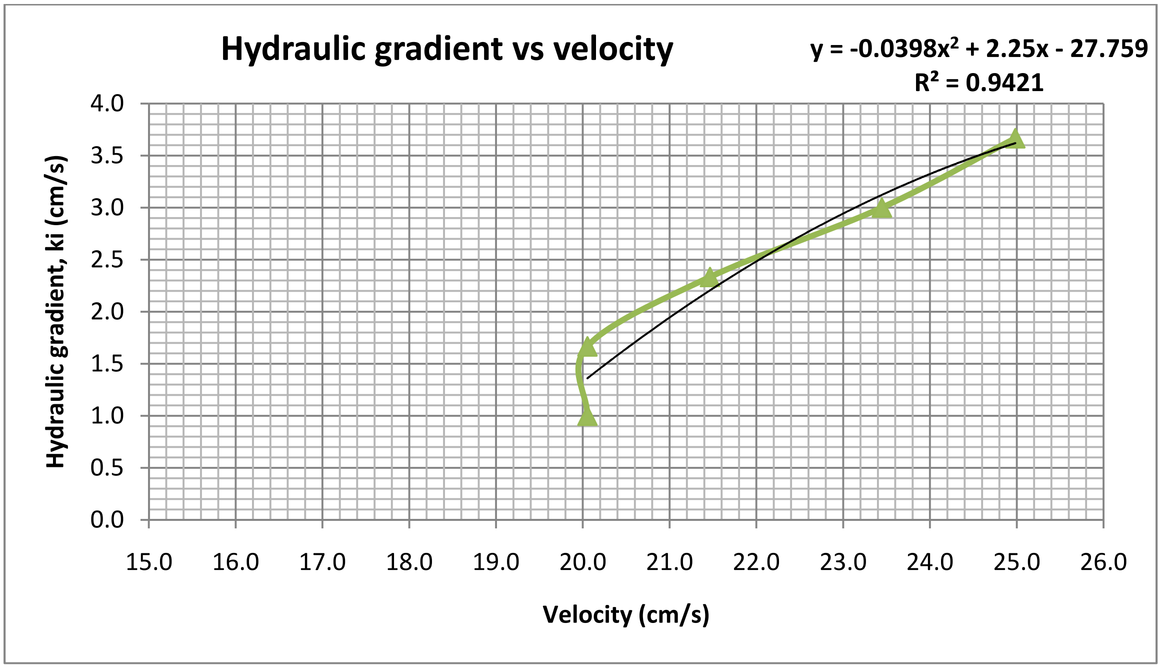

Figure 4-27. Hydraulic gradient and flow velocity for different elevation of water in falling head permeameter

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

In this study laboratory tests were conducted on pervious concrete, aggregate and greensand. These three media represented the three layers of the exfiltration trench respectively. Ten cylindrical specimens, each 4 inches in diameter and 6 inches in height, of pervious concrete were prepared for permeability, porosity, clogging and artificial runoff tests. Three cylindrical specimens 4 inches in diameter and 8 inches in height of pervious concrete were prepared for compressive strength. Three rectangular prism specimens 3x4x16 inches in dimensions of pervious concrete were prepared for freeze and thaw tests. The pervious concrete mixture was prepared according to the ACI 522R – 08 (ACI, 2008). For the concrete mix only gravel # 67, Portland cement and tap water were used. Fine aggregate was avoided due to the reduction in permeability.

The average permeability of the ten cylindrical molds of pervious concrete specimens at 20C° was 4.6 cm/s by using tapwater however the flow regime was transient due to elevation head and velocity head in falling head permeameter, but it is assumed that the flow regime would be laminar in the field since the elevation and velocity heads will be negligible. The permeability for both transient and laminar flow was determined there was only negligible difference. The average total suspended solids in the effluent during these tests were 99.1 mg/L. The average amount of total suspended solids per cubic centimeter of the concrete mix was 8.1×10^{-4} gr/cm^3.

All the values for permeability and total suspended solids vary according to the porosity of each specimen. Porosity is dominant factor in the analysis of the permeability and total suspended solids analysis of the pervious concrete mix. High porous specimens had high permeability due to the lager voids and these large voids could not be clogged as easily as it does for medium and small voids. The average porosity for this concrete mix was 37.5%.

Three ORM pervious concrete specimens were tested for sand clogging. In the sand clogging test of the pervious concrete specimens, 10 to 15 clogging tests were performed. In each test 40 g of sand per 10 L of tapwater were used in the influent of the permeameter. After the permeability test the effluent was analyzed for suspended solids. After the TSS analysis, maintenance was performed on the specimens and post maintenance permeability was determined.

After ten tests on specimen one by using 400 g of sand in 100 L of tapwater, the permeability was reduced by 55%. Fifteen tests were conducted on the second specimen; by using 600 g of sand in 150 L of tapwater the permeability was reduced by 75%. On specimen three 16 tests were conducted by using 640 g of sand in 160 L of tapwater the permeability was reduced by 92%. The permeability reduced by 62.9% in average for all three specimens at 400 g of sand.

Maintenance of the specimens was performed by using surface brushing, vacuuming and pressure washing. In the maintenance surface brushing and vacuuming were more effective than pressure washing. The problem with pressure washing is, it will force the particles further into the second and third layers and cause more clogging especially in the field. The permeability recovery after the maintenance was 58%, 69% and 59% respectively for all three specimens in comparison to their initial permeability. Average percent removal for all three specimens was; 1) surface brushing 5%; 2) vacuuming 9.8%; 3) pressure washing 2.7%.

In the A6 soil tests of pervious concrete mix, 10 – 16 tests were performed per specimen. In each test 40 – 80 g of A6 soil were introduced in 10 L of tapwater. The permeability of the concrete specimens did not reduce significantly as it did for the sand test. Great amounts of the introduced A6 soil were recovered in the effluent. The permeability recovery after the maintenance for all three specimens was above 90% although little soil had been retained inside of the specimens. The average mass of A6 soil in the effluent of the three specimens was 6.82 g/L. In the maintenance of specimens that received A6 soil pressure washing was more effective than surface brushing and vacuuming. However, pressure washing in the field will not be a good option since it forces the suspended particles to lower layers and could cause the clogging in the aggregate or filter layers.

The average tap water permeability of the filter media greensand was 0.12 cm/s. Three tests were conducted on each of the three specimens of greensand with A6 soil. Fifteen grams of A6 soil per 5 L of tapwater were used for each test. After three tests with a total of 45 g of A6 soil in 15 L of tapwater, the permeability dropped by 53% in average for all three specimens. The difference between introduced soil and suspended solids recovered in effluent was 99%.

Artificial runoff tests with three different concentrations high, medium and low were conducted on three pervious concrete specimens and greensand specimens simultaneously. In these tests permeability of the pervious concrete and greensand were analyzed and removal of total suspended solids including particle size analysis, total metals and dissolved metals were determined.

For the high concentration artificial runoff permeability of the pervious concrete was only reduced by 18 % of the initial permeability. With an average influent TSS concentration of 737 mg/L pervious concrete removed 20.2% of the suspended solids. Maintenance of the concrete specimens was not effective in recovery of the permeability. The permeability stayed at 18% reduction. Since the concentration of particles was high in the influent to the constant head permeameter containing greensand permeability was reduced by 74.1% by the second test. The influent average TSS was 588.1 mg/L The greensand removed 95.4% of the suspended solids.

Particle size analysis was conducted only on the influent and effluent of falling head permeability. The size of the particles in the influent and effluent of falling head permeability was the same. The size of the 90% of the particles was 8.0 µm and size of the 10% of the particles was 0.8 µm.

Statistical analysis was done on the results of total and dissolved metals of the high concentration of artificial. Total cadmium and copper reduced by 8% in the pervious concrete the other total metals reduction were less that 3%. Dissolved iron reduced by 12% and dissolved nickel reduced by 25% in pervious concrete. Total metals were reduced to a great percentage in filter media. The reduction range was 85 – 97%. Some of dissolved metals did not reduce even there are some increase in dissolved iron and dissolved zinc. It is concluded that filter media (greensand) is a good agent in filtering the total metal rather than dissolved metals.

For the medium concentration, permeability of pervious concrete was not reduced. Total suspended solids difference between the influent falling head and effluent falling head were 10.2% from an average influent TSS concentration of 209 mg/L 10.2% of the suspended solids were caught in concrete specimen. In constant head test the greensand permeability was reduced by 79.4% after the ninth test. From an average influent TSS concentration of 187.7 mg/L greensand removed 88.7% of the suspended solids. Particle size analysis could not be conducted due to the low concentration in samples.

For medium concentration influent total metals did not reduce in pervious concrete. Only dissolved iron and dissolved nickel reduced by 46.8% and 2.5% respectively by pervious concrete. Total metals were reduced in filter media. The reduction range was 52 – 87%. Some of dissolved metal did not reduce even there are some increases in dissolved iron. The efficiency of pervious concrete and filter media decreased with reduction in concentration of influent.

For the low concentration, falling head permeability of the pervious concrete did not reduce at all. Pervious concrete removed 18% of the suspended solids from an influent with an average of 9 mg/L. In constant head test the greensand permeability was not reduced at all. Greensand removed 82.4% of the suspended solids. Particle size analysis was not conducted due to low concentration of particles in the sample.

Total nickel, total lead and total zinc reduced by 26.3%, 27.4% and 16% respectively by the pervious concrete. Only dissolved iron was reduced by 10% in pervious concrete. Total metals were reduced in filter media. The reduction range was 12 – 92% for total iron in filter media. Some of dissolved metal reduced in filter media and there are some anomalies in dissolved iron and dissolved zinc. The efficiency of pervious concrete and filter media decreased by reduction in concentration of influent from high concentration to medium and from medium to low concentration. The detailed analyses of total metal and dissolved metal are in chapter 4.

Compressive strength of the pervious concrete was determined. The peak loads each specimen with diameter of 4 inches and height of 8 inches, resisted was between 2600 to 3000 lbs which was 210 to 240 psi. This value is lower than the recommended value of 500 psi for the pervious concrete.

Pervious concrete specimens were tested for rapid freeze and thaw strength. After 22 rapid freeze and thaw cycle the pervious concrete specimens lost 18.5 to 20.3% of their mass. The rapid freeze and thaw test creates a very harsh condition for the concrete for example the temperature variation is very rapid and the specimen in the freeze and thaw machine is fully saturated both conditions rarely happen in the natural environment.

Type 3 gravel simulates the second layer in the exfiltration trench. Type 3 gravel was tested for the permeability and suspended solids. The tests were performed on washed and unwashed samples of type 3 gravel. The average permeability of three samples of the unwashed type 3 gravel was 4.4 cm/s and total suspended solids was 5568.1 mg in 30 liters of cumulative tapwater effluent. The average permeability of three washed type 3 gravel samples was 4.18 cm/s and total suspended solids was 1442.3 mg in 30 liters of cumulative effluent. The average permeability difference between washed and unwashed samples was 5%.and the average total suspended solids was 4 times higher in effluent of unwashed samples compared to washed samples.

In the comparison of ODOT and ORM specimens showed that ORM specimens had higher average permeability than the ODOT specimen, the average permeability of ORM specimen were 4.6 cm/s and average permeability of ODOT specimens were 3.7 cm/s. The TSS in the effluent of tapwater permeability was higher in ODOT compared to ORM. The average TSS for the ORM was 99 mg/L and the average TSS for the ODOT specimens was 288 mg/L. ODOT and ORM specimens had the almost the porosity 42% and 37.5% respectively. In the sand clogging tests the ODOT specimens clogged more quickly than the ORM specimens and permeability reduction in the ODOT specimens was higher than the ORM specimens. In A6 soil test ORM and ODOT specimens did not clog and the TSS in effluent for both was similar.

Greensand had higher average permeability than the ordinary sand. The average permeability of the greensand was 012 cm/s and the average permeability of the ordinary sand was 0.064 cm/s. In the A6 soil clogging test the greensand clogged more quickly than the ordinary sand due to the uniformity in the size of greensand particles. After the introduction of 45 g of A6 soil in the 15 liters of cumulative influent the permeability of greensand reduced by 53% and permeability of ordinary for the same amount of A6 soil was 11.6%. In the A6 clogging test greensand removed 97.8% of the particles and ordinary sand 66.7% of the particles.

The flowrate in the trench was found by continuity equation. The flowrate depends on the total head loss and surface area of the trench. The total head loss can be obtained from piezometer pipes in the trench. According to the continuity equation 95% of the total head loss occurs in the filter media and only 5% occurs in pervious concrete and type3 gravel. The equivalent permeability of all system which includes pervious concrete, type 3 gravel and filter media was 0.341 cm/s.

5.2. Conclusions

Based on the findings of this thesis the ORM mix has higher average permeability of 4.6 cm/s compared to 3.7 cm/s for ODOT specimens and better performance in removing contaminants than ODOT mix. In the clogging tests ODOT mix was clogged quickly and permeability recovery after the maintenance was less than the permeability recovery in ORM mix, thus this study recommends the ORM mix as first layer of exfiltration trench.

The comparison of greensand and ordinary sand showed that greensand had higher average permeability of 012 cm/s compared to 0.064 cm/s of ordinary sand. In the A6 soil clogging tests the permeability of the greensand dropped by 53% compared to 11.6% for the ordinary sand for the same amount of A6 soil concentration. If the concentration of the influent is higher than 740 mg/L using greensand is not a good option since it will be clogged quickly also ordinary sand is more cost effective than greensand.

It is recommended that the backfill gravel for the second layer of the exfiltration trench be washed since washed aggregate has less suspended solids.

5.3. Recommendations

Comprehensive field study is needed to verify the findings of this study. The materials in the field must meet the standard specification, which has been used in this study. Porosity is dominant factor in permeability and clogging of pervious concrete. High porous concrete mix has high permeability and can be maintained easily in case of clogging compared to medium and low porous pervious concrete. Further study is needed to determine the relationship of porosity and permeability in pervious concrete.

Maintenance of clogged porous concrete specimens varied according to porosity, for high porous concrete specimen surface brushing and vacuuming were effective, but for low porous concrete specimen pressure washing showed effective results, however based on the findings of this study, pressure washing is not a good method of maintenance in the field. Pressure washing force the particles to the next layers and cause more clogging in the lower layers. More studies are needed to find how to make vacuuming and surface brushing more dominant than pressure washing in the maintenance process.

In order to have better understanding of the relationship between clogging tests and porosity, at least three concrete mixes with small, medium and large aggregate sizes are to be made.

According to the results of artificial run off tests, greensand cleaning efficiency was 80 to 98% depends on the concentration of the particles, however greensand clogged easily and quickly with higher concentration. Before using the greensand in the field the runoff influent to the exfiltration trench should be monitored and tested. If the particles' concentration between two events is higher than 737 mg/L, than greensand should not be used. Once the filter media (greensand) is clogged there is no way of maintaining it back except removing the layer and washing it which is not possible in the field. This study recommends the usage of greensand for the low concentration flows.

In the pervious concrete mix design, washed aggregate suppose to be used, since washed aggregate reduced the amount of the suspend solids and helps stronger bonding of the aggregates in concrete mix.

Type 3 aggregate in the second layer of the exfiltration trench should be washed before using it. This study shows that suspended solids difference between unwashed and washed type 3 aggregate sample was great this huge difference could be a clogging source for the underlying layers.

REFERENCES

ACI (2008). Specification for Pervious Concrete Pavements. ACI 522R-08.

ASTM (1997). Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing. ASTM Designation: C 666-97.

ASTM (2006). Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. ASTM Designation: C 192/ C 192M-06.

ASTM (2007a). Standard Test Method for Particle-Size Analysis of Soils. ASTM Designation: D422-07.

ASTM (2007b). Standard Test Methods for Determining Sediment Concentration in Water Samples. ASTM Designation: D3977 – 07.

ASTM (2009a) Standard Specification for Portland Cement. ASTM Designation: C150 / C150M – 09.

ASTM (2009b) Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate. ASTM Designation: C29 / C29M – 09.

ASTM (2009c). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM Designation: C39/C39M-09.

ASTM (2010). Standard Practice for Capping Cylindrical Concrete Specimens. ASTM Designation: C617.

Barret, M., Irish, L., Malina, J., & Charbeneau, R. (1998). Characterization of highway runoff in Austin, Texas area. *Journal of Environmental Engineering*, 131-137.

Bear, J. (1979). Hydraulics of Groundwater. Haifa, Israel: McGraw-Hill.

Corbett, R.G., & Manner, B.M. (1975). Water Quality and Potential Environmental impacts of highway runoff in Ohio. Final Report, *Department of Geology*, University of Akron.

Dannecker, W., Au, M., & Stechmann. (1990). Substance load in rainwater from different streets in Hamburg. The science of total environment, 93, 385-392.

Deletic, A., & Orr, D. (2005). Pollution Buildup on Road Surfaces. *Journal of Environmental Engineering , 131* (1), 49 - 59.

Deletic, A.B., & Maksimovic, C. T. (1998). Evaluation of Water Quality Factors in Storm Runoff from Paved Areas. *Journal of Environmental Engineering* , *124*(9), 869 - 879.

Dennison, M. (1996). *Storm Water Discharges Regulatory Compliance and Best Management Practices*. Lewis Publishers of CRC Press Inc. Florida.

Federal Highway Administration. (1985). *Effects of Highway Runoff on receiving waters*, volume 11, Report no. FHWA / RD- 84 / 063.

Forest Service Research (1998). *Runoff quality from parking lots*, note NE-253, U.S. Forest Services.

Geldof,G., Jacobson,P., & Fujita,S. (1994). Urban stormwater in infiltration perspective. *Water science and Technology* , *28*(7), 1955-1974.

Geosyntec Consultants, & Wright Water Engineers Inc. (2008). *Overview of Performance by BMP Category and Common Pollutant Type*. Retrieved September 2010, from International Stormwater Best Management Practices (BMP) Database: www.bmpdatabase.org.

Guo,T. (2004). *Study of Storm Water Treatment with Multi-Chamber Pipe-Final Phase and Laboratory Study of Freezing Pointn Depression on Pavement*. Retrieved http://etd.ohiolink.edu/send-pdf.cgi/Guo%20Ting.pdf?ohiou1176320540.

Hamilton, R.S., & Harrison, R. M. (1991). *Highway Pollution*: *In Studies in Environmental Sciences* (pp. 189,199). Newyork: Elsevier Science Publishers.

Hares, R., & Ward, N. (1999). Comparison of the heavy metal content of motorway storm water following discharge into wet biofiltration and dry detention ponds along the London Orbital (M25) motorway. *The science of the total environment*, 235, 169-178.

Huffman, D. (2005). Understanding Pervious Concrete. The Construction Specifie, 42 - 49.

Kayhanian, M., & Stenstrom, M.K. (2005). *First Flush Phenomenon Characterization*. **C**alifornia Department of Transportation Division of Environmental Analysis, CA.

Kayhanian, M., Singh, A., Suvarkropp, C., Steve, B., & Stestrom, M.K. (2003). Impact of AnnualAverage Daily Traffic on Highway Runoff Pollutant Concentrations. *Journal of Environmental Engineering* , *29*(11) 975-990.

Kevern, J. T., Haselbach, L., & Schaefer, V. R. (2009). hot weather comparative heat balance in pervious concrete and impervious concrete system. *2nd International Conference on Countermeasures toUrban Heat Islands*. Berkeley, CA: E.O. Lawrence Berkeley National Laboratory.

Li, Y., Lau, S. L., Kayhanian, M., & Stenstrom, M. K. (2005). Particle size distribution in highway runoff. *Journal of Environmental Engineering*, *131* (9), 1267-1276.

Li,Y., Buchberger, S. G., & Sansalone, J. J. (1999). Variably saturated flow in stomwater partial exfiltration trench. *Journal Environmental Engineering*, *125*(6), 556 - 565.

Meininger, K.R. (1998). No-Fines Pervious Concrete for Paving. *Concrete International Conference, 10*(8), 20 – 27.

Mitchell, G.F., Riefler, R.G., & Russ, A. (2010). Vegetated Biofilter for Post Construction Storm Water Management for Linear Transportation Projects, ODOT/FHWA State Job Number 134349, 226 pages.

Montes, F., Valavala, S., & Haselbach, L.M. (2005). A New Test Method for Porosity Measurements of Portland Cement Pervious Concrete. *Journal of ASTM International, 2*(1), 13.

ODOT (2008). Construction Material and Specification: Material Details, Aggregates. Section 668.

ODOT (2010). Location and design manual volume two drainage design 2010, Exfiltration Trench. Section 1117.1.

Rader, L. (2003). How to operate and maintain manganese greensand treatment units. Retrieved from: http://www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tb/how_to_manganese_greensand.pdf, visited on 09/13/10.

Sansalone, J.J., & Buchberger, S. B. (1997a). characterization of solid and metal element distribution in urban highway stormwater. *Water science technology*, *36* (8-9), 155-160.

Sansalone, J.J., & Buchberger, S.G. (1995). An infiltration device as best management practice for immobilizing heavy metals in urban highway runoff. *Water science and technology, 32*(1), 119 - 125.

Sansalone, J.J., & Buchberger, S.G. (1996). Characterization of Metals and Solids in Urban Highway Winter Snow and Spring Rainfall-Runoff. *Department of Civil and Environmental Engineering*, The University of Cincinnati, Cincinnati, Ohio.

Sansalone, J.J., & Buchberger, S.G. (1997b). Partitioning and first flush of metals in urban storm water. *Journal of Environmental Engineering, 123*(2), 134 -143.

Sansalone, J.J., Koran, J. M., Smithson, J.A., & Buchberger, S.G. (1998). Physical Characteristics of Urban Roadway Solids Transported During Rain. *Journal of Environmental Engineering, 124* (5), 427 - 440.

Thurston, H.W. (2006). Opportunity Costs of Residential Best Management Practices for Stormwater Runoff Control. *Journal of Water Resources planning and management, 132* (20), 89 - 96.

USEPA, (Ed.). (2004). Stormwater Best Management Practice Design Guide General Consideration. (Vol.1) Cincinnati, Ohio.

USEPA, (Ed.). (2010). Polluted Runoff (Nonpoint Source Pollution). Clean Water Act Section 319.

Wawszkiewicz, M. (2010). Update on ODOT's L&D manual for post-construction control BMP'S [Powerpoint slides]. Retrieved from: www.dot.state.oh.us/Divisions/.../bmp/.../ODOT-Post_Con_CEAO.ppt, visited on 08/10/10.

Wilson, F.R., & Stonehouse, D. L. (1983). Environmental Impact Assessment: Highway Location. *Journal of Transportation Engineering, 109*(6), 759-768.

Yousef, Y. A., Wanielista, M.P., & Haper, N.H. (1986). Design and Effectiveness of Urban Retention Basins, urban runoff quality, impact and quality enhance technology, Urbona, B. and Roesner, L.A., Eds.

APPENDICES

Appendix – 1: Falling Head Permeability Results

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – I)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.8 in	14.73 cm
	6.2 in	15.75 cm
	5.9 in	14.99 cm
Average Length, L:		15.155 cm
Volume:		1228.7 cm^3
Weight $_{PVC+Concrete}$		2398.5 g

Table A1-1**.** Falling Head Permeability Sample-I

Test No	**h_1**	**h_2**	**Head**	**t**	**L**	**h_1/h_2**	**Temperature**	**$K_{@20}$**	**K_T**	**$Mass_{in}$**	**$Mass_{out}$**
	cm	**cm**	**cm**	**s**	**cm**		**C°**	**cm/s**	**cm/s**	**g**	**g**
1	94.6	48.9	45.7	2.23	15.16	1.94	24.4	4.044	4.45	10000	9967.3
2	94.6	48.9	45.7	2.27	15.16	1.94	24.4	3.97	4.41	10000	9743.3
3	94.6	48.9	45.7	2.28	15.16	1.94	24.4	3.96	4.4	10000	9967
4	94.6	48.9	45.7	2.29	15.16	1.94	24.4	3.94	4.4	10000	9978
							Average	**3.98**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – II)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	6.875 in	17.5 cm
	5.75 in	14.6 cm
	5.875 in	14.9 cm
Average Length, L:		15.7 cm
Volume:		1269.9 cm^3
Weight $_{PVC+Concrete}$		2270.8 g

Table A1-2. Falling Head Permeability Sample-II

Test No	h_1	h_2	Head	t	L	h_1/h_2	Temperature	$K_{@20}$	K_T	$Mass_{in}$	$Mass_{out}$
	cm	cm	cm	s	cm		C°	cm/s	cm/s	g	g
1	94.6	48.9	45.7	1.96	15.16	1.94	25	4.7	5.3	10000	9815
2	94.6	48.9	45.7	2.02	15.16	1.94	21.7	4.91	5.1	10000	9929.3
3	94.6	48.9	45.7	2.01	15.16	1.94	18.3	5.4	5.14	10000	9956.4
							Average	**4.99**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample –III)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.875 in	14.9 cm
	6.44 in	16.4 cm
	5.625 in	14.3 cm
Average Length, L:		15.19 cm
Volume:		1269.9 cm^3
Weight $_{PVC+Concrete}$		2296.8 g

Table A1-3. Falling Head Permeability Sample-III

Test No	**h_1 cm**	**h_2 cm**	**Head cm**	**t s**	**L cm**	**h_1/h_2**	**Temperature C°**	**$K_{@20}$ cm/s**	**K_T cm/s**	**$Mass_{in}$ g**	**$Mass_{out}$ g**
1	94.6	48.9	45.7	2.24	15.16	1.94	24.4	4.03	4.5	10000	9815
2	94.6	48.9	45.7	2.22	15.16	1.94	24.4	4.07	4.52	10000	9882.6
3	94.6	48.9	45.7	2.22	15.16	1.94	24.4	5.07	4.52	10000	9860
							Average	**4.1**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – IV)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	6. 56 in	16.7cm
	5.62 in	14.3 cm
	5.7 in	14.44 cm
Average Length, L:		15.13 cm
Volume:		1226.9 cm^3
Weight $_{PVC+Concrete}$		2309.1 g

Table A1-4. Falling Head Permeability Sample-IV

Test No	h_1	h_2	Head	t	L	h_1/h_2	Temperature	$K_{@20}$	K_T	$Mass_{in}$	$Mass_{out}$
	cm	cm	cm	s	cm		C°	cm/s	cm/s	g	g
1	94.6	48.9	45.7	1.99	15.16	1.94	26.1	4.4	5.3	10000	9960.3
2	94.6	48.9	45.7	2.03	15.16	1.94	26.1	4.3	5.1	10000	9940.3
3	94.6	48.9	45.7	1.99	15.16	1.94	26.1	4.4	5.14	10000	9910.3
							Average	**4.33**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – V)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	6.375 in	16.2cm
	6.375 in	16.2cm
	5.7 in	14.44 cm
Average Length, L:		15.6 cm
Volume:		1265.6 cm^3
Weight $_{PVC+Concrete}$		2343 g

Table A1-5. Falling Head Permeability Sample-V

Test No	h_1 cm	h_2 cm	Head cm	t s	L cm	h_1/h_2	Temperature C°	$K_{@20}$ cm/s	K_T cm/s	$Mass_{in}$ g	$Mass_{out}$ g
1	94.6	48.9	45.7	2.3	15.16	1.94	26.1	3.88	4.48	10000	9896
2	94.6	48.9	45.7	2.29	15.16	1.94	26.1	3.9	4.5	10000	9820
3	94.6	48.9	45.7	2.26	15.16	1.94	26.1	3.96	4.6	10000	9827
							Average	**3.92**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – VI)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.7 in	14.4 cm
	5.8 in	14.7 cm
	5.8 in	14.7 cm
Average Length, L:		14.64cm
Volume:		1187.5cm^3
Weight $_{PVC+Concrete}$		2343 g

Table A1-6. Falling Head Permeability Sample-VI

Test No	**h_1**	**h_2**	**Head**	**t**	**L**	**h_1/h_2**	**Temperature**	**$K_{@20}$**	**K_T**	**$Mass_{in}$**	**$Mass_{out}$**
	cm	**cm**	**cm**	**s**	**cm**		**C°**	**cm/s**	**cm/s**	**g**	**g**
1	94.6	48.9	45.7	1.95	15.16	1.94	24.4	4.47	5.3	10000	9869
2	94.6	48.9	45.7	1.94	15.16	1.94	24.4	4.49	5.1	10000	9838.7
3	94.6	48.9	45.7	1.94	15.16	1.94	24.4	4.49	5.14	10000	9827
							Average	**4.48**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample –VII)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.8 in	14.7 cm
	6.1 in	15.5 cm
	5.8 in	14.7 cm
Average Length, L:		14.98 cm
Volume:		1214.9 cm^3
Weight $_{PVC+Concrete}$		2201.6 g

Table A1-7. Falling Head Permeability Sample-VII

Test No	h_1	h_2	Head	t	L	h_1/h_2	Temperature	$K_{@20}$	K_T	$Mass_{in}$	$Mass_{out}$
	cm	cm	cm	s	cm		C°	cm/s	cm/s	g	g
1	94.6	48.9	45.7	2.05	15.16	1.94	23.3	4.5	4.83	10000	9905
2	94.6	48.9	45.7	2.07	15.16	1.94	21.1	4.6	4.78	10000	9864.4
3	94.6	48.9	45.7	2.1	15.16	1.94	18.3	4.9	4.71	10000	9919
							Average	**4.68**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample –VIII)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.8 in	14.7 cm
	5.9 in	14.9 cm
	5.8 in	14.7 cm
Average Length, L:		14.8 cm
Volume:		1201.2 cm^3
Weight $_{\text{PVC+Concrete}}$		2256.6 g

Table A1-8. Falling Head Permeability Sample-VIII

Test No	**h_1 cm**	**h_2 cm**	**Head cm**	**t s**	**L cm**	**h_1/h_2**	**Temperature C°**	**$K_{@20}$ cm/s**	**K_T cm/s**	**$Mass_{in}$ g**	**$Mass_{out}$ g**
1	94.6	48.9	45.7	2.19	15.16	1.94	23.9	4.07	4.47	10000	9894.5
2	94.6	48.9	45.7	2.19	15.16	1.94	26.1	3.87	4.47	10000	9833.4
3	94.6	48.9	45.7	2.18	15.16	1.94	24.4	4.04	4.49	10000	9908.5
							Average	**3.997**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample – IX)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.7 in	14.5 cm
	6.1 in	15.56 cm
	5.8 in	14.7 cm
Average Length, L:		14.9 cm
Volume:		1208.1 cm^3
Weight $_{PVC+Concrete}$		2267.4 g

Table A1-9. Falling Head Permeability Sample-IX

Test No	h_1	h_2	Head	t	L	h_1/h_2	Temperature	$K_{@20}$	K_T	$Mass_{in}$	$Mass_{out}$
	cm	**cm**	**cm**	**s**	**cm**		**C°**	**cm/s**	**cm/s**	**g**	**g**
1	94.6	48.9	45.7	1.95	15.16	1.94	18.9	5.2	5.04	10000	9894.5
2	94.6	48.9	45.7	1.88	15.16	1.94	17.8	5.5	5.23	10000	9833.4
3	94.6	48.9	45.7	1.88	15.16	1.94	15.8	5.8	5.23	10000	9908.5
							Average	**5.51**			

Falling Head Permeability
Material used: Ohio Ready Mix Concrete (Sample –X)

Diameter of Sample, D:		10.16 cm
Area, A:		81.07 cm^2
Length, L:	5.7 in	14.5cm
	5.8 in	14.7 cm
	5.8 in	14.7 cm
Average Length, L:		14.64cm
Volume:		1187.5 cm^3
Weight $_{PVC+Concrete}$		2158.3 g

Table A1-10.Falling Head Permeability Sample-X

Test No	h_1	h_2	Head	t	L	h_1/h_2	Temperature	$K_{@20}$	K_T	$Mass_{in}$	$Mass_{out}$
	cm	cm	cm	s	cm		C°	cm/s	cm/s	g	g
1	94.6	48.9	45.7	1.85	15.16	1.94	17.2	5.6	5.22	10000	9894.5
2	94.6	48.9	45.7	1.85	15.16	1.94	16.7	5.7	5.22	10000	9886.7
3	94.6	48.9	45.7	1.85	15.16	1.94	15.6	5.8	5.22	10000	9943
							Average	**5.71**			

Appendix – 2: Porosity Results

Porosity
Ohio Ready Mix (Sample – I)

Table A2-1. Porosity Sample-I

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm3	C°	g/cm3	%
2321.5	1246	436.6	126.4	1884.9	1119.6	14.732	14.986	15.748	15.2	10.116	1228.1	26.1	0.9968	37.48

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \qquad \text{Equation A2-1}$$

$\rho_{AC} = 1.33$ g/cm^3
$V_{AC} = 328.3$ cm^3
$W_{ACD} = 390.7$ g
$W_{ACS} = 62.4$ g

Ohio Ready Mix (Sample – II)

Table A2-2. Porosity Sample-II

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm3	%
2179	1140.5	436.6	126.4	1742.4	1014.1	14.9225	14.605	17.46	15.7	10.16	1269.2	26.1	0.9968	42.43

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \quad \text{Equation A2-2}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – III)

Table A2-3. Porosity Sample-III

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2296.8	1185.5	436.6	126.4	1860.2	1059.1	14.92	16.35	14.29	15.2	10.16	1230.6	26.1	0.9968	37.48

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \quad \text{Equation A2-3}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – IV)

Table A2-4. Porosity Sample-IV

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2309.1	1143	436.6	126.4	1872.5	1016.6	16.7	14.29	14.45	15.1	10.16	1226.4	15	0.9991	30.14

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \qquad \text{Equation A2-4}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – V)

Table A2-5. Porosity Sample-V

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2343	1183	436.6	126.4	1906.4	1056.6	15.75	14.29	15.75	15.3	10.16	1236.6	15	0.9991	31.22

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \quad \text{Equation A2-5}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – VI)

Table A2-6. Porosity Sample-VI

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2255.8	1168	436.6	126.4	1819.2	1042.6	14.5	14.73	14.73	14.6	10.16	1186.9	24.4	0.998	34.4

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \quad \text{Equation A2-6}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – VII)

Table A2-7. Porosity Sample-VII

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2201.6	1198	436.6	126.4	1765	1071.6	14.73	14.73	15.5	15.0	10.16	1214.3	12.8	0.9994	42.9

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \quad \text{Equation A2-7}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – VIII)

Table A2-8. Porosity Sample-VIII

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2256.6	1231	436.6	126.4	1820	1104.6	14.7	14.7	15	14.8	10.16	1200.6	13.9	0.9993	40.4

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \qquad \text{Equation A2-8}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – IX)

Table A2-9. Porosity Sample-IX

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2267.4	1229	436.6	126.4	1830.8	1102.6	14.478	14.73	15.5	14.9	10.16	1207.5	13.9	0.9993	39.65

$$\textbf{Porosity, P (\%)} = \left[1 - \left(\left(W_D - \frac{W_S}{\rho_W}\right)/V_T\right)\right] * 100 \qquad \text{Equation A2-9}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Ohio Ready Mix (Sample – X)

Table A2-10. Porosity Sample-X

W_{TD}	W_{TS}	W_{ACD}	W_{ACS}	W_D	W_S	H_1	H_2	H_3	H_{ave}	D_{ave}	V_T	W_{Tep}	ρ_W	Porosity
g	g	g	g	g	g	cm	cm	cm	cm	cm	cm^3	C°	g/cm^3	%
2158.3	1164	436.6	126.4	1721.7	1037.6	14.48	14.73	14.73	14.6	10.16	1186.9	15	0.9991	42.3

$$\textbf{Porosity, P (\%)} = \left[\mathbf{1} - \left(\left(\boldsymbol{W_D} - \frac{\boldsymbol{W_S}}{\boldsymbol{\rho_W}}\right)/\boldsymbol{V_T}\right)\right] * \mathbf{100} \quad \text{Equation A2-10}$$

$\rho_{AC} = 1.33\ g/cm^3$
$V_{AC} = 328.3\ cm^3$
$W_{ACD} = 390.7\ g$
$W_{ACS} = 62.4\ g$

Appendix – 3: Total Suspended Solids Results

Total Suspended Solids
Material Used: Ohio Ready Mix Concrete (Sample – I) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.24 cm
Volume of Specimen, V: 1235.56 cm^3
TSS collected: 98.96 mg/L
Cumulative V_{water}: 10.00 L

Table A3-1. Total Suspended Solids Sample-1-1

Filter #	**Mass Filter**	**Mass Filter + Residue**	**Mass Residue**	**Sample Size**	**TSS**
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.27149	1.35632	0.08483	1000	84.83
2	1.27343	1.35672	0.08329	1000	83.29
3	1.28539	1.36869	0.0833	1000	83.30
4	1.26005	1.34566	0.08561	1000	85.61
5	1.26896	1.35224	0.08328	1000	83.28
6	1.23387	1.31316	0.07929	1000	79.29
7	1.2326	1.32338	0.09078	1000	90.78
8	1.25104	1.34732	0.09628	1000	96.28
9	1.25257	1.32721	0.07464	1000	74.64
10	1.2245	1.45279	0.22829	1000	228.29
				Average	98.96

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
98.96	86.54464	6.207182	111.3734

Material Used: Ohio Ready Mix Concrete (Sample – I) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.24 cm
Volume of Specimen, V: 1235.56 cm^3
TSS collected: 37.01 mg/L
Cumulative V_{water}: 20.00 L

Table A3-2. Total Suspended Solids Sample 1-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.22424	1.2307	0.00646	1000	6.46
2	1.24473	1.24888	0.00415	1000	4.15
3	1.21816	1.22372	0.00556	1000	5.56
4	1.21045	1.2171	0.00665	1000	6.65
5	1.21059	1.21726	0.00667	1000	6.67
6	1.23202	1.23933	0.00731	1000	7.31
7	1.25448	1.26108	0.0066	1000	6.60
8	1.24216	1.25505	0.01289	1000	12.89
9	1.24722	1.26058	0.01336	1000	13.36
10	1.23996	1.54041	0.30045	1000	300.45
				Average	37.01

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
37.01	30.63806	3.185971	43.38194

Material Used: Ohio Ready Mix Concrete (Sample – I) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.24 cm
Volume of Specimen, V: 1235.56 cm^3
TSS collected: 2.02 mg/L
Cumulative V_{water}: 30.00 L

Table A3-3. Total Suspended Solids Sample 1-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.22834	1.23133	0.00299	1000	2.99
2	1.25467	1.25555	0.00088	1000	0.88
3	1.25857	1.25969	0.00112	1000	1.12
4	1.24624	1.24669	0.00045	1000	0.45
5	1.23707	1.23723	0.00016	1000	0.16
6	1.27045	1.27074	0.00029	1000	0.29
7	1.28089	1.28151	0.00062	1000	0.62
8	1.24829	1.24865	0.00036	1000	0.36
9	1.24797	1.2484	0.00043	1000	0.43
10	1.23962	1.25252	0.0129	1000	12.90
				Average	2.02

Mean TSS	Minµ-2σ	STDEV	Maxµ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
2.02	0.27947	0.870265	3.76053

The overall TSS collection for Sample – I is 137.9 mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – II) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.66 cm
Volume of Specimen, V: 1269.6cm^3
TSS collected: 113.3 mg/L
Cumulative V_{water}: 10.00 L

Table A3-4. Total Suspended Solids Sample 2-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.28024	1.40525	0.12501	1000	125.01
2	1.25707	1.39096	0.13389	1000	133.89
3	1.23422	1.35094	0.11672	1000	116.72
4	1.23459	1.34944	0.11485	1000	114.85
5	1.24084	1.35225	0.11141	1000	111.41
6	1.28404	1.39131	0.10727	1000	107.27
7	1.23644	1.33682	0.10038	1000	100.38
8	1.2275	1.31482	0.08732	1000	87.32
9	1.23351	1.31982	0.08631	1000	86.31
10	1.21814	1.36798	0.14984	1000	149.84
				Average	113.30

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
113.30	81.38528	15.95736	145.2147

Material Used: Ohio Ready Mix Concrete (Sample – II) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.66 cm
Volume of Specimen, V: 1269.6cm^3
TSS collected: 6.48 mg/L
Cumulative V_{water}: 20.00 L

Table A3-5. Total Suspended Solids Sample 2-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23349	1.23913	0.00564	1000	5.64
2	1.25366	1.27027	0.01661	1000	16.61
3	1.22257	1.22264	7E-05	1000	0.07
4	1.24108	1.24152	0.00044	1000	0.44
5	1.23575	1.2362	0.00045	1000	0.45
6	1.23301	1.23432	0.00131	1000	1.31
7	1.26068	1.26121	0.00053	1000	0.53
8	1.25433	1.25539	0.00106	1000	1.06
9	1.25148	1.25165	0.00017	1000	0.17
10	1.26519	1.3037	0.03851	1000	38.51
				Average	6.48

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
6.48	-4.34954	5.41427	17.30754

Material Used: Ohio Ready Mix Concrete (Sample – II) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.66 cm
Volume of Specimen, V: 1269.6cm^3
TSS collected: 4.88mg/L
Cumulative V_{water}: 30.00 L

Table A3-6. Total Suspended Solids Sample 2-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.26341	1.26374	0.00033	1000	0.33
2	1.23117	1.23206	0.00089	1000	0.89
3	1.28378	1.28481	0.00103	1000	1.03
4	1.23782	1.23982	0.002	1000	2.00
5	1.2879	1.28823	0.00033	1000	0.33
6	1.25901	1.25917	0.00016	1000	0.16
7	1.2446	1.24502	0.00042	1000	0.42
8	1.2767	1.27712	0.00042	1000	0.42
9	1.24567	1.2458	0.00013	1000	0.13
10	1.24126	1.26452	0.02326	540	43.07
				Average	4.88

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
4.88	3.686052	0.596178	6.070763

The overall TSS collection for Sample – II, is 124.66mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – III) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.18 cm
Volume of Specimen, V: 1230.69
TSS collected: 65.28 mg/L
Cumulative V_{water}: 10.00 L

Table A3-7. Total Suspended Solids 3-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.25822	1.3676	0.10938	1400	78.13
2	1.24482	1.34626	0.10144	1400	72.46
3	1.21843	1.28098	0.06255	1400	44.68
4	1.23567	1.3128	0.07713	1400	55.09
5	1.20276	1.28455	0.08179	1400	58.42
6	1.2269	1.30246	0.07556	1400	53.97
7	1.26549	1.34151	0.07602	1400	54.30
8	1.26501	1.33381	0.0688	1400	49.14
9	1.24884	1.32572	0.07688	1400	54.91
10	1.22998	1.49333	0.26335	2000	131.68
				Average	65.28

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
65.28	43.85324	10.71249	86.70319

Material Used: Ohio Ready Mix Concrete (Sample – III) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.18 cm
Volume of Specimen, V: 1230.69
TSS collected: 2.42 mg/L
Cumulative V_{water}: 20.00 L

Table A3-8. Total Suspended Solids Sample 3-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2372	1.239	0.0018	1000	1.80
2	1.2469	1.24713	0.00023	1000	0.23
3	1.24148	1.24151	3E-05	1000	0.03
4	1.27068	1.27091	0.00023	1000	0.23
5	1.22963	1.23005	0.00042	1000	0.42
6	1.22981	1.23013	0.00032	1000	0.32
7	1.25109	1.25138	0.00029	1000	0.29
8	1.26593	1.26617	0.00024	1000	0.24
9	1.24508	1.2456	0.00052	1000	0.52
10	1.24289	1.25805	0.01516	755	20.08
				Average	2.42

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
2.42	1.370002	0.522972	3.461892

Material Used: Ohio Ready Mix Concrete (Sample – III) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.18 cm
Volume of Specimen, V: 1230.69
TSS collected: 1.29 mg/L
Cumulative V_{water}: 30.00 L

Table A3-9. Total Suspended Solids Sample 3-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23527	1.23623	0.00096	1000	0.96
2	1.23947	1.23986	0.00039	1000	0.39
3	1.27228	1.27228	0	1000	0.00
4	1.235	1.23527	0.00027	1000	0.27
5	1.27396	1.27396	0	1000	0.00
6	1.24714	1.24835	0.00121	1000	1.21
7	1.21334	1.21429	0.00095	1000	0.95
8	1.2317	1.23224	0.00054	1000	0.54
9	1.23048	1.23246	0.00198	1000	1.98
10	1.23374	1.23867	0.00493	750	6.57
				Average	1.29

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
1.29	0.00014	0.643739	2.574811

The overall TSS collection for Sample – III, is 124.66mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – IV) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.13 cm
Volume of Specimen, V: 1226.64 cm^3
TSS collected: 97.82 mg/L
Cumulative V_{water}: 10.00 L

Table A3-10. Total Suspended Solids Sample 4-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2666625	1.364768	0.098105	1000	98.11
2	1.26776	1.353548	0.085787	1000	85.79
3	1.2386325	1.322908	0.084275	1000	84.27
4	1.24123	1.329245	0.088015	1000	88.02
5	1.229055	1.31731	0.088255	1000	88.26
6	1.2428775	1.327613	0.084735	1000	84.74
7	1.2497475	1.336803	0.087055	1000	87.05
8	1.2510675	1.33548	0.084413	1000	84.41
9	1.2458325	1.324885	0.079053	1000	79.05
10	1.2251075	1.42361	0.198503	1000	198.50
				Average	97.82

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
97.82	87.60682	5.106341	108.0322

Material Used: Ohio Ready Mix Concrete (Sample – IV) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.13 cm
Volume of Specimen, V: 1226.64 cm^3
TSS collected: 14.02 mg/L
Cumulative V_{water}: 20.00 L

Table A3-11. Total Suspended Solids Sample 4-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2331725	1.238555	0.005382	1000	5.38
2	1.24761	1.254765	0.007155	1000	7.16
3	1.230645	1.233368	0.002722	1000	2.72
4	1.2476525	1.25083	0.003177	1000	3.18
5	1.2267575	1.23058	0.003822	1000	3.82
6	1.230645	1.235128	0.004482	1000	4.48
7	1.2539025	1.258423	0.00452	1000	4.52
8	1.2573475	1.263715	0.006368	1000	6.37
9	1.2464475	1.25313	0.006683	1000	6.68
10	1.247105	1.340108	0.093002	970	95.88
				Average	14.02

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
14.02	10.87018	1.57448	17.1681

Material Used: Ohio Ready Mix Concrete (Sample – IV) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.13 cm
Volume of Specimen, V: 1226.64 cm^3
TSS collected: 1.68 mg/L
Cumulative V_{water}: 30.00 L

Table A3-12. Total Suspended Solids Sample 4-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.245465	1.246918	0.001453	1000	1.45
2	1.2354075	1.23607	0.000663	1000	0.66
3	1.264625	1.265145	0.00052	1000	0.52
4	1.246235	1.24698	0.000745	1000	0.74
5	1.2616925	1.261863	0.00017	1000	0.17
6	1.25177	1.252318	0.000548	1000	0.55
7	1.24979	1.250445	0.000655	1000	0.66
8	1.247	1.247363	0.000363	1000	0.36
9	1.24789	1.248663	0.000773	1000	0.77
10	1.2420625	1.25294	0.010878	1000	10.88
				Average	1.68

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
1.68	0.966386	0.355057	2.386614

The overall TSS collection of Sample – IV, is 113.52mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – V) Test: 1

Diameter of Specimen, D: 10.16 cm

Area of Specimen, A: 81.07 cm^2

Height of Specimen L: 15.61 cm

Volume of Specimen, V: 1265.55 cm^3

TSS collected: 78.55 mg/L

Cumulative V_{water}: 10.00 L

Table A3-13. Total Suspended Solids Sample 5-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.26925	1.330408	0.061158	1000	61.16
2	1.2454425	1.306048	0.060605	1000	60.61
3	1.2405525	1.306513	0.06596	1000	65.96
4	1.2507275	1.325378	0.07465	1000	74.65
5	1.23801	1.30678	0.06877	1000	68.77
6	1.2324875	1.297135	0.064648	1000	64.65
7	1.2540325	1.330978	0.076945	1000	76.94
8	1.25698	1.326878	0.069897	1000	69.90
9	1.2507575	1.32167	0.070912	1000	70.91
10	1.23981	1.41181	0.172	1000	172.00
				Average	78.55

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
78.55	67.29499	5.629754	89.81401

Material Used: Ohio Ready Mix Concrete (Sample – V) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.61 cm
Volume of Specimen, V: 1265.55 cm^3
TSS collected: 9.97 mg/L
Cumulative V_{water}: 20.00 L

Table A3-14. Total Suspended Solids Sample 5-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2264225	1.234423	0.008	1000	8.00
2	1.244145	1.251628	0.007483	1000	7.48
3	1.239255	1.24681	0.007555	1000	7.55
4	1.2441775	1.251573	0.007395	1000	7.39
5	1.236115	1.24336	0.007245	1000	7.24
6	1.23061	1.237685	0.007075	1000	7.07
7	1.2350075	1.24378	0.008773	1000	8.77
8	1.2505575	1.25889	0.008333	1000	8.33
9	1.238185	1.249273	0.011087	1000	11.09
10	1.232245	1.259033	0.026787	1000	26.79
				Average	9.97

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
2.55	1.07373	0.74026	4.03477

Material Used: Ohio Ready Mix Concrete (Sample – V) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 15.61 cm
Volume of Specimen, V: 1265.55 cm^3
TSS collected: 2.55 mg/L
Cumulative V_{water}: 30.00 L

Table A3-15. Total Suspended Solids Sample 5-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23428	1.236193	0.001912	1000	1.91
2	1.24754	1.24894	0.0014	1000	1.40
3	1.252625	1.254155	0.00153	1000	1.53
4	1.2493975	1.253068	0.00367	1000	3.67
5	1.2464925	1.248133	0.00164	1000	1.64
6	1.2516075	1.253633	0.002025	1000	2.02
7	1.2444975	1.24654	0.002042	1000	2.04
8	1.24222	1.245153	0.002933	1000	2.93
9	1.2291675	1.23175	0.002582	1000	2.58
10	1.2449375	1.250745	0.005807	1000	5.81
				Average	2.55

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
2.55	1.07373	0.74026	4.03477

The overall TSS collection of Sample – V, is 91.08mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – VI) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.72 cm^3
TSS collected: 79.73 mg/L
Cumulative V_{water}: 10.00 L

Table A3-16. Total Suspended Solids Sample 6-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2567	1.3299	0.0732	1000	73.20
2	1.29572	1.32025	0.02453	1000	24.53
3	1.21649	1.29102	0.07453	1000	74.53
4	1.23461	1.30908	0.07447	1000	74.47
5	1.20366	1.2802	0.07654	1000	76.54
6	1.2267	1.30352	0.07682	1000	76.82
7	1.26446	1.3455	0.08104	1000	81.04
8	1.26072	1.34597	0.08525	1000	85.25
9	1.24841	1.32679	0.07838	1000	78.38
10	1.22781	1.38034	0.15253	1000	152.53
				Average	79.73

Mean TSS	Minµ-2σ	STDEV	Maxµ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
79.73	43.618	18.0555	115.84

Material Used: Ohio Ready Mix Concrete (Sample – VI) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.72 cm^3
TSS collected: 9.57 mg/L
Cumulative V_{water}: 20.00 L

Table A3-17. Total Suspended Solids Sample 6-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23776	1.24539	0.00763	1000	7.63
2	1.24515	1.25278	0.00763	1000	7.63
3	1.24037	1.2456	0.00523	1000	5.23
4	1.2684	1.27379	0.00539	1000	5.39
5	1.23106	1.23881	0.00775	1000	7.75
6	1.22774	1.23673	0.00899	1000	8.99
7	1.24936	1.26002	0.01066	1000	10.66
8	1.26697	1.27825	0.01128	1000	11.28
9	1.24201	1.25469	0.01268	1000	12.68
10	1.24038	1.25827	0.01789	970	18.44
				Average	9.57

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
9.57	4.445491	2.561419	14.69117

Material Used: Ohio Ready Mix Concrete (Sample – VI) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.72 cm^3
TSS collected: 0.73 mg/L
Cumulative V_{water}: 30.00 L

Table A3-18. Total Suspended Solids Sample 6-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.25484	1.25637	0.00153	1000	1.53
2	1.21632	1.21681	0.00049	1000	0.49
3	1.24387	1.24443	0.00056	1000	0.56
4	1.26588	1.26614	0.00026	1000	0.26
5	1.24784	1.24804	0.0002	1000	0.20
6	1.23048	1.23101	0.00053	1000	0.53
7	1.26033	1.26096	0.00063	1000	0.63
8	1.23131	1.23144	0.00013	1000	0.13
9	1.26744	1.26799	0.00055	1000	0.55
10	1.25363	1.25605	0.00242	1000	2.42
				Average	0.73

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
0.73	-0.0926	0.411302	1.552604

The overall TSS collection of Sample – VI, is 90.03mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – VII) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.99 cm
Volume of Specimen, V: 1215.29cm^3
TSS collected: 87.75 mg/L
Cumulative V_{water}: 10.00 L

Table A3-19. Total Suspended Solids Sample 7-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.2759	1.34779	0.07189	1000	71.89
2	1.2086	1.27719	0.06859	1000	68.59
3	1.2404	1.31157	0.07117	1000	71.17
4	1.2601	1.37075	0.11065	1000	110.65
5	1.2368	1.3218	0.085	1000	85.00
6	1.2201	1.30099	0.08089	1000	80.89
7	1.2674	1.36643	0.09903	1000	99.03
8	1.2771	1.36129	0.08419	1000	84.19
9	1.2637	1.34492	0.08122	1000	81.22
10	1.2616	1.38647	0.12487	1000	124.87
				Average	87.75

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
87.75	60.34537	13.70231	115.1546

Material Used: Ohio Ready Mix Concrete (Sample – VII) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.99 cm
Volume of Specimen, V: 1215.29 cm^3
TSS collected: 12.15 mg/L
Cumulative V_{water}: 20.00 L

Table A3-20. Total Suspended Solids Sample 7-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23613	1.24551	0.00938	1000	9.38
2	1.2434	1.25288	0.00948	1000	9.48
3	1.23817	1.24761	0.00944	1000	9.44
4	1.25729	1.26668	0.00939	1000	9.39
5	1.24407	1.25323	0.00916	1000	9.16
6	1.24391	1.2526	0.00869	1000	8.69
7	1.23007	1.24097	0.0109	1000	10.90
8	1.2602	1.26936	0.00916	1000	9.16
9	1.21602	1.23043	0.01441	1000	14.41
10	1.22304	1.2545	0.03146	1000	31.46
				Average	12.15

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
12.15	8.630902	1.758049	15.6631

Material Used: Ohio Ready Mix Concrete (Sample – VII) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.99 cm
Volume of Specimen, V: 1215.29 cm^3
TSS collected: 4.58 mg/L
Cumulative V_{water}: 30.00 L

Table A3-21. Total Suspended Solids Sample 7-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.26578	1.2702	0.00442	1000	4.42
2	1.25192	1.25582	0.0039	1000	3.90
3	1.24099	1.24484	0.00385	1000	3.85
4	1.24971	1.25432	0.00461	1000	4.61
5	1.23168	1.23562	0.00394	1000	3.94
6	1.2422	1.2462	0.004	1000	4.00
7	1.2471	1.25095	0.00385	1000	3.85
8	1.23251	1.23804	0.00553	1000	5.53
9	1.17703	1.18054	0.00351	1000	3.51
10	1.25478	1.26301	0.00823	1000	8.23
				Average	4.58

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
4.58	3.379822	0.602089	5.788178

The overall TSS collection of Sample – VII, is 104.48 mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – VIII) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.82 cm
Volume of Specimen, V: 1201.5 cm^3
TSS collected: 103.88 mg/L
Cumulative V_{water}: 10.00 L

Table A3-22. Total Suspended Solids Sample 8-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.27078	1.37142	0.10064	1000	100.64
2	1.27382	1.37343	0.09961	1000	99.61
3	1.285	1.37959	0.09459	1000	94.59
4	1.25844	1.35721	0.09877	1000	98.77
5	1.2678	1.36619	0.09839	1000	98.39
6	1.23429	1.32734	0.09305	1000	93.05
7	1.23219	1.33899	0.1068	1000	106.80
8	1.24951	1.35041	0.1009	1000	100.90
9	1.25138	1.34581	0.09443	1000	94.43
10	1.22453	1.37617	0.15164	1000	151.64
				Average	103.88

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
103.88	95.45434	4.213829	112.3097

Material Used: Ohio Ready Mix Concrete (Sample – VIII) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.82 cm
Volume of Specimen, V: 1201.5 cm^3
TSS collected: 22.48 mg/L
Cumulative V_{water}: 20.00 L

Table A3-23. Total Suspended Solids Sample 8-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.22403	1.24525	0.02122	1000	21.22
2	1.24505	1.26227	0.01722	1000	17.22
3	1.21851	1.23576	0.01725	1000	17.25
4	1.21112	1.22898	0.01786	1000	17.86
5	1.21126	1.22815	0.01689	1000	16.89
6	1.23162	1.24871	0.01709	1000	17.09
7	1.25366	1.27585	0.02219	1000	22.19
8	1.24027	1.26257	0.0223	1000	22.30
9	1.24568	1.26932	0.02364	1000	23.64
10	1.23886	1.28795	0.04909	1000	49.09
				Average	22.48

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
22.48	16.96401	2.755494	27.98599

Material Used: Ohio Ready Mix Concrete (Sample – VIII) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.82 cm
Volume of Specimen, V: 1201.5 cm^3
TSS collected: 3.36 mg/L
Cumulative V_{water}: 30.00 L

Table A3-24. Total Suspended Solids Sample 8-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23	1.23244	0.00244	1000	2.44
2	1.25531	1.25674	0.00143	1000	1.43
3	1.25844	1.26045	0.00201	1000	2.01
4	1.24621	1.24773	0.00152	1000	1.52
5	1.23676	1.23862	0.00186	1000	1.86
6	1.27162	1.2752	0.00358	1000	3.58
7	1.27934	1.28332	0.00398	1000	3.98
8	1.2508	1.25564	0.00484	1000	4.84
9	1.24883	1.25471	0.00588	1000	5.88
10	1.24182	1.25059	0.00877	1000	8.77
				Average	3.63

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
3.63	0.453501	1.58875	6.808499

The overall TSS collection of Sample – VIII, is 129.99 mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – IX) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.9 cm
Volume of Specimen, V: 1207.99 cm^3
TSS collected: 69.03 mg/L
Cumulative V_{water}: 10.00 L

Table A3-25. Total Suspended Solids Sample 9-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.27309	1.31869	0.0456	1000	45.60
2	1.25462	1.29797	0.04335	1000	43.35
3	1.21957	1.25972	0.04015	1000	40.15
4	1.24915	1.29808	0.04893	1000	48.93
5	1.24337	1.28891	0.04554	1000	45.54
6	1.25147	1.29894	0.04747	1000	47.47
7	1.25155	1.3079	0.05635	1000	56.35
8	1.2378	1.2849	0.0471	1000	47.10
9	1.23863	1.2986	0.05997	1000	59.97
10	1.24356	1.4994	0.25584	1000	255.84
				Average	69.03

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
69.03	56.59329	6.218354	81.46671

Material Used: Ohio Ready Mix Concrete (Sample – IX) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.9 cm
Volume of Specimen, V: 1207.99 cm^3
TSS collected: 1.67 mg/L
Cumulative V_{water}: 20.00 L

Table A3-26. Total Suspended Solids Sample 9-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.20898	1.20898	0	1000	0.00
2	1.24111	1.24189	0.00078	1000	0.78
3	1.25853	1.25944	0.00091	1000	0.91
4	1.23832	1.23952	0.0012	1000	1.20
5	1.25987	1.26138	0.00151	1000	1.51
6	1.21739	1.21876	0.00137	1000	1.37
7	1.20757	1.20893	0.00136	1000	1.36
8	1.23584	1.23709	0.00125	1000	1.25
9	1.24862	1.25233	0.00371	1000	3.71
10	1.22505	1.22962	0.00457	1000	4.57
				Average	1.67

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
1.67	-0.3301	0.998048	3.662096

Material Used: Ohio Ready Mix Concrete (Sample – IX) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.9 cm
Volume of Specimen, V: 1207.99 cm^3
TSS collected: 0.32 mg/L
Cumulative V_{water}: 30.00 L

Table A3-27. Total Suspended Solids Sample 9-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.20723	1.20787	0.00064	1000	0.64
2	1.24447	1.24467	0.0002	1000	0.20
3	1.2389	1.23911	0.00021	1000	0.21
4	1.26655	1.26655	0	1000	0.00
5	1.24373	1.24384	0.00011	1000	0.11
6	1.24636	1.24665	0.00029	1000	0.29
7	1.24175	1.24177	2E-05	1000	0.02
8	1.25797	1.25811	0.00014	1000	0.14
9	1.26209	1.26263	0.00054	1000	0.54
10	1.24998	1.25101	0.00103	1000	1.03
				Average	0.32

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
0.32	-0.12239	0.220196	0.758391

The overall TSS collection of Sample – IX, is 71.01 mg/L and the cumulative water is 30 L.

Material Used: Ohio Ready Mix Concrete (Sample – X) Test: 1
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.7cm^3
TSS collected: 53.56 mg/L
Cumulative V_{water}: 10.00 L

Table A3-28. Total Suspended Solids Sample 10-1

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.25723	1.28373	0.0265	1000	26.50
2	1.24473	1.2756	0.03087	1000	30.87
3	1.21724	1.27517	0.05793	1000	57.93
4	1.23522	1.27547	0.04025	1000	40.25
5	1.20407	1.25022	0.04615	1000	46.15
6	1.22409	1.26127	0.03718	1000	37.18
7	1.26499	1.31059	0.0456	1000	45.60
8	1.26351	1.31091	0.0474	1000	47.40
9	1.24932	1.29735	0.04803	1000	48.03
10	1.22955	1.3852	0.15565	1000	155.65
				Average	53.56

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
53.56	34.32731	9.614343	72.78469

Material Used: Ohio Ready Mix Concrete (Sample – X) Test: 2
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.7cm^3
TSS collected: 3.6 mg/L
Cumulative V_{water}: 20.00 L

Table A3-29. Total Suspended Solids Sample 10-2

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23655	1.23795	0.0014	1000	1.40
2	1.24702	1.24947	0.00245	1000	2.45
3	1.24181	1.24443	0.00262	1000	2.62
4	1.26998	1.27111	0.00113	1000	1.13
5	1.22926	1.23068	0.00142	1000	1.42
6	1.22952	1.23067	0.00115	1000	1.15
7	1.24873	1.24937	0.00064	1000	0.64
8	1.26592	1.26654	0.00062	1000	0.62
9	1.24242	1.24501	0.00259	1000	2.59
10	1.24203	1.26406	0.02203	1000	22.03
				Average	3.60

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
3.60	2.007384	0.798808	5.202616

Material Used: Ohio Ready Mix Concrete (Sample – X) Test: 3
Diameter of Specimen, D: 10.16 cm
Area of Specimen, A: 81.07 cm^2
Height of Specimen L: 14.65 cm
Volume of Specimen, V: 1187.7cm^3
TSS collected: 1.68 mg/L
Cumulative V_{water}: 30.00 L

Table A3-30. Total Suspended Solids Sample 10-3

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
1	1.23411	1.23426	0.00015	1000	0.15
2	1.23846	1.23853	7E-05	1000	0.07
3	1.27217	1.27222	5E-05	1000	0.05
4	1.23512	1.24367	0.00855	1000	8.55
5	1.2738	1.27445	0.00065	1000	0.65
6	1.24625	1.24648	0.00023	1000	0.23
7	1.2098	1.21012	0.00032	1000	0.32
8	1.2276	1.22882	0.00122	1000	1.22
9	1.22872	1.22912	0.0004	1000	0.40
10	1.23317	1.23837	0.0052	1000	5.20
				Average	1.68

Mean TSS	Minμ-2σ	STDEV	Maxμ+2σ
mg/L	(mg/L)	mg/L	(mg/L)
1.68	-3.80709	2.745546	7.175093

The overall TSS collection of Sample – X, is 58.85 mg/L and the cumulative water is 30 L

Appendix – 4: Sand Clogging Tests Results

Material used: Ohio Ready Mix Concrete (Sample – I) Sand Clogging Tests

Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 15.155 cm
Volume: 1228.7 cm^3
Weight $_{PVC+Concrete}$ 2398.5 g

Table A4-1. Sand Maintenance Sample-1

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	Mass Type 2 Added	Accumulated Amount of Type 2 added	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)		(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.438462036	0.0000	23.25	16.8	17	0	4	40.0	40.0	0.0136
2	4.01931401	9.4435	30.1	9.9	27	0	4	40.0	80.0	0.0081
3	3.644401262	17.8904	31	9.1	36	0	4	40.0	120.0	0.0074
4	3.245239306	26.8837	33	7.3	43	0	4	40.0	160.0	0.0060
5	3.085256788	30.4882	29	11.2	54	0	4	40.0	200.0	0.0091
6	2.945017843	33.6478	22	17.8	72	0	4	40.0	240.0	0.0145
7	2.595386182	41.5251	26	14.0	86	0	4	40.0	280.0	0.0114
8	2.398538426	45.9601	30	9.9	96	0	4	40.0	320.0	0.0081
9	2.284563542	48.5280	27	13.4	109	0	4	40.0	360.0	0.0109
10	1.978047378	55.4339	27	13.2	123	42	4	40.0	400.0	0.0107
		Total	**277**		**81**	**42**		**400**		**0.0998**

Table A4-1.1. Sand Maintenance Summary Sample-1

Amount of sand recovered in maintenance		
Surface brushing =	6.2	g
Vacuuming =	19.5	g
Pressure washing =	15.96903	g
Permeability Recovery =	58.2	%
Initial permeability =	3.978	cm/s
Porosity =	38.46	%

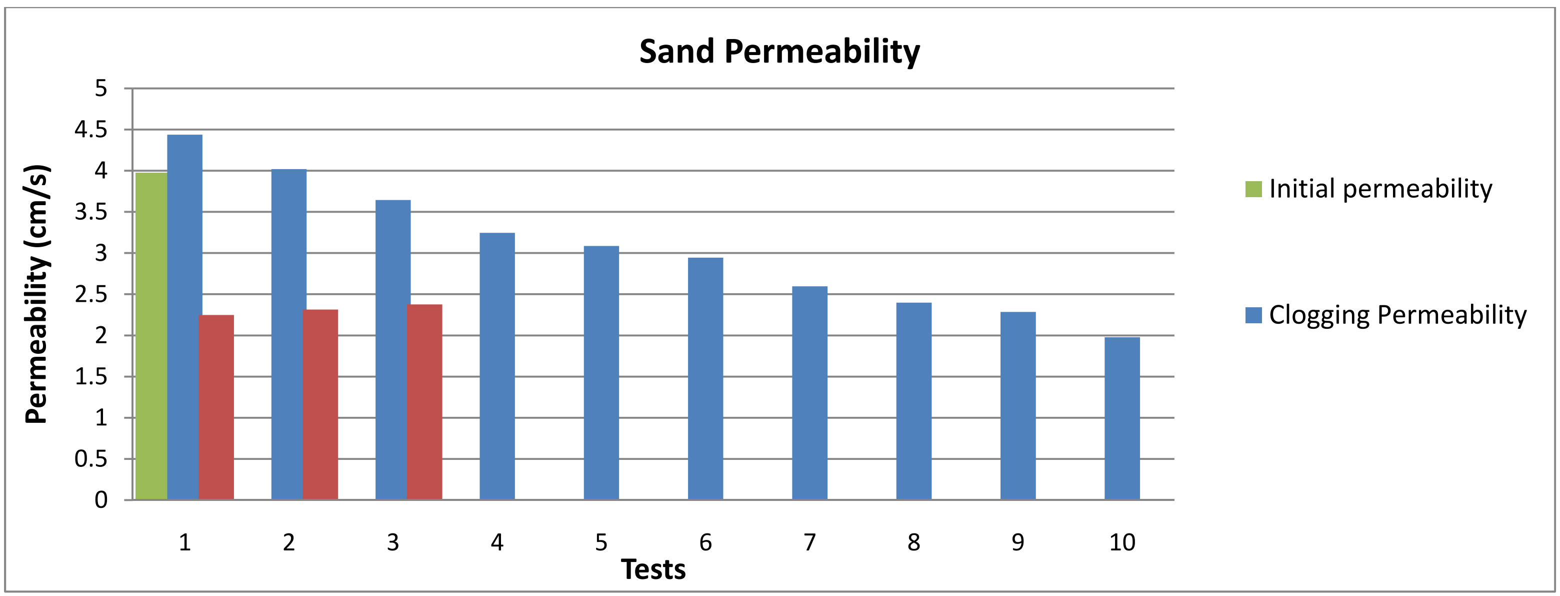

Figure A4-1. Sand clogging permeability

Material used: Ohio Ready Mix Concrete (Sample – II)
Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 15.7 cm
Volume: 1269.9 cm^3
Weight $_{PVC+Concrete}$ 2270.8 g

Table A4-2. Sand Maintenance Sample-2

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	CumulativeTSS Retained	Maintenance	Concentration	Mass Type 2 Added	Accumulated Amount of Type 2 added	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)		(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.251185	0.0000	18.90	21.10	21	0	4	40.0	40.0	0.0166
2	3.611761	15.0411	24.91	15.09	36	0	4	40.0	80.0	0.0119
3	3.319209	21.9227	28.96	11.04	47	0	4	40.0	120.0	0.0087
4	2.906832	31.6230	25.55	14.45	62	0	4	40.0	160.0	0.0114
5	2.838754	33.2244	27.48	12.52	74	0	4	40.0	200.0	0.0099
6	2.313943	45.5695	19.29	20.71	95	0	4	40.0	240.0	0.0163
7	1.815402	57.2966	13.95	26.05	121	0	4	40.0	280.0	0.0205
8	1.34652	68.3260	25.48	14.52	135	0	4	40.0	320.0	0.0114
9	1.255764	70.4609	26.87	13.13	149	0	4	40.0	360.0	0.0103
10	1.142604	73.1227	12.94	27.06	176	0	4	40.0	400.0	0.0213
11	1.118799	73.6826	31.99	8.01	184	0	4	40.0	440.0	0.0063
12	1.103523	74.0420	37.97	2.03	186	0	4	40.0	480.0	0.0016
13	1.002145	76.4267	19.01	20.99	207	0	4	40.0	520.0	0.0165
14	1.035617	75.6393	39.39	0.61	207	0	4	40.0	560.0	0.0005
15	1.05983	75.0698	16.61	23.39	231	154	4	40.0	600.0	0.0184
		Total	**369.30**		**76.6**			**600**		**0.1817**

Table A4-2.1. Sand Maintenance Summary Sample-2

Amount of sand recovered in maintenance		
Surface brushing =	78.3	g
Vacuuming =	69.3	g
Pressure washing =	6.52298	g
Permeability Recovery =	69.70	%
Initial permeability =	4.99	cm/s
Porosity =	42.43	%

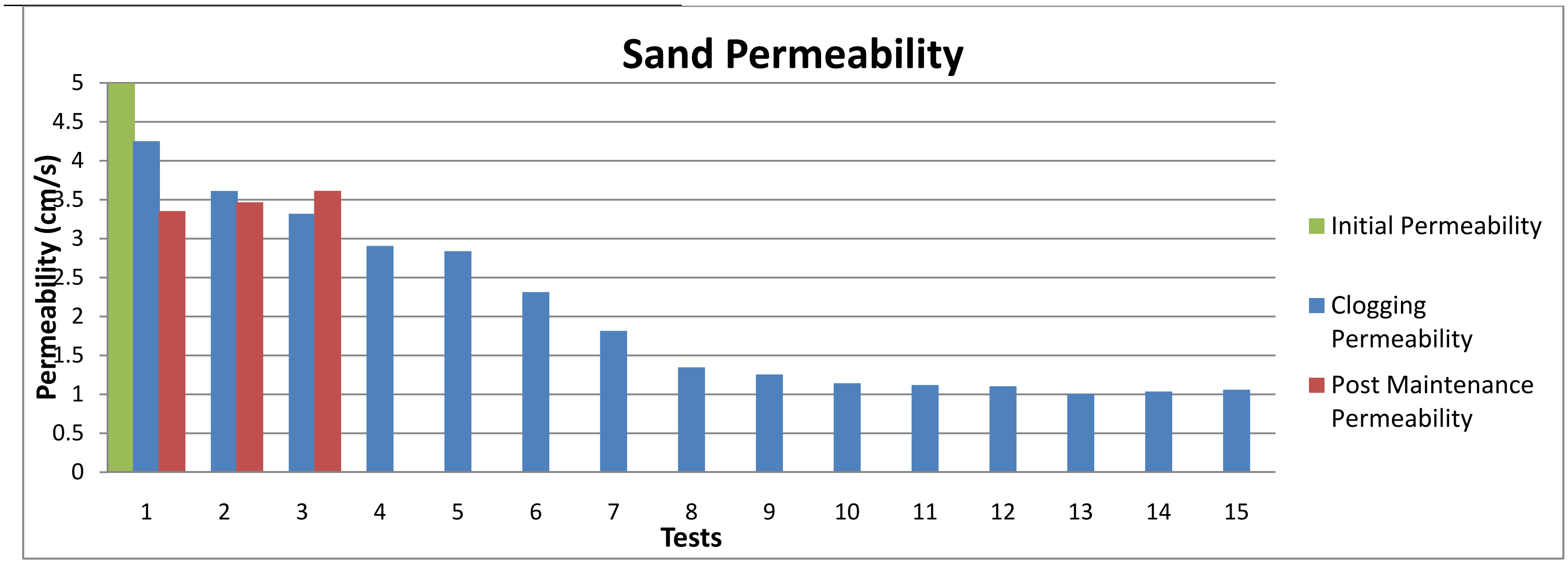

Figure A4-2. Sand clogging permeability

Material used: Ohio Ready Mix Concrete (Sample –III)
Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 15.19 cm
Volume: 1269.9 cm^3
Weight $_{PVC+Concrete}$ 2296.8 g

Table A4-3. Sand Maintenance Sample-3

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	Mass Type 2 Added	Accumulated Amount of Type 2 added	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	**(%)**	**(g)**		**(g)**	**g**	**(g/L)**	**(g)**	**(g)**	**g/cm^3**
1	3.335089	17.8549	20.28	19.72	20	0	4	40.0	40.0	0.0160
2	3.124867	23.0328	27.62	12.38	32	0	4	40.0	80.0	0.0101
3	2.982267	26.5451	26.83	13.17	45	0	4	40.0	120.0	0.0107
4	2.696646	33.5802	28.14	11.86	57	0	4	40.0	160.0	0.0096
5	2.393127	41.0560	23.60	16.40	74	0	4	40.0	200.0	0.0133
6	2.162281	46.7418	29.26	10.74	84	0	4	40.0	240.0	0.0087
7	2.097494	48.3376	22.78	17.22	102	0	4	40.0	280.0	0.0140
8	2.035074	49.8750	29.47	10.53	112	0	4	40.0	320.0	0.0086
9	1.828949	54.9520	25.83	14.17	126	0	4	40.0	360.0	0.0115
10	1.621112	60.0711	23.89	16.11	142	0	4	40.0	400.0	0.0131
11	1.110331	72.6520	21.13	18.87	161	0	4	40.0	440.0	0.0153
12	1.074684	73.5300	28.99	11.01	172	0	4	40.0	480.0	0.0089
13	0.810525	80.0363	22.16	17.84	190	0	4	40.0	520.0	0.0145
14	0.488928	87.9574	7.87	32.13	222	0	4	40.0	560.0	0.0261
15	0.342302	91.5689	3.43	36.57	259	0	4	40.0	600.0	0.0297
16	0.302455	92.5504	2.1529	37.85	297	197.4014		40.0	640.0	0.0307
		Total	**343.42**		**99.2**			**640**		**0.2101**

Table A4-3.1. Sand Maintenance Summary Sample-3

Surface brushing =	98.00	g
Vacuuming =	81.50	g
Pressure washing =	17.90	g
Permeability Recovery =	59.14	%
Initial permeability =	4.06	cm/s
Porosity =	34.70	%

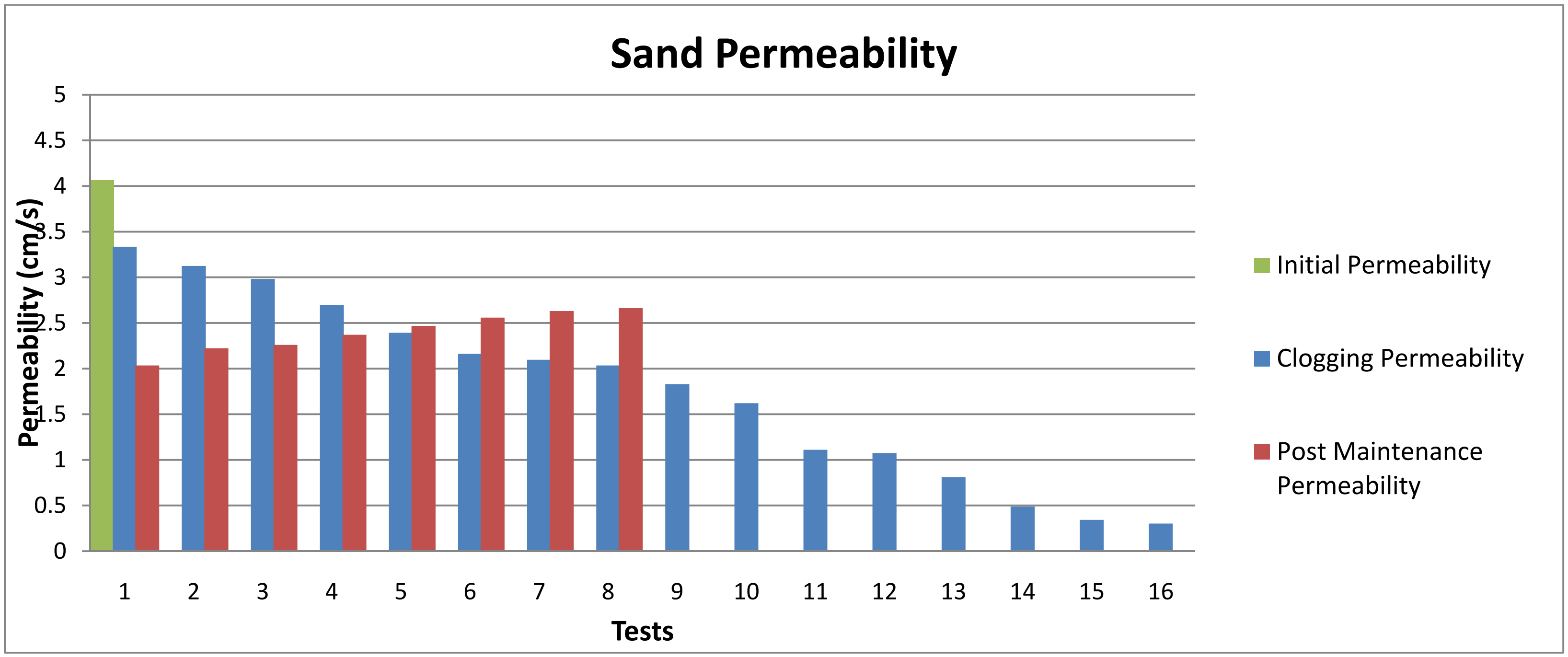

Figure A4-3. Sand clogging permeability

Appendix – 5: A6 Soil Clogging Tests Results

Material used: Ohio Ready Mix Concrete (Sample – IV) A6 Soil Clogging Test

Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 15.13 cm
Volume: 1226.9 cm^3
Weight $_{PVC+Concrete}$ 2309.1 g

Table A5-1. A6 Soil Maintenance Sample-4

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	CumulativeTSS Retained	Maintenance	Concentration	Mass Type 2 Added	Accumulated Amount of Type 2 added	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.268531	1.3428	35.7159	4.28	4	0	4	40.0	40.0	0.0035
2	4.131468	4.5107	38.91	1.09	5	0	4	40.0	80.0	0.0009
3	4.300356	0.6072	36.03	3.97	9	0	4	40.0	120.0	0.0032
4	4.508616	-4.2062	37.88	2.12	11	0	4	40.0	160.0	0.0017
5	4.414293	-2.0262	37.69	2.31	14	0	4	40.0	200.0	0.0019
6	4.481176	-3.5720	38.13	1.87	16	0	4	40.0	240.0	0.0015
7	3.737178	13.6238	84.30	-4.30	11	0	4	80.0	320.0	-0.0035
8	3.486431	19.4192	77.01	2.99	14	0	4	80.0	400.0	0.0024
9	2.867014	33.7356	75.31	4.69	19	0	4	80.0	480.0	0.0038
10	3.437535	20.5493	77.82	2.18	21	0	4	80.0	560.0	0.0018
11	3.787621	12.4579	73.35	6.65	28	0	4	80.0	640.0	0.0054
12	3.873369	10.4761	74.76	5.24	33	0	4	80.0	720.0	0.0043
13	3.665867	15.2720	75.80	4.20	37	0	4	80.0	800.0	0.0034
14	4.018104	7.1308	70.69	9.31	47	0	4	80.0	880.0	0.0076
15	4.027013	6.9249	73.74	6.26	53	16	4	80.0	960.0	0.0051
		Total	**907.14**	**36.8**		**16**		**960**		**0.0431**

Table A5-1.1. A6 Soil Maintenance Summary Sample-4

Initial permeability =	4.33	cm/s
Porosity =	31.14	%
Amount of sand recovered in maintenance		
Surface brushing =	1	g
Vacuuming =	6.7	g
Pressure washing =	8.35	g
Permeability Recovery =	94.0	%
Note: The maintenance has been done after test# 15.		

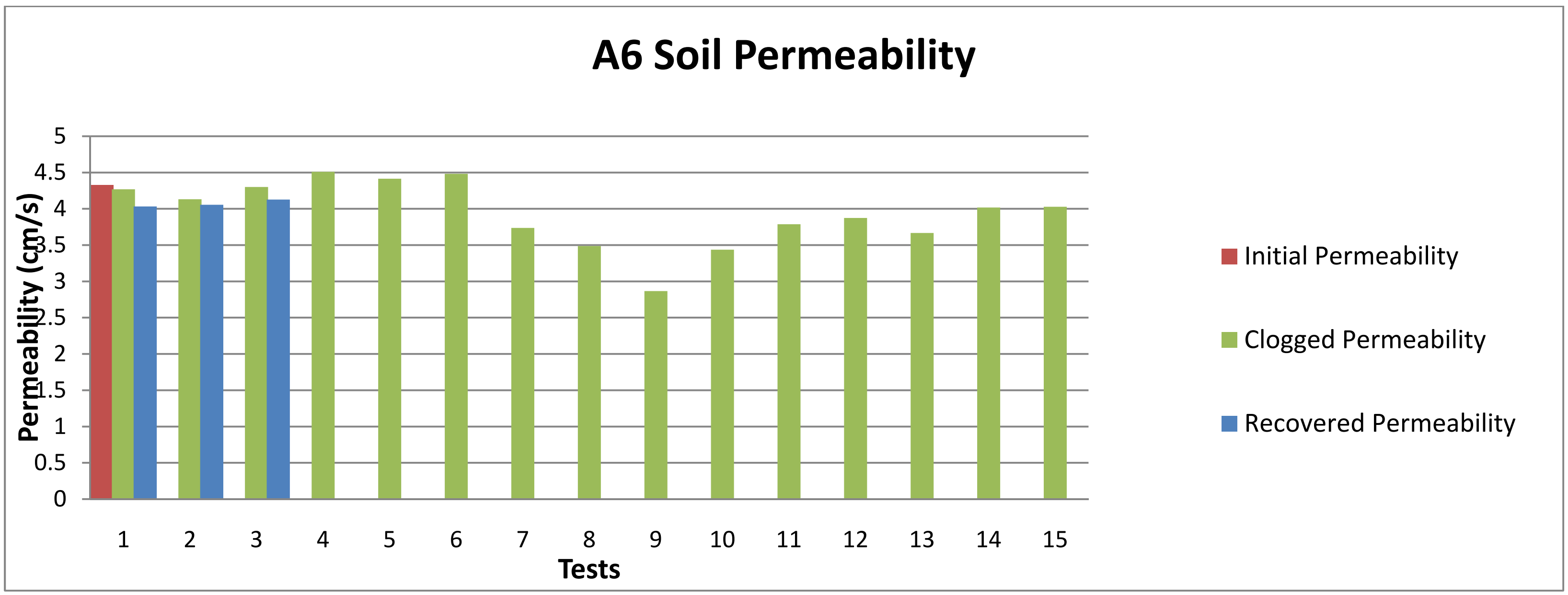

Figure A5-1. A6 soil permeability

Material used: Ohio Ready Mix Concrete (Sample – V) A6 Soil Clogging Test
Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 15.6 cm
Volume: 1265.6 cm^3
Weight $_{PVC+Concrete}$ 2343 g

Table A5-2. A6 Soil Maintenance Sample-5

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	Mass Added (A6)	Accumulated Amount of added (A6)	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	3.6	8.4	67.1	12.86	13	0	8	80.0	80.0	0.0102
2	3.4	12.5	71.9	8.06	21	0	8	80.0	160.0	0.0064
3	3.3	15.1	74.8	5.15	26	0	8	80.0	240.0	0.0041
4	3.3	15.2	68.9	11.10	37	0	8	80.0	320.0	0.0088
5	3.4	13.3	56.6	23.37	61	0	8	80.0	400.0	0.0185
6	3.3	15.5	77.5	2.46	63	19	8	80.0	480.0	0.0019
		Total	**417.00**		**44**	**19**			**Total**	**0.0498**

Table A5-2.1. A6 Soil Maintenance Summary Sample-5

Initial permeability =	3.915394	cm/s
Porosity =	31.22	%
Amount of sand recovered in maintenance		
Surface brushing =	2.5	g
Vacuuming =	6.4	g
Pressure washing =	10.2	g
Permeability Recovery =	98.1	%
Note: The maintenance has been don after test#6		

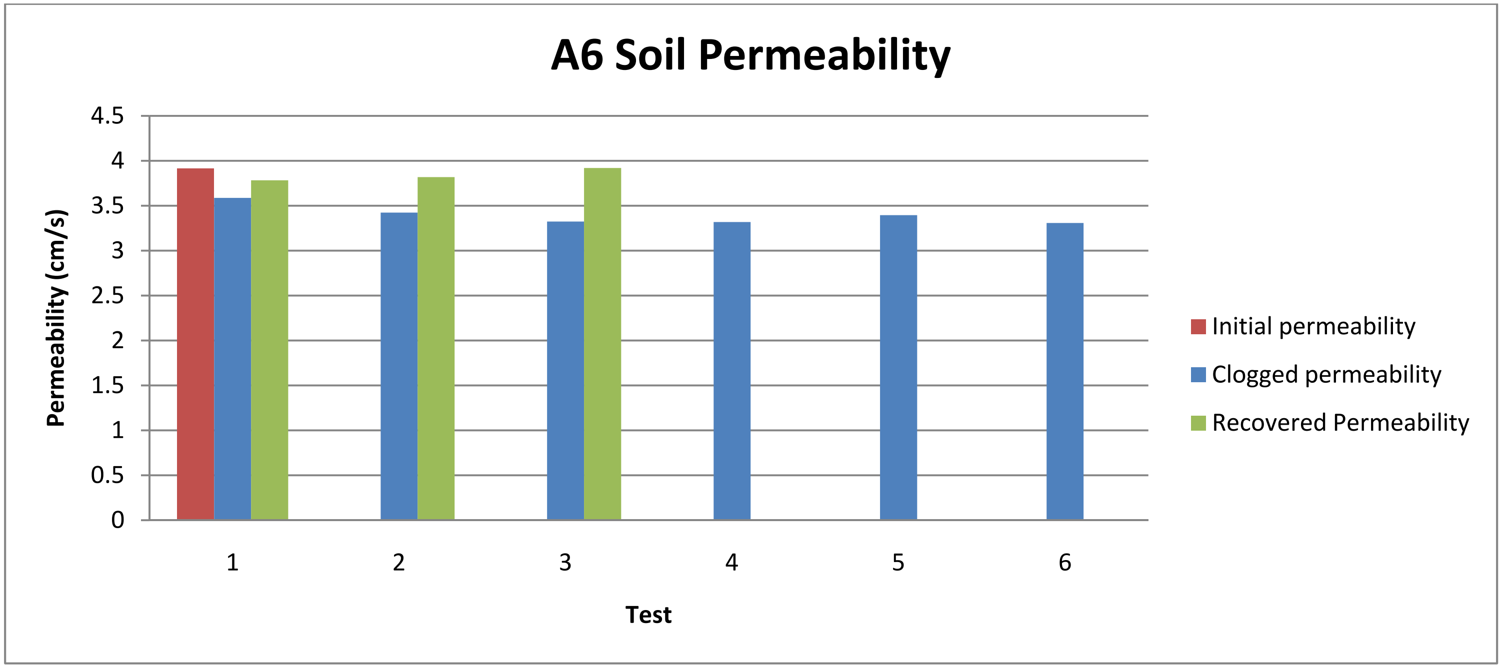

Figure A5-2. A6 soil permeability

Material used: Ohio Ready Mix Concrete (Sample – VI) Clogging Test A6 Soil
Diameter of Sample, D: 10.16 cm
Area, A: 81.07 cm^2
Average Length, L: 14.64cm
Volume: 1187.5cm^3
Weight $_{PVC+Concrete}$ 2343 g

Table A5-3. A6 Soil Maintenance Sample-6

Tests	$k_{@20°C}$	Percent Permeability Reduction	TSS Passing	TSS Retained	Cumulative TSS Retained	Maintenance	Concentration	Mass Added (A6)	Accumulated Amount of added (A6)	Amount of Sand Retained per Unit Volume of Concrete
	(cm/s)	(%)	(g)	(g)	(g)	g	(g/L)	(g)	(g)	g/cm^3
1	4.287944	4.4055	73.51068	6.49	6	0	8	80.0	80.0	0.0055
2	4.150258	7.4750	73.50502	6.49	13	0	8	80.0	160.0	0.0055
3	3.9993	10.8405	77.24939	2.75	16	0	8	80.0	240.0	0.0023
4	4.036899	10.0022	76.01497	3.99	20	0	8	80.0	320.0	0.0034
5	4.094542	8.7172	76.53009	3.47	23	0	8	80.0	400.0	0.0029
6	3.976292	11.3534	73.80888	6.19	29	5	8	80.0	480.0	0.0052
		Total	450.62		24	5			**Total**	**0.0247**

Table A5-3.1A6 Soil Maintenance Summary Sample-6

Initial permeability =	4.49	cm/s
Porosity =	34.39	%
Amount of sand recovered in maintenance		
Surface brushing =	1	g
Vacuuming =	1.2	g
Pressure washing =	2.9	g
Permeability Recovery =	95.4	%
Note: The maintenance has been don after test# 15		

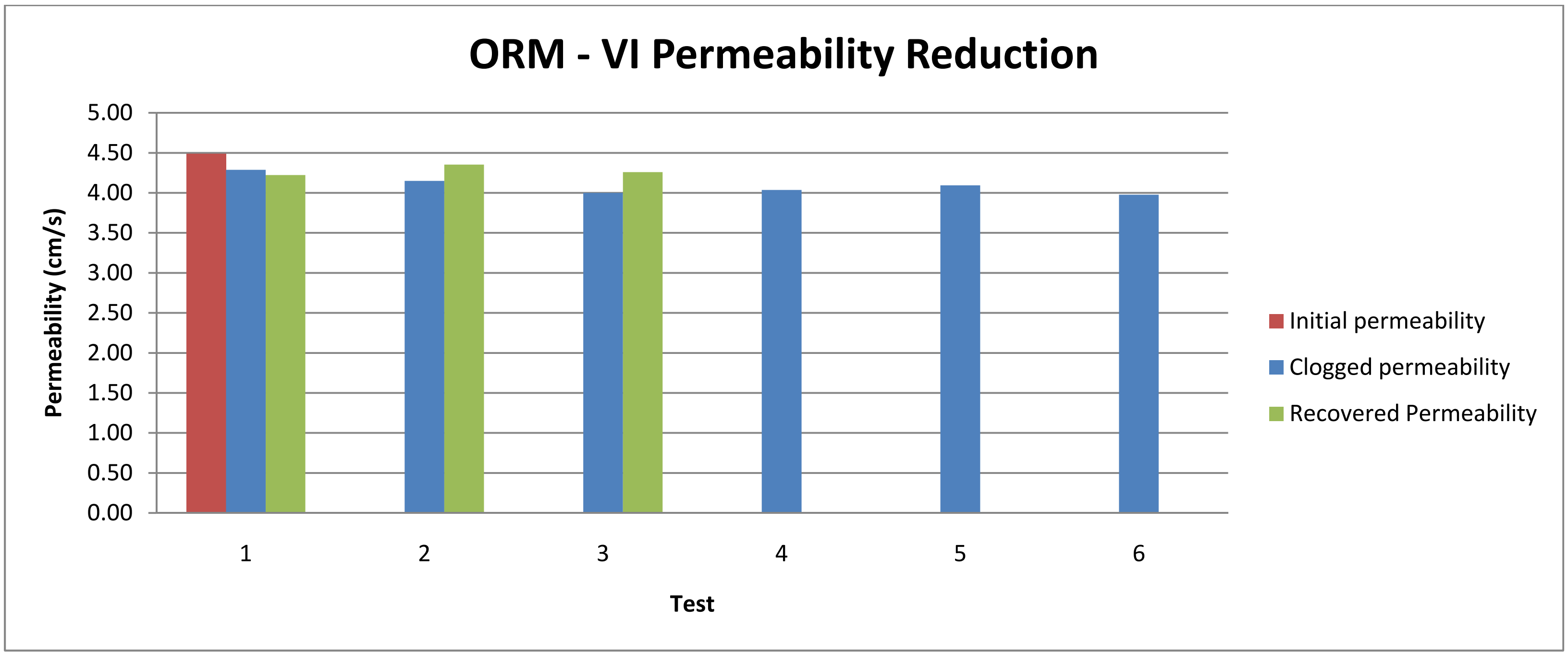

Figure A5-3. A6 soil permeability

Appendix – 6: Artificial Runoff High Concentration Test Results

Artificial Runoff High Concentration
Material used: Ohio Ready Mix Concrete (Sample –VII)

Diameter of Sample, D:	10.16 cm
Area, A:	81.07 cm^2
Average Length, L:	14.98 cm
Volume:	1214.9 cm^3
Weight $_{PVC+Concrete}$	2201.6 g

Table A6-1. Initial Data of Artificial Runoff High Concentration

$Vol_{Conc\ Runoff}$	=	L
$Mass_{A\text{-}6\ Soil}$	=	110.55 g
$Vol_{Filling\ Tank}$	=	150 L
Initial pH	7.26	
Initial Temp	19.78	°C

Table A6-2. Target High Concentration in Artificial Roadway Runoff

Metal	High Concentration
total Cd (µg/L)	500
total Cr (µg/L)	625
total Cu (µg/L)	875
total Fe (µg/L)	16500
total Ni (µg/L)	2375
total Pb (µg/L)	5375
total Zn (µg/L)	2300
pH	7.0±0.1
TSS (mg/L)	360

pH and Temperature of IFH, EFH and ECH of ten tests.
IFH ==> Influent Falling Head
EFH ==> Effluent Falling Head
ECH ==> Effluent Constant Head

Table A6-3. Influent and Effluent pH and Temperature Artificial Runoff High Concentration

IFH			EFH			ECH		
Run	**1**	**IFH**	**Run**	**1**	**EFH**	**Run**	**1**	**ECH**
Temp:	22.02	°C	Temp:	22.02	°C	Temp:	23.8	°C
pH:	7.52		pH:	7.49		pH:	7.06	
Run	**2**	**IFH**	**Run**	**2**	**EFH**	**Run**	**2**	**ECH**
Temp:	23.1	°C	Temp:	22.64	°C	Temp:	25.5	°C
pH:	7.1		pH:	7.43		pH:	7.31	
Run	**3**	**IFH**	**Run**	**3**	**EFH**	**Run**	**3**	**ECH**
Temp:	23.41	°C	Temp:	23.92	°C	Temp:	22.67	°C
pH:	7.61		pH:	7.75		pH:	7.31	
Run	**4**	**IFH**	**Run**	**4**	**EFH**	**Run**	**4**	**ECH**
Temp:	23.7	°C	Temp:	23.61	°C	Temp:		°C
pH:	7.73		pH:	7.84		pH:		
Run	**5**	**IFH**	**Run**	**5**	**EFH**	**Run**	**5**	**ECH**
Temp:	22.56	°C	Temp:	23.37	°C	Temp:		°C
pH:	7.74		pH:	7.89		pH:		
Run	**6**	**IFH**	**Run**	**6**	**EFH**	**Run**	**6**	**ECH**
Temp:	24.7	°C	Temp:	23.75	°C	Temp:		°C
pH:	7.89		pH:	8		pH:		
Run	**7**	**IFH**	**Run**	**7**	**EFH**	**Run**	**7**	**ECH**
Temp:	23.83	°C	Temp:	23.36	°C	Temp:		°C
pH:	7.94		pH:	8		pH:		
Run	**8**	**IFH**	**Run**	**8**	**EFH**	**Run**	**8**	**ECH**
Temp:	22.44	°C	Temp:	23.43	°C	Temp:		°C
pH:	7.79		pH:	8.06		pH:		
Run	**9**	**IFH**	**Run**	**9**	**EFH**	**Run**	**9**	**ECH**
Temp:	23.6	°C	Temp:	23.61	°C	Temp:		°C
pH:	7.96		pH:	8.01		pH:		
Run	**10**	**IFH**	**Run**	**10**	**EFH**	**Run**	**10**	**ECH**
Temp:	22.34	°C	Temp:	23.08	°C	Temp:		°C
pH:	7.72		pH:	8.04		pH:		

Table A6-4. Artificial Runoff High Concentration Falling Head Permeability

Test No.	H_1	H_2	Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	2.11	14.986	1.935065	22.02	4.5	4.7	10000	9927.7
2	94.6	48.9	45.7	2.13	14.986	1.935065	22.64	4.4	4.6	10000	9964.5
3	94.6	48.9	45.7	2.13	14.986	1.935065	23.92	4.2	4.6	10000	9947.2
4	94.6	48.9	45.7	2.19	14.986	1.935065	23.61	4.1	4.5	10000	9877.5
5	94.6	48.9	45.7	2.15	14.986	1.935065	23.37	4.2	4.6	10000	9857.9
6	94.6	48.9	45.7	2.28	14.986	1.935065	23.75	3.9	4.3	10000	9935.8
7	94.6	48.9	45.7	2.24	14.986	1.935065	23.36	4.1	4.4	10000	9853.8
8	94.6	48.9	45.7	2.32	14.986	1.935065	23.42	3.9	4.3	10000	9939.9
9	94.6	48.9	45.7	2.46	14.986	1.935065	23.61	3.7	4.0	10000	9467.4

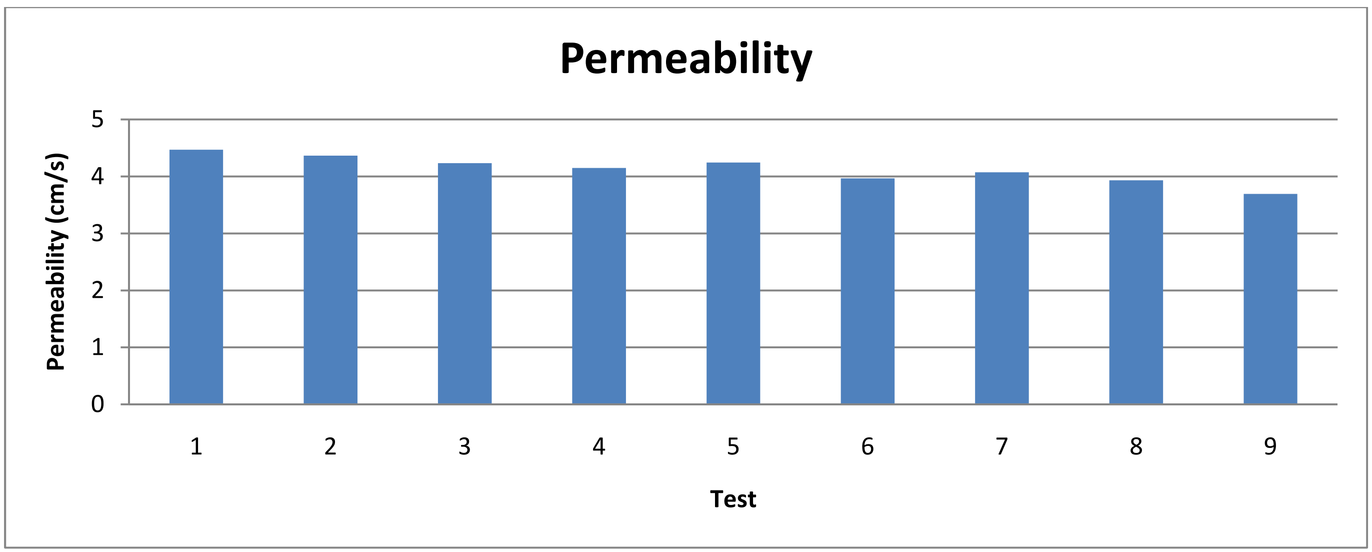

Figure A6-1. Artificial runoff high concentration permeability (A6-1)

Artificial Runoff High Concentration Effluent Constant Head Permeability
Material Used:Green Sand
Diameter, D 10.2 cm
Area, A 81.1 cm2
Length, L 10.16 cm

Table A6 -5. Greensand Test-1

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	64	49.5	14.5	830	60	0.17	0.70	23.8	0.109275
2	36	23	13	550	60	0.11	0.78	23.8	0.080766
3	26	12	14	460	60	0.095	0.73	23.8	0.062725
								Average =	0.084256

Table A6-6. Greensand Test-2

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	11.5	6.5	5	75	60	0.015418	2.032	23.5	0.028836
2	17	9	8	65	60	0.013362	1.27	23.5	0.015619
3	12	5.5	6.5	71	60	0.014596	1.563	23.5	0.020998
								Average =	0.021818

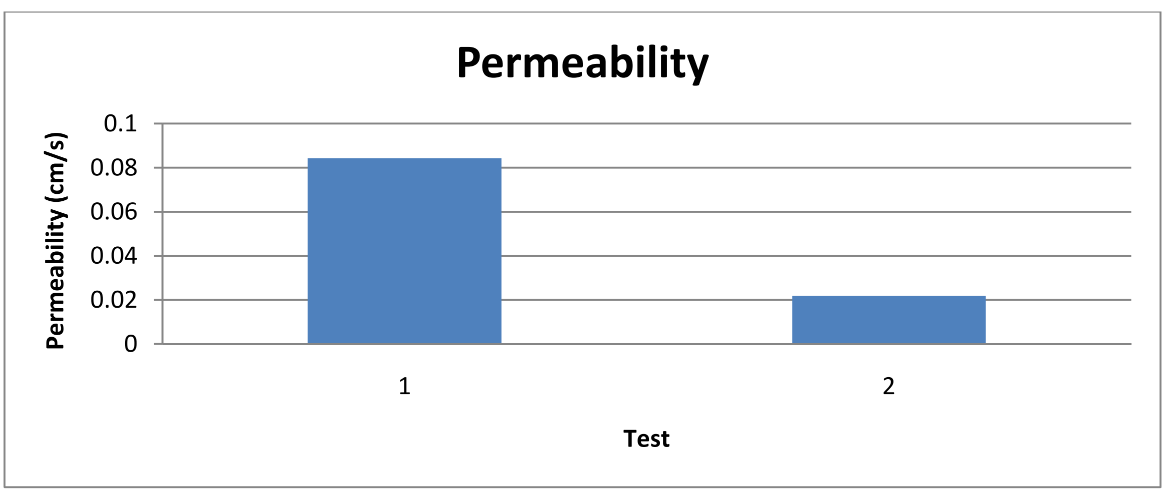

Figure A6-2. Constant head permeability

Permeability Reduction 74.11% from test # 1 to test # 2

Table A6-7. Artificial Runoff High Concentration Influent Falling Head TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-IFH-TSS	1.27171	1.63693	250	1460.88		365.22
2	OR1-T2-IFH-TSS	1.26039	1.48278	250	889.56		222.39
3	OR1-T3-IFH-TSS	1.22274	1.42879	250	824.2		206.05
			Average	**750**	**1058.213**	**Subtotal**	**793.66**
1	OR2-T1-IFH-TSS	1.2601	1.59612	250	1344.08		336.02
2	OR2-T2-IFH-TSS	1.23983	1.57653	250	1346.8		336.7
3	OR2-T3-IFH-TSS	1.23562	1.60545	250	1479.32		369.83
			Average	**750**	**1390.067**	**Subtotal**	**1042.55**
1	OR3-T1-IFH-TSS	1.22789	1.5246	250	1186.84		296.71
2	OR3-T2-IFH-TSS	1.22544	1.48287	250	1029.72		257.43
3	OR3-T3-IFH-TSS	1.2322	1.4925	250	1041.2		260.3
			Average	**750**	**1085.92**	**Subtotal**	**814.44**
1	OR4-T1-IFH-TSS	1.22905	1.50251	250	1093.84		273.46
2	OR4-T2-IFH-TSS	1.20948	1.39943	250	759.8		189.95
3	OR4-T3-IFH-TSS	1.22957	1.4974	250	1071.32		267.83
			Average	**750**	**974.9867**	**Subtotal**	**731.24**
1	OR5-T1-IFH-TSS	1.23611	1.53747	250	1205.44		301.36
2	OR5-T2-IFH-TSS	1.25161	1.47942	250	911.24		227.81
3	OR5-T3-IFH-TSS	1.25391	1.50448	250	1002.28		250.57
			Average	**750**	**1039.653**	**Subtotal**	**779.74**
1	OR6-T1-IFH-TSS	1.21987	1.54587	250	1304		326
2	OR6-T2-IFH-TSS	1.24961	1.48804	250	953.72		238.43
3	OR6-T3-IFH-TSS	1.24439	1.49256	250	992.68		248.17
			Average	**750**	**1083.467**	**Subtotal**	**812.6**
1	OR7-T1-IFH-TSS	1.23539	1.52003	250	1138.56		284.64
2	OR7-T2-IFH-TSS	1.25867	1.50837	250	998.8		249.7
3	OR7-T3-IFH-TSS	1.26378	1.51646	250	1010.72		252.68
			Average	**750**	**1049.36**	**Subtotal**	**787.02**
1	OR8-T1-IFH-TSS	1.26555	1.45806	250	770.04		192.51
2	OR8-T2-IFH-TSS	1.23914	1.48803	250	995.56		248.89
3	OR8-T3-IFH-TSS	1.2741	1.49167	250	870.28		217.57
			Average	**750**	**878.6267**	**Subtotal**	**658.97**
1	OR9-T1-IFH-TSS	1.25753	1.39397	250	545.76		136.44
2	OR9-T2-IFH-TSS	1.248	1.37593	250	511.72		127.93
3	OR9-T3-IFH-TSS	1.26109	1.39952	250	553.72		138.43
			Average	**750**	**537.0667**	**Subtotal**	**402.8**
1	OR10-T1-IFH-TSS	1.26107	1.53654	250	1101.88		275.47
2	OR10-T2-IFH-TSS	1.25306	1.5592	250	1224.56		306.14
3	OR10-T3-IFH-TSS	1.24897	1.50296	250	1015.96		253.99
			Average	**750**	**1114.133**	**Subtotal**	**835.6**
				Average	**928.3176**	**Total**	**7658.62**

Table A6-8. Artificial Runoff High Concentration Effluent Falling Head TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-EFH-TSS	1.27246	1.65936	0.3869	1547.6		386.9
2	OR1-T2-EFH-TSS	1.27272	1.61351	0.34079	1363.16		340.79
3	OR1-T3-EFH-TSS	1.24062	1.56389	0.32327	1293.08		323.27
			Average	**1.05096**	**1401.28**	**Subtotal**	**1050.96**
1	OR2-T1-EFH-TSS	1.24453	1.43511	0.19058	762.32		190.58
2	OR2-T2-EFH-TSS	1.23367	1.46028	0.22661	906.44		226.61
3	OR2-T3-EFH-TSS	1.27113	1.47377	0.20264	810.56		202.64
			Average	**0.61983**	**826.44**	**Subtotal**	**619.83**
1	OR3-T1-EFH-TSS	1.24323	1.4377	0.19447	777.88		194.47
2	OR3-T2-EFH-TSS	1.27585	1.48119	0.20534	821.36		205.34
3	OR3-T3-EFH-TSS	1.27489	1.47399	0.1991	796.4		199.1
			Average	**0.59891**	**798.5467**	**Subtotal**	**598.91**
1	OR4-T1-EFH-TSS	1.2243	1.41889	0.19459	778.36		194.59
2	OR4-T2-EFH-TSS	1.25445	1.4626	0.20815	832.6		208.15
3	OR4-T3-EFH-TSS	1.27189	1.44265	0.17076	683.04		170.76
			Average	**0.5735**	**764.6667**	**Subtotal**	**573.5**
1	OR5-T1-EFH-TSS	1.2619	1.48362	0.22172	886.88		221.72
2	OR5-T2-EFH-TSS	1.26401	1.44523	0.18122	724.88		181.22
3	OR5-T3-EFH-TSS	1.27164	1.46409	0.19245	769.8		192.45
			Average	**0.59539**	**793.8533**	**Subtotal**	**595.39**
1	OR6-T1-EFH-TSS	1.2543	1.40967	0.15537	621.48		155.37
2	OR6-T2-EFH-TSS	1.22417	1.38536	0.16119	644.76		161.19
3	OR6-T3-EFH-TSS	1.24717	1.41093	0.16376	655.04		163.76
			Average	**0.48032**	**640.4267**	**Subtotal**	**480.32**
1	OR7-T1-EFH-TSS	1.23119	1.38989	0.1587	634.8		158.7
2	OR7-T2-EFH-TSS	1.26329	1.43515	0.17186	687.44		171.86
3	OR7-T3-EFH-TSS	1.25446	1.42982	0.17536	701.44		175.36
			Average	**0.50592**	**674.56**	**Subtotal**	**505.92**
1	OR8-T1-EFH-TSS	1.24721	1.35004	0.10283	411.32		102.83
2	OR8-T2-EFH-TSS	1.23743	1.3548	0.11737	469.48		117.37
3	OR8-T3-EFH-TSS	1.24357	1.35595	0.11238	449.52		112.38
			Average	**0.33258**	**443.44**	**Subtotal**	**332.58**
1	OR9-T1-EFH-TSS	1.24415	1.51911	0.27496	1099.84		274.96
2	OR9-T2-EFH-TSS	1.24086	1.42072	0.17986	719.44		179.86
3	OR9-T3-EFH-TSS	1.25827	1.48248	0.22421	896.84		224.21
			Average	**0.67903**	**905.3733**	**Subtotal**	**679.03**
1	OR10-T1-EFH-TSS	1.25187	1.47418	0.22231	889.24		222.31
2	OR10-T2-EFH-TSS	1.26115	1.49698	0.23583	943.32		235.83
3	OR10-T3-EFH-TSS	1.25854	1.47939	0.22085	883.4		220.85
			Average	**0.67899**	**905.32**	**Subtotal**	**678.99**
				Average	**741.2642**	**Total**	**6115.43**

Table A6-9. Artificial Runoff High Concentration Effluent Constant Head TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	S1-T1-EFH-TSS	1.25883	1.27606	0.01723	68.92		17.23
2	S1-T2-EFH-TSS	1.26482	1.28138	0.01656	66.24		16.56
3	S1-T3-EFH-TSS	1.25787	1.2754	0.01753	70.12		17.53
			Average	**0.05132**	**68.42667**	**Subtotal**	**51.32**
1	S2-T1-EFH-TSS	1.26242	1.26937	0.00695	27.8		6.95
2	S2-T2-EFH-TSS	1.25572	1.26397	0.00825	33		8.25
3	S2-T3-EFH-TSS	1.28177	1.2915	0.00973	38.92		9.73
			Average	**0.02493**	**33.24**	**Subtotal**	**24.93**
1	S3-T1-EFH-TSS	1.23966	1.24034	0.00068	2.72		0.68
2	S3-T2-EFH-TSS	1.23966	1.24023	0.00057	2.28		0.57
3	S3-T3-EFH-TSS	1.24228	1.24881	0.00653	26.12		6.53
			Average	**0.00778**	**10.37333**	**Subtotal**	**7.78**
				Average	**28.01**	**Total**	**84.03**

Particle size of the influent and effluent falling head permeability of high concentration of artificial runoff.

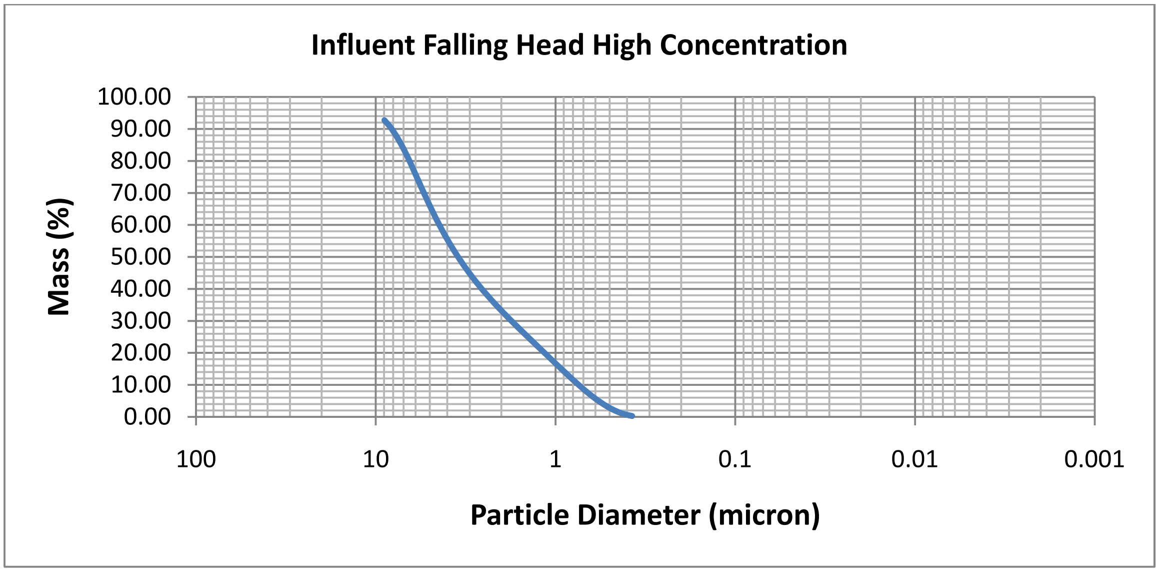

Figure A6-3. Influent particle size

Summary of Figure A6-3

D_{90}	8.3	µm
D_{60}	4.5	µm
D_{50}	3.5	µm
D_{10}	0.75	µm

Summary of Figure A6-4

D_{90}	8	µm
D_{60}	4.6	µm
D_{50}	3.6	µm
D_{10}	0.8	µm

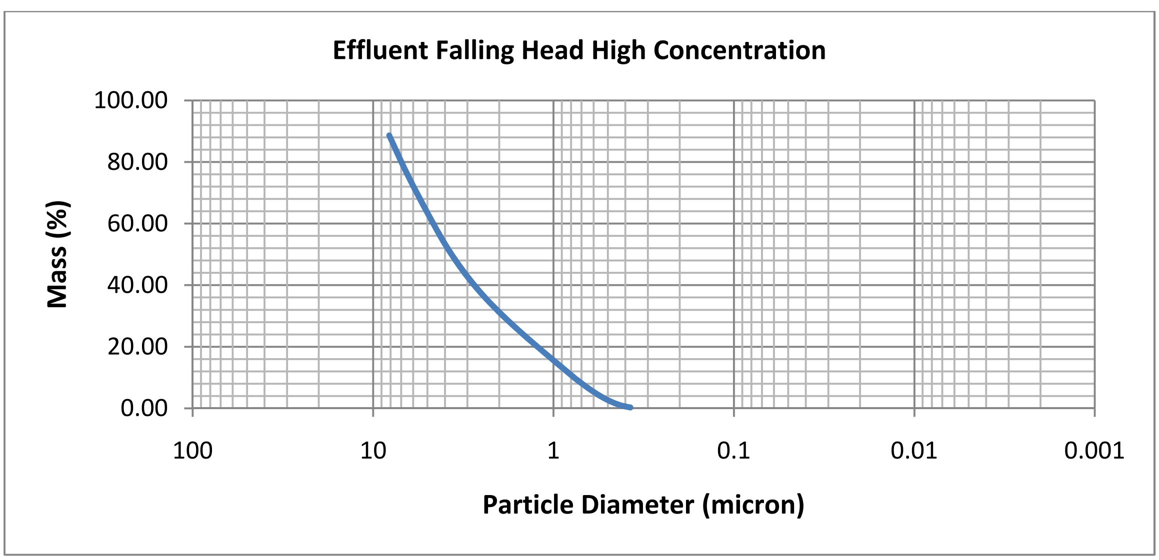

Figure A6-4. Effluent particle size

Appendix – 7: Artificial Runoff Medium Concentration Tests Results

Artificial Runoff Medium Concentration
Material used: Ohio Ready Mix Concrete (Sample –VIII)

Diameter of Sample, D:	10.16 cm
Area, A:	81.07 cm^2
Average Length, L:	14.8 cm
Volume:	1201.2 cm^3
Weight $_{PVC+Concrete}$	2256.6 g

Table A7-1. Initial Data of Artificial Runoff Medium Concentration

$Vol_{Conc\ Runoff}$	=	L
$Mass_{A\text{-}6\ Soil}$	=	31.05 g
$Vol_{Filling\ Tank}$	=	150L
Initial pH	6.95	
Initial Temp	19	°C

Table A7-2. Target Medium Concentration in Artificial Roadway Runoff

Metal	Medium
total Cd (µg/L)	100
total Cr (µg/L)	125
total Cu (µg/L)	175
total Fe (µg/L)	7720
total Ni (µg/L)	475
total Pb (µg/L)	1075
total Zn (µg/L)	500
pH	7.0±0.1
TSS (mg/L)	140

pH and Temperature of IFH, EFH and ECH of ten tests.
IFH ==> Influent Falling Head
EFH ==> Effluent Falling Head
ECH ==> Effluent Constant Head

Table A7-3. Influent and Effluent pH and Temperature Artificial Runoff Medium Concentration

IFH			EFH			ECH		
Run	**1**	**IFH**	**Run**	**1**	**EFH**	**Run**	**1**	**ECH**
Temp:	21.14	°C	Temp:	21.14	°C	Temp:	23.19	°C
pH:	7.09		pH:	7.19		pH:	7	
Run	**2**	**IFH**	**Run**	**2**	**EFH**	**Run**	**2**	**ECH**
Temp:	21.64	°C	Temp:	20.43	°C	Temp:	21.74	°C
pH:	7.1		pH:	7.2		pH:	7.41	
Run	**3**	**IFH**	**Run**	**3**	**EFH**	**Run**	**3**	**ECH**
Temp:	20.58	°C	Temp:	20.13	°C	Temp:	21.44	°C
pH:	7.19		pH:	7.2		pH:	7.37	
Run	**4**	**IFH**	**Run**	**4**	**EFH**	**Run**	**4**	**ECH**
Temp:	20.77	°C	Temp:	21.02	°C	Temp:	22.17	°C
pH:	7.22		pH:	7.36		pH:	7.39	
Run	**5**	**IFH**	**Run**	**5**	**EFH**	**Run**	**5**	**ECH**
Temp:	21.44	°C	Temp:	20.62	°C	Temp:	22.07	°C
pH:	7.45		pH:	7.7		pH:	7.41	
Run	**6**	**IFH**	**Run**	**6**	**EFH**	**Run**	**6**	**ECH**
Temp:	21.11	°C	Temp:	21.07	°C	Temp:	22.74	°C
pH:	7.72		pH:	7.84		pH:	7.42	
Run	**7**	**IFH**	**Run**	**7**	**EFH**	**Run**	**7**	**ECH**
Temp:	21.44	°C	Temp:	21.19	°C	Temp:	22.43	°C
pH:	7.81		pH:	7.94		pH:	7.45	
Run	**8**	**IFH**	**Run**	**8**	**EFH**	**Run**	**8**	**ECH**
Temp:	22.33	°C	Temp:	21.31	°C	Temp:	22.07	°C
pH:	7.84		pH:	8.08		pH:	7.44	
Run	**9**	**IFH**	**Run**	**9**	**EFH**	**Run**	**9**	**ECH**
Temp:	23.26	°C	Temp:	22.28	°C	Temp:	22.89	°C
pH:	7.87		pH:	8		pH:	7.44	
Run	**10**	**IFH**	**Run**	**10**	**EFH**	**Run**	**10**	**ECH**
Temp:	22.75	°C	Temp:	22.14	°C	Temp:	22.86	°C
pH:	7.84		pH:	8.03		pH:	7.27	

Table A7-4. Artificial Runoff Medium Concentration Falling Head Permeability

Test No.	H_1	H_2	Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	2.24	14.81667	1.935065	21.4	4.222024	4.366557	10000	9931.3
2	94.6	48.9	45.7	2.27	14.81667	1.935065	20.43	4.267484	4.308849	10000	9967.2
3	94.6	48.9	45.7	2.25	14.81667	1.935065	20.13	4.332804	4.34715	10000	9958.7
4	94.6	48.9	45.7	2.24	14.81667	1.935065	21.02	4.262196	4.366557	10000	9967.6
5	94.6	48.9	45.7	2.26	14.81667	1.935065	20.62	4.266026	4.327915	10000	9934.4
6	94.6	48.9	45.7	2.25	14.81667	1.935065	21.19	4.223256	4.34715	10000	9996.6
7	94.6	48.9	45.7	2.23	14.81667	1.935065	21.07	4.271221	4.386138	10000	9975.7
8	94.6	48.9	45.7	2.25	14.81667	1.935065	21.31	4.213258	4.34715	10000	9970.3
9	94.6	48.9	45.7	2.24	14.81667	1.935065	22.26	4.132946	4.366557	10000	9968.4
10	94.6	48.9	45.7	2.26	14.81667	1.935065	22.14	4.115414	4.327915	10000	9971.2

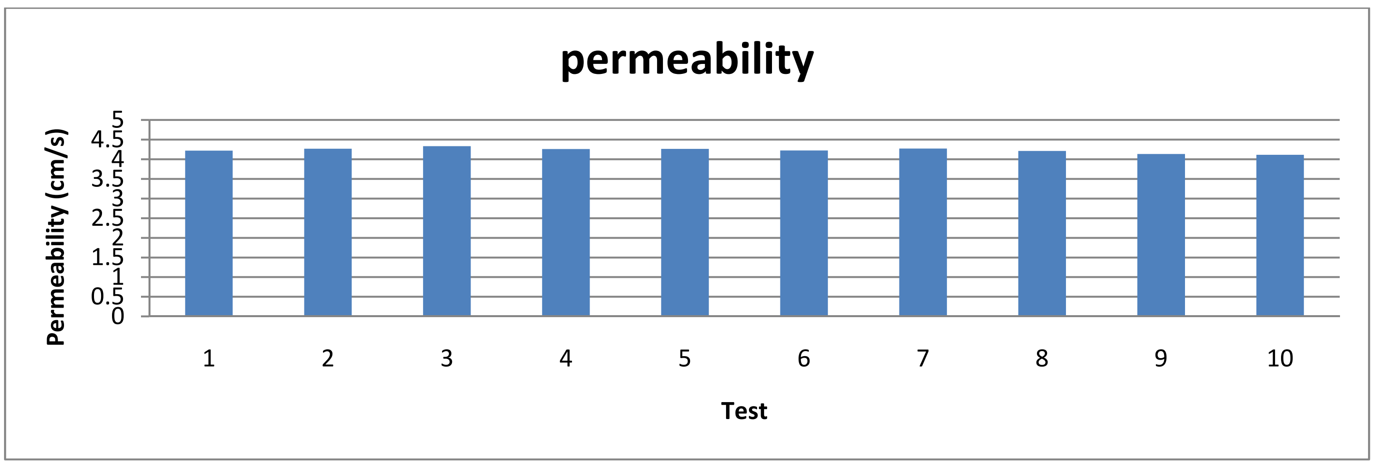

Figure A7-1. Artificial runoff medium concentration permeability

Artificial Runoff Medium Concentration Effluent Constant Head Permeability
Material Used:Green Sand
Diameter, D 10.2 cm
Area, A 81.1 cm2
Length, L 10.16 cm

Table A7-5. Greensand Test-1

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	22.5	13	9.5	800	60	0.164	1.1	23.19	0.163011
2	27	17	10	790	60	0.162	1.016	23.19	0.152925
3	30	20.5	9.5	780	60	0.161	1.07	23.19	0.158936
4	28	17	11	775	60	0.159	0.924	23.19	0.136383
								Average =	0.152814

Table A7-6. Greensand Test-2

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	30	11.5	18.5	770	60	0.158293	0.55	21.74	0.083456
2	32.5	14	18.5	765	60	0.157265	0.55	21.74	0.082914
3	33.5	13.5	20	785	60	0.161377	0.51	21.74	0.0787
4	35.5	15	20.5	720	60	0.148014	0.496	21.74	0.070423
5	37.25	16	21.25	670	60	0.137736	0.478	21.74	0.06322
								Average =	0.075742

Table A7-7. Greensand Test-3

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	33	8.5	24.5	720	60	0.148014	0.4147	21.44	0.059349
2	39.5	15.5	24	705	60	0.144931	0.4233	21.44	0.059323
3	38.5	17.5	21	710	60	0.145959	0.484	21.44	0.068279
4	37	17	20	655	60	0.134652	0.508	21.44	0.066139
5	37.5	17.5	20	650	60	0.133624	0.508	21.44	0.065634
								Average =	0.063745

Table A7-8. Greensand Test-4

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	28.5	16.5	12	695	60	0.142875	0.85	22.17	0.114762
2	26.5	12.5	14	675	60	0.138763	0.73	22.17	0.095537
3	32	12	20	645	60	0.132596	0.508	22.17	0.063903
4	26	13.5	12.5	615	60	0.126429	0.813	22.17	0.09749
5	32	13	19	610	60	0.125401	0.535	22.17	0.063617
								Average =	0.087062

Table A7-9. Greensand Test-5

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	31	6	25	565	60	0.11615	0.41	22.07	0.044886
2	31	6	25	585	60	0.120262	0.41	22.07	0.046475
3	29	7	22	570	60	0.117178	0.462	22.07	0.051458
4	29	7	22	545	60	0.112039	0.462	22.07	0.049201
5	29	6	23	520	60	0.106899	0.442	22.07	0.044903
								Average =	0.047384

Table A7-10. Greensand Test-6

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	27	7	20	510	60	0.104844	0.508	22.7	0.049942
2	26	7	19	495	60	0.10176	0.535	22.7	0.051025
3	26	10	16	455	60	0.093537	0.635	22.7	0.055696
4	28	8	20	430	60	0.088397	0.508	22.7	0.042108
5	26	10	16	405	60	0.083258	0.635	22.7	0.049575
								Average =	0.049669

Table A7-11. Greensand Test-7

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	25.5	7	18.5	395	60	0.081202	0.55	22.43	0.042111
2	24	6.5	17.5	385	60	0.079147	0.581	22.43	0.043391
3	24.5	7.5	17	360	60	0.074007	0.598	22.43	0.041767
4	24	6	18	365	60	0.075035	0.56	22.43	0.039994
5	24	7	17	345	60	0.070924	0.598	22.43	0.040026
								Average =	0.041458

Table A7-12. Greensand Test-8

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	22	5	17	345	60	0.070924	0.598	22.07	0.040306
2	21	4	17	330	60	0.06784	0.598	22.07	0.038554
3	20	4	16	305	60	0.062701	0.635	22.07	0.03786
4	20	4	16	290	60	0.059617	0.635	22.07	0.035998
								Average =	0.038179

Table A7-13. Greensand Test-9

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	21	5	16	270	60	0.055505	0.635	22.86	0.032895
2	18	3	15	255	60	0.052422	0.677	22.86	0.033139
3	18	4	14	242	60	0.049749	0.7257	22.86	0.033696
4	18	3	15	223	60	0.045843	0.6773	22.86	0.02898
5	17	2	15	220	60	0.045227	0.6773	22.86	0.02859
								Average =	0.03146

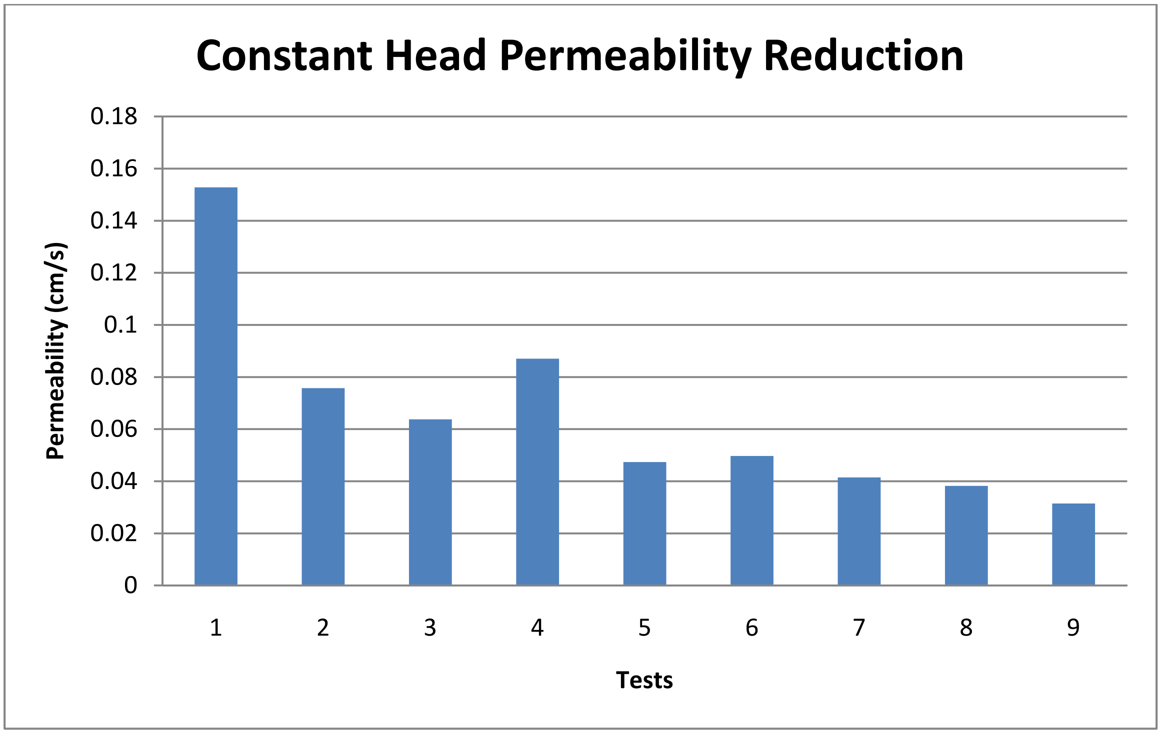

Figure A7-2. Constant head permeability

The constant head permeability reduced to 10.6% of initial permeability after 9 tests. The green sand specimen clogged completely.

Table A7-14. Artificial Runoff Medium Concentration Influent Falling Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-IFH-TSS	1.21496	1.2738	250	235.36		58.84
2	OR1-T2-IFH-TSS	1.2294	1.29271	250	253.24		63.31
3	OR1-T3-IFH-TSS	1.2078	1.26301	250	220.84		55.21
			Average	**750**	**236.48**	**Subtotal**	**177.36**
1	OR2-T1-IFH-TSS	1.22151	1.29786	250	305.4		76.35
2	OR2-T2-IFH-TSS	1.21524	1.26792	250	210.72		52.68
3	OR2-T3-IFH-TSS	1.18462	1.23516	250	202.16		50.54
			Average	**750**	**239.4267**	**Subtotal**	**179.57**
1	OR3-T1-IFH-TSS	1.18251	1.24698	250	257.88		64.47
2	OR3-T2-IFH-TSS	1.19738	1.26212	250	258.96		64.74
3	OR3-T3-IFH-TSS	1.21044	1.28105	250	282.44		70.61
			Average	**750**	**266.4267**	**Subtotal**	**199.82**
1	OR4-T1-IFH-TSS	1.22486	1.27534	250	201.92		50.48
2	OR4-T2-IFH-TSS	1.24123	1.29325	250	208.08		52.02
3	OR4-T3-IFH-TSS	1.20432	1.25433	250	200.04		50.01
			Average	**750**	**203.3467**	**Subtotal**	**152.51**
1	OR5-T1-IFH-TSS	1.21411	1.28271	250	274.4		68.6
2	OR5-T2-IFH-TSS	1.24702	1.32821	250	324.76		81.19
3	OR5-T3-IFH-TSS	1.19414	1.2657	250	286.24		71.56
			Average	**750**	**295.1333**	**Subtotal**	**221.35**
1	OR6-T1-IFH-TSS	1.24178	1.31872	250	307.76		76.94
2	OR6-T2-IFH-TSS	1.24313	1.31986	250	306.92		76.73
3	OR6-T3-IFH-TSS	1.25026	1.33101	250	323		80.75
			Average	**750**	**312.56**	**Subtotal**	**234.42**
1	OR7-T1-IFH-TSS	1.24206	1.32246	250	321.6		80.4
2	OR7-T2-IFH-TSS	1.22767	1.30096	250	293.16		73.29
3	OR7-T3-IFH-TSS	1.23626	1.31967	250	333.64		83.41
			Average	**750**	**316.1333**	**Subtotal**	**237.1**
1	OR8-T1-IFH-TSS	1.2418	1.33983	250	392.12		98.03
2	OR8-T2-IFH-TSS	1.20914	1.29181	250	330.68		82.67
3	OR8-T3-IFH-TSS	1.27946	1.35348	250	296.08		74.02
			Average	**750**	**339.6267**	**Subtotal**	**254.72**
1	OR9-T1-IFH-TSS	1.19992	1.26818	250	273.04		68.26
2	OR9-T2-IFH-TSS	1.27928	1.36827	250	355.96		88.99
3	OR9-T3-IFH-TSS	1.1792	1.23959	250	241.56		60.39
			Average	**750**	**290.1867**	**Subtotal**	**217.64**
1	OR10-T1-IFH-TSS	1.24658	1.28439	250	151.24		37.81
2	OR10-T2-IFH-TSS	1.21996	1.25839	250	153.72		38.43
3	OR10-T3-IFH-TSS	1.24195	1.28132	250	157.48		39.37
			Average	**750**	**154.1467**	**Subtotal**	**115.61**
				Average	**241.2242**	**Total**	**1990.1**

Table A7-15. Artificial Runoff Medium Concentration Effluent Falling Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-EFH-TSS	1.19698	1.24986	250	211.52		52.88
2	OR1-T2-EFH-TSS	1.20923	1.2603	250	204.28		51.07
3	OR1-T3-EFH-TSS	1.23328	1.28476	250	205.92		51.48
			Average	**750**	**207.24**	**Subtotal**	**155.43**
1	OR2-T1-EFH-TSS	1.22501	1.2859	250	243.56		60.89
2	OR2-T2-EFH-TSS	1.22758	1.2898	250	248.88		62.22
3	OR2-T3-EFH-TSS	1.22985	1.28402	250	216.68		54.17
			Average	**750**	**236.3733**	**Subtotal**	**177.28**
1	OR3-T1-EFH-TSS	1.24797	1.30101	250	212.16		53.04
2	OR3-T2-EFH-TSS	1.25008	1.30346	250	213.52		53.38
3	OR3-T3-EFH-TSS	1.23684	1.29692	250	240.32		60.08
			Average	**750**	**222**	**Subtotal**	**166.5**
1	OR4-T1-EFH-TSS	1.22465	1.27949	250	219.36		54.84
2	OR4-T2-EFH-TSS	1.21588	1.26828	250	209.6		52.4
3	OR4-T3-EFH-TSS	1.21798	1.2877	250	278.88		69.72
			Average	**750**	**235.9467**	**Subtotal**	**176.96**
1	OR5-T1-EFH-TSS	1.22023	1.28485	250	258.48		64.62
2	OR5-T2-EFH-TSS	1.25629	1.31273	250	225.76		56.44
3	OR5-T3-EFH-TSS	1.22297	1.2835	250	242.12		60.53
			Average	**750**	**242.12**	**Subtotal**	**181.59**
1	OR6-T1-EFH-TSS	1.24609	1.3059	250	239.24		59.81
2	OR6-T2-EFH-TSS	1.26215	1.32276	250	242.44		60.61
3	OR6-T3-EFH-TSS	1.25454	1.32751	250	291.88		72.97
			Average	**750**	**257.8533**	**Subtotal**	**193.39**
1	OR7-T1-EFH-TSS	1.24017	1.29958	250	237.64		59.41
2	OR7-T2-EFH-TSS	1.24585	1.3039	250	232.2		58.05
3	OR7-T3-EFH-TSS	1.2352	1.30772	250	290.08		72.52
			Average	**750**	**253.3067**	**Subtotal**	**189.98**
1	OR8-T1-EFH-TSS	1.26868	1.32302	250	217.36		54.34
2	OR8-T2-EFH-TSS	1.25028	1.30848	250	232.8		58.2
3	OR8-T3-EFH-TSS	1.22144	1.27129	250	199.4		49.85
			Average	**750**	**216.52**	**Subtotal**	**162.39**
1	OR9-T1-EFH-TSS	1.20387	1.26095	250	228.32		57.08
2	OR9-T2-EFH-TSS	1.21637	1.27449	250	232.48		58.12
3	OR9-T3-EFH-TSS	1.23062	1.28739	250	227.08		56.77
			Average	**750**	**229.2933**	**Subtotal**	**171.97**
1	OR10-T1-EFH-TSS	1.21059	1.28076	250	280.68		70.17
2	OR10-T2-EFH-TSS	1.23909	1.30909	250	280		70
3	OR10-T3-EFH-TSS	1.25145	1.32227	250	283.28		70.82
			Average	**750**	**281.32**	**Subtotal**	**210.99**
				Average	**216.543**	**Total**	**1786.48**

Table A7-16. Artificial Runoff Medium Concentration Effluent Constant Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	S1-T1-EFH-TSS	1.19334	1.19819	250	19.4		4.85
2	S1-T2-EFH-TSS	1.22517	1.22975	250	18.32		4.58
3	S1-T3-EFH-TSS	1.19158	1.19818	250	26.4		6.6
			Average	**750**	**21.37333**	**Subtotal**	**16.03**
1	S2-T1-EFH-TSS	1.24056	1.24716	250	26.4		6.6
2	S2-T2-EFH-TSS	1.22755	1.23164	250	16.36		4.09
3	S2-T3-EFH-TSS	1.2424	1.24695	250	18.2		4.55
			Average	**750**	**20.32**	**Subtotal**	**15.24**
1	S3-T1-EFH-TSS	1.23229	1.23893	250	26.56		6.64
2	S3-T2-EFH-TSS	1.20784	1.21483	250	27.96		6.99
3	S3-T3-EFH-TSS	1.24867	1.25546	250	27.16		6.79
			Average	**750**	**27.22667**	**Subtotal**	**20.42**
1	S4-T1-EFH-TSS	1.18349	1.18925	250	23.04		5.76
2	S4-T2-EFH-TSS	1.24337	1.24906	250	22.76		5.69
3	S4-T3-EFH-TSS	1.25621	1.26125	250	20.16		5.04
			Average	**750**	**21.98667**	**Subtotal**	**16.49**
1	S5-T1-EFH-TSS	1.25495	1.26122	250	25.08		6.27
2	S5-T2-EFH-TSS	1.23391	1.23995	250	24.16		6.04
3	S5-T3-EFH-TSS	1.20958	1.21594	250	25.44		6.36
			Average	**750**	**24.89333**	**Subtotal**	**18.67**
1	S6-T1-EFH-TSS	1.25674	1.2626	250	23.44		5.86
2	S6-T2-EFH-TSS	1.24067	1.24658	250	23.64		5.91
3	S6-T3-EFH-TSS	1.26815	1.27385	250	22.8		5.7
			Average	**750**	**23.29333**	**Subtotal**	**17.47**
1	S7-T1-EFH-TSS	1.24467	1.24936	250	18.76		4.69
2	S7-T2-EFH-TSS	1.26482	1.26981	250	19.96		4.99
3	S7-T3-EFH-TSS	1.2502	1.25477	250	18.28		4.57
			Average	**750**	**19**	**Subtotal**	**14.25**
1	S8-T1-EFH-TSS	1.26629	1.27098	250	18.76		4.69
2	S8-T2-EFH-TSS	1.25038	1.25515	250	19.08		4.77
3	S8-T3-EFH-TSS	1.24617	1.25098	250	19.24		4.81
			Average	**750**	**19.02667**	**Subtotal**	**14.27**
1	S9-T1-EFH-TSS	1.2051	1.20951	250	17.64		4.41
2	S9-T2-EFH-TSS	1.24766	1.25204	250	17.52		4.38
3	S9-T3-EFH-TSS	1.22283	1.22741	250	18.32		4.58
			Average	**750**	**17.82667**	**Subtotal**	**13.37**
1	S10-T1-EFH-TSS	1.20672	1.22425	250	70.12		17.53
2	S10-T2-EFH-TSS	1.23774	1.25747	250	78.92		19.73
3	S10-T3-EFH-TSS	1.229	1.24752	250	74.08		18.52
			Average	**750**	**74.37333**	**Subtotal**	**55.78**
				Average	**26.932**	**Total**	**201.99**

Appendix – 8: Artificial Runoff Low Concentration Tests Results

Artificial Runoff Low Concentration
Material used: Ohio Ready Mix Concrete (Sample –IX)

Diameter of Sample, D:	10.16 cm
Area, A:	81.07 cm^2
Average Length, L:	14.8 cm
Volume:	1201.2 cm^3
Weight $_{PVC+Concrete}$	2267.6 g

Table A8-1. Initial Data of Artificial Runoff Medium Concentration

$Vol_{Conc\ Runoff}$	=	L
$Mass_{A\text{-}6\ Soil}$	=	1.35 g
$Vol_{Filling\ Tank}$	=	150 L
Initial pH	7.06	
Initial Temp	21.96	°C

Table A8-2. Target Low Concentration in Artificial Roadway Runoff

Metal	Low
total Cd (μg/L)	20
total Cr (μg/L)	25
total Cu (μg/L)	35
total Fe (μg/L)	250
total Ni (μg/L)	95
total Pb (μg/L)	215
total Zn (μg/L)	25
pH	7.0±0.1
TSS (mg/L)	10

IFH ==> Influent Falling Head
EFH ==> Effluent Falling Head
ECH ==> Effluent Constant Head

Table A8-3. Influent and Effluent Low Concentration pH and Temperature

IFH			EFH			ECH		
Run	**1**	**IFH**	**Run**	**1**	**EFH**	**Run**	**1**	**ECH**
Temp:	22.72	°C	Temp:	23.61	°C	Temp:	23.53	°C
pH:	7.24		pH:	7.39		pH:	7.13	
Run	**2**	**IFH**	**Run**	**2**	**EFH**	**Run**	**2**	**ECH**
Temp:	24.15	°C	Temp:	23.21	°C	Temp:	22.53	°C
pH:	7.34		pH:	7.44		pH:	7.56	
Run	**3**	**IFH**	**Run**	**3**	**EFH**	**Run**	**3**	**ECH**
Temp:	23.1	°C	Temp:	23.28	°C	Temp:	23.52	°C
pH:	7.3		pH:	7.5		pH:	7.6	
Run	**4**	**IFH**	**Run**	**4**	**EFH**	**Run**	**4**	**ECH**
Temp:	22.98	°C	Temp:	23.64	°C	Temp:	23.46	°C
pH:	7.46		pH:	7.64		pH:	7.63	
Run	**5**	**IFH**	**Run**	**5**	**EFH**	**Run**	**5**	**ECH**
Temp:	23.66	°C	Temp:	23.71	°C	Temp:	23.27	°C
pH:	7.83		pH:	8.07		pH:	7.6	
Run	**6**	**IFH**	**Run**	**6**	**EFH**	**Run**	**6**	**ECH**
Temp:	23.56	°C	Temp:	23.13	°C	Temp:	23.01	°C
pH:	8.1		pH:	8.25		pH:	7.69	
Run	**7**	**IFH**	**Run**	**7**	**EFH**	**Run**	**7**	**ECH**
Temp:	22.95	°C	Temp:	23.12	°C	Temp:	23.3	°C
pH:	7.63		pH:	7.7		pH:	7.66	
Run	**8**	**IFH**	**Run**	**8**	**EFH**	**Run**	**8**	**ECH**
Temp:	23.31	°C	Temp:	23.24	°C	Temp:	23.29	°C
pH:	8.02		pH:	8.22		pH:	7.73	
Run	**9**	**IFH**	**Run**	**9**	**EFH**	**Run**	**9**	**ECH**
Temp:	23.33	°C	Temp:	23.74	°C	Temp:	23.38	°C
pH:	8.15		pH:	8.26		pH:	7.74	
Run	**10**	**IFH**	**Run**	**10**	**EFH**	**Run**	**10**	**ECH**
Temp:	23.77	°C	Temp:	23.74	°C	Temp:	23.43	°C
pH:	8.17		pH:	8.28		pH:	7.75	

After test – 6 2 mL of H_2SO_4 is added to adjust the pH to 7.22

Table A8-4. Artificial Runoff Low Concentration Falling Head Permeability

Test No.	H_1	H_2	Head	t	L	h_1/h_2	Temperature	$k_{@20°C}$	k_T	$Mass_{in}$	$Mass_{out}$
	(cm)	(cm)	(cm)	(s)	(cm)		(°C)	(cm/s)	(cm/s)	(g)	(g)
1	94.6	48.9	45.7	1.88	14.90133	1.935065	23.61	4.804946	5.232436	10000	9959.3
2	94.6	48.9	45.7	1.87	14.90133	1.935065	23.2	4.875354	5.260417	10000	10004.8
3	94.6	48.9	45.7	1.89	14.90133	1.935065	23.3	4.812833	5.204751	10000	9992.8
4	94.6	48.9	45.7	1.91	14.90133	1.935065	23.6	4.729475	5.150251	10000	9944.8
5	94.6	48.9	45.7	1.9	14.90133	1.935065	23.7	4.742977	5.177358	10000	9956.6
6	94.6	48.9	45.7	1.9	14.90133	1.935065	23.1	4.809765	5.177358	10000	9920
7	94.6	48.9	45.7	1.9	14.90133	1.935065	23.1	4.809765	5.177358	10000	9944.7
8	94.6	48.9	45.7	1.89	14.90133	1.935065	23.2	4.823763	5.204751	10000	9976.5
9	94.6	48.9	45.7	1.88	14.90133	1.935065	23.8	4.782446	5.232436	10000	9976.5
10	94.6	48.9	45.7	1.87	14.90133	1.935065	23.7	4.819068	5.260417	10000	9951.9

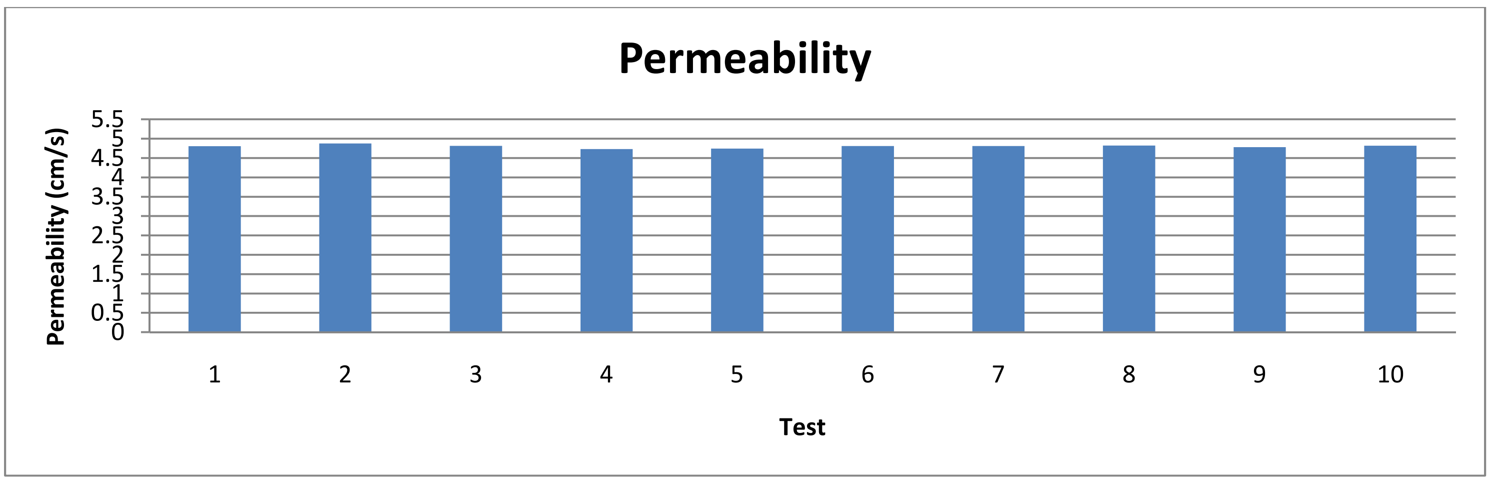

Figure A8-1. Artificial runoff low concentration falling head permeability

Artificial Runoff low Concentration Effluent Constant Head Permeability
Material Used:Green Sand
Diameter, D 10.2 cm
Area, A 81.1 cm2
Length, L 10.16 cm

Table A8-5. Greensand Test-1

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	40.5	19	21.5	910	60	0.187074	0.47255814	23.6	0.081
2	42.5	17	25.5	905	60	0.186046	0.398431373	23.6	0.068
3	46.5	22	24.5	915	60	0.188102	0.414693878	23.6	0.072
								Average =	0.074

Table A8-6. Greensand Test-2

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	39.5	13.5	26	910	60	0.187074	0.39076923	23.2	0.068
2	47.5	24	23.5	915	60	0.188102	0.43234042	23.2	0.075
3	47	24	23	920	60	0.18913	0.44173913	23.2	0.077
4	46	23	23	905	60	0.186046	0.44173913	23.2	0.076
								Average =	0.074

Table A8-7. Greensand Test-3

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	43.5	20	23.5	940	60	0.193241	0.432340426	23.3	0.077255
2	47	24.5	22.5	940	60	0.193241	0.451555556	23.3	0.080688
3	44.5	22	22.5	925	60	0.190157	0.451555556	23.3	0.079401
4	45	22.5	22.5	925	60	0.190157	0.451555556	23.3	0.079401
								Average =	0.079186

Table A8-8. Greensand Test-4

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	43	20.5	22.5	945	60	0.194269	0.451555556	23.6	0.080556
2	40	17	23	940	60	0.193241	0.44173913	23.6	0.078388
3	44.5	22.5	22	925	60	0.190157	0.461818182	23.6	0.080643
4	43.5	21.5	22	930	60	0.191185	0.461818182	23.6	0.081079
								Average =	0.080167

Table A8-9. Greensand Test-5

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	43	20.5	22.5	945	60	0.194269	0.451555556	23.7	0.080363
2	44	22	22	935	60	0.192213	0.461818182	23.7	0.08132
3	45.5	24.5	21	945	60	0.194269	0.483809524	23.7	0.086103
4	43	21	22	950	60	0.195297	0.461818182	23.7	0.082625
								Average =	0.082603

Table A8-10. Greensand Test-6

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	43.5	22	21.5	935	60	0.192213	0.47255814	23.1	0.084383
2	43	21.5	21.5	930	60	0.191185	0.47255814	23.1	0.083932
3	43	21.5	21.5	930	60	0.191185	0.47255814	23.1	0.083932
4	46	25.5	20.5	905	60	0.186046	0.495609756	23.1	0.08566
								Average =	0.084476

Table A8-11. Greensand Test-7

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	43	22	21	940	60	0.19324	0.48380952	23.1	0.08685
2	42.5	21	21.5	945	60	0.19427	0.47255814	23.1	0.08529
3	43	22	21	925	60	0.19016	0.48380952	23.1	0.08547
4	42	21	21	945	60	0.19427	0.48380952	23.1	0.08732
								Average =	0.08623

Table A8-12. Greensand Test-8

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	42	21	21	945	60	0.194269	0.483809524	23.2	0.087109
2	43	22	21	930	60	0.191185	0.483809524	23.2	0.085726
3	43	22	21	910	60	0.187074	0.483809524	23.2	0.083883
4	43	22	21	935	60	0.192213	0.483809524	23.2	0.086187
								Average =	0.085726

Table A8-13Greensand Test-9

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	40	19	21	940	60	0.193241	0.483809524	23.7	0.085648
2	40	19	21	935	60	0.192213	0.483809524	23.7	0.085192
3	41.5	20.5	21	920	60	0.18913	0.483809524	23.7	0.083826
4	40.5	19.5	21	935	60	0.192213	0.483809524	23.7	0.085192
								Average =	0.084965

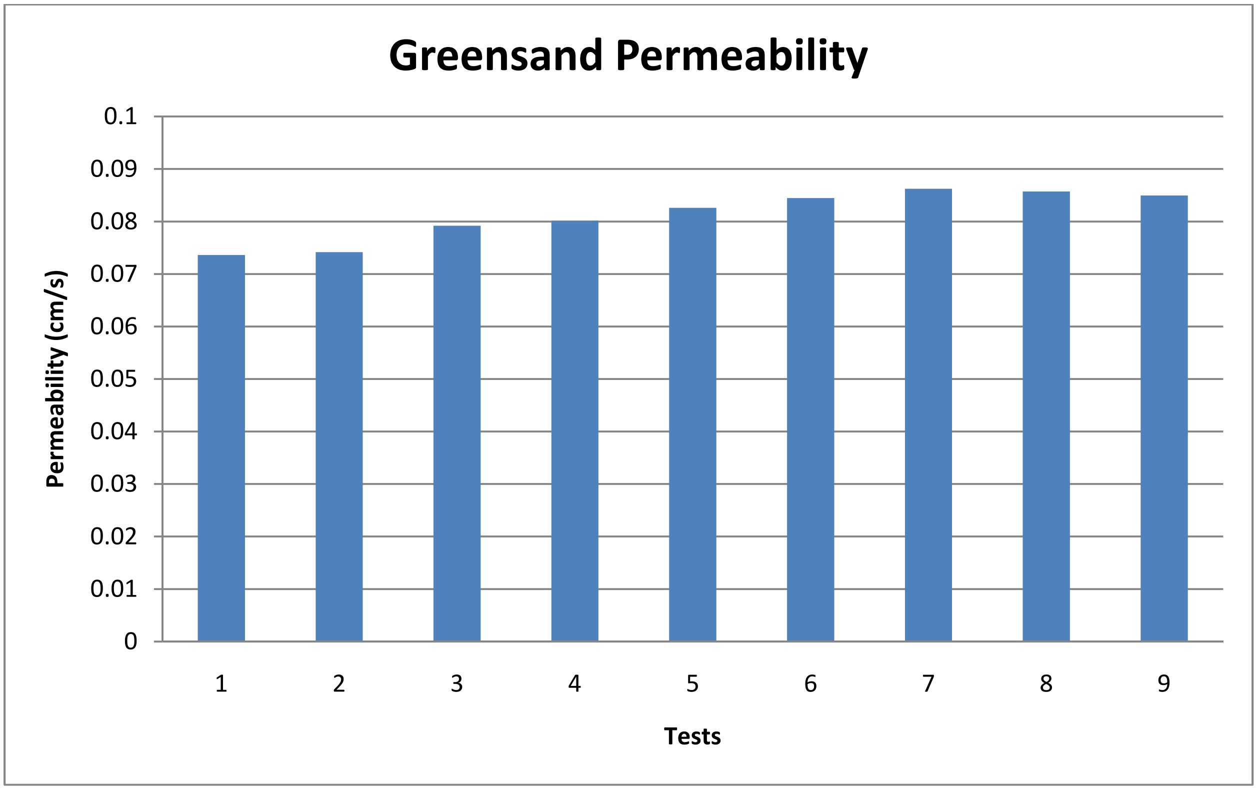

Figure A8-2. Greensand permeability

The constant head permeability did not reduced at all.

Table A8-14. Artificial Runoff Low Concentration Influent Falling Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-IFH-TSS	1.23732	1.23949	250	8.68		2.17
2	OR1-T2-IFH-TSS	1.25557	1.25919	250	14.48		3.62
3	OR1-T3-IFH-TSS	1.28859	1.29089	250	9.2		2.3
			Average	**750**	**10.78667**	**Subtotal**	**8.09**
1	OR2-T1-IFH-TSS	1.25176	1.25532	250	14.24		3.56
2	OR2-T2-IFH-TSS	1.26858	1.27204	250	13.84		3.46
3	OR2-T3-IFH-TSS	1.25433	1.2581	250	15.08		3.77
			Average	**750**	**14.38667**	**Subtotal**	**10.79**
1	OR3-T1-IFH-TSS	1.27168	1.27733	250	22.6		5.65
2	OR3-T2-IFH-TSS	1.26019	1.26359	250	13.6		3.4
3	OR3-T3-IFH-TSS	1.25179	1.25617	250	17.52		4.38
			Average	**750**	**17.90667**	**Subtotal**	**13.43**
1	OR4-T1-IFH-TSS	1.27025	1.27204	250	7.16		1.79
2	OR4-T2-IFH-TSS	1.25042	1.25362	250	12.8		3.2
3	OR4-T3-IFH-TSS	1.20544	1.20864	250	12.8		3.2
			Average	**750**	**10.92**	**Subtotal**	**8.19**
1	OR5-T1-IFH-TSS	1.25002	1.25291	250	11.56		2.89
2	OR5-T2-IFH-TSS	1.25031	1.25323	250	11.68		2.92
3	OR5-T3-IFH-TSS	1.2272	1.23063	250	13.72		3.43
			Average	**750**	**12.32**	**Subtotal**	**9.24**
1	OR6-T1-IFH-TSS	1.25081	1.25385	250	12.16		3.04
2	OR6-T2-IFH-TSS	1.27189	1.27492	250	12.12		3.03
3	OR6-T3-IFH-TSS	1.25812	1.2609	250	11.12		2.78
			Average	**750**	**11.8**	**Subtotal**	**8.85**
1	OR7-T1-IFH-TSS	1.22094	1.22478	250	15.36		3.84
2	OR7-T2-IFH-TSS	1.24343	1.247	250	14.28		3.57
3	OR7-T3-IFH-TSS	1.2656	1.27026	250	18.64		4.66
			Average	**750**	**16.09333**	**Subtotal**	**12.07**
1	OR8-T1-IFH-TSS	1.25502	1.2579	250	11.52		2.88
2	OR8-T2-IFH-TSS	1.23109	1.23422	250	12.52		3.13
3	OR8-T3-IFH-TSS	1.24658	1.24935	250	11.08		2.77
			Average	**750**	**11.70667**	**Subtotal**	**8.78**
1	OR9-T1-IFH-TSS	1.23927	1.24285	250	14.32		3.58
2	OR9-T2-IFH-TSS	1.27566	1.27917	250	14.04		3.51
3	OR9-T3-IFH-TSS	1.22882	1.23271	250	15.56		3.89
			Average	**750**	**14.64**	**Subtotal**	**10.98**
1	OR10-T1-IFH-TSS	1.24973	1.25255	250	11.28		2.82
2	OR10-T2-IFH-TSS	1.24531	1.24841	250	12.4		3.1
3	OR10-T3-IFH-TSS	1.23311	1.23564	250	10.12		2.53
			Average	**750**	**11.26667**	**Subtotal**	**8.45**
				Average	**13.18267**	**Total**	**98.87**

Table A8-15. Artificial Runoff Low Concentration Effluent Falling Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	OR1-T1-EFH-TSS	1.26421	1.26778	250	14.28		3.57
2	OR1-T2-EFH-TSS	1.23939	1.24215	250	11.04		2.76
3	OR1-T3-EFH-TSS	1.2307	1.23367	250	11.88		2.97
			Average	**750**	**12.4**	**Subtotal**	**9.3**
1	OR2-T1-EFH-TSS	1.24611	1.24939	250	13.12		3.28
2	OR2-T2-EFH-TSS	1.21926	1.22283	250	14.28		3.57
3	OR2-T3-EFH-TSS	1.24881	1.25224	250	13.72		3.43
			Average	**750**	**13.70667**	**Subtotal**	**10.28**
1	OR3-T1-EFH-TSS	1.25124	1.25342	250	8.72		2.18
2	OR3-T2-EFH-TSS	1.2438	1.24617	250	9.48		2.37
3	OR3-T3-EFH-TSS	1.24269	1.2453	250	10.44		2.61
			Average	**750**	**9.546667**	**Subtotal**	**7.16**
1	OR4-T1-EFH-TSS	1.23831	1.24081	250	10		2.5
2	OR4-T2-EFH-TSS	1.23545	1.23767	250	8.88		2.22
3	OR4-T3-EFH-TSS	1.24935	1.25232	250	11.88		2.97
			Average	**750**	**10.25333**	**Subtotal**	**7.69**
1	OR5-T1-EFH-TSS	1.21419	1.21712	250	11.72		2.93
2	OR5-T2-EFH-TSS	1.25183	1.2543	250	9.88		2.47
3	OR5-T3-EFH-TSS	1.26827	1.27128	250	12.04		3.01
			Average	**750**	**11.21333**	**Subtotal**	**8.41**
1	OR6-T1-EFH-TSS	1.28799	1.29005	250	8.24		2.06
2	OR6-T2-EFH-TSS	1.25096	1.25395	250	11.96		2.99
3	OR6-T3-EFH-TSS	1.26367	1.26604	250	9.48		2.37
			Average	**750**	**9.893333**	**Subtotal**	**7.42**
1	OR7-T1-EFH-TSS	1.24105	1.24386	250	11.24		2.81
2	OR7-T2-EFH-TSS	1.22472	1.2274	250	10.72		2.68
3	OR7-T3-EFH-TSS	1.2566	1.25957	250	11.88		2.97
			Average	**750**	**11.28**	**Subtotal**	**8.46**
1	OR8-T1-EFH-TSS	1.25198	1.25447	250	9.96		2.49
2	OR8-T2-EFH-TSS	1.23337	1.23614	250	11.08		2.77
3	OR8-T3-EFH-TSS	1.28272	1.28566	250	11.76		2.94
			Average	**750**	**10.93333**	**Subtotal**	**8.2**
1	OR9-T1-EFH-TSS	1.25856	1.26129	250	10.92		2.73
2	OR9-T2-EFH-TSS	1.24762	1.2502	250	10.32		2.58
3	OR9-T3-EFH-TSS	1.26126	1.26397	250	10.84		2.71
			Average	**750**	**10.69333**	**Subtotal**	**8.02**
1	OR10-T1-EFH-TSS	1.23965	1.24178	250	8.52		2.13
2	OR10-T2-EFH-TSS	1.25843	1.26035	250	7.68		1.92
3	OR10-T3-EFH-TSS	1.26056	1.26268	250	8.48		2.12
			Average	**750**	**8.226667**	**Subtotal**	**6.17**
				Average	**10.81467**	**Total**	**81.11**

Table A8-16. Artificial Runoff Low Concentration Effluent Constant Head Permeability TSS

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS/Vol	TSS	
	g	g	g	mL	mg/L	mg	
1	S1-T1-EFH-TSS	1.26595	1.26878	250	11.32		2.83
2	S1-T2-EFH-TSS	1.24815	1.24994	250	7.16		1.79
3	S1-T3-EFH-TSS	1.27557	1.27805	250	9.92		2.48
			Average	**750**	**9.466667**	**Subtotal**	**7.1**
1	S2-T1-EFH-TSS	1.21596	1.2163	250	1.36		0.34
2	S2-T2-EFH-TSS	1.25738	1.25777	250	1.56		0.39
3	S2-T3-EFH-TSS	1.24127	1.24164	250	1.48		0.37
			Average	**750**	**1.466667**	**Subtotal**	**1.1**
1	S3-T1-EFH-TSS	1.22312	1.2232	250	0.32		0.08
2	S3-T2-EFH-TSS	1.25162	1.25189	250	1.08		0.27
3	S3-T3-EFH-TSS	1.27057	1.27105	250	1.92		0.48
			Average	**750**	**1.106667**	**Subtotal**	**0.83**
1	S4-T1-EFH-TSS	1.24606	1.24649	250	1.72		0.43
2	S4-T2-EFH-TSS	1.24693	1.24693	250	0		0
3	S4-T3-EFH-TSS	1.27863	1.27893	250	1.2		0.3
			Average	**750**	**0.973333**	**Subtotal**	**0.73**
1	S5-T1-EFH-TSS	1.21789	1.21806	250	0.68		0.17
2	S5-T2-EFH-TSS	1.22616	1.22625	250	0.36		0.09
3	S5-T3-EFH-TSS	1.26844	1.27067	250	8.92		2.23
			Average	**750**	**3.32**	**Subtotal**	**2.49**
1	S6-T1-EFH-TSS	1.24803	1.24803	250	0		0
2	S6-T2-EFH-TSS	1.23533	1.23545	250	0.48		0.12
3	S6-T3-EFH-TSS	1.26502	1.26546	250	1.76		0.44
			Average	**750**	**0.746667**	**Subtotal**	**0.56**
1	S7-T1-EFH-TSS	1.26793	1.26808	250	0.6		0.15
2	S7-T2-EFH-TSS	1.26239	1.26259	250	0.8		0.2
3	S7-T3-EFH-TSS	1.22983	1.2301	250	1.08		0.27
			Average	**750**	**0.826667**	**Subtotal**	**0.62**
1	S8-T1-EFH-TSS	1.28168	1.28168	250	0		0
2	S8-T2-EFH-TSS	1.27073	1.27078	250	0.2		0.05
3	S8-T3-EFH-TSS	1.2822	1.28223	250	0.12		0.03
			Average	**750**	**0.106667**	**Subtotal**	**0.08**
1	S9-T1-EFH-TSS	1.2246	1.2246	250	0		0
2	S9-T2-EFH-TSS	1.25745	1.25745	250	0		0
3	S9-T3-EFH-TSS	1.2517	1.2517	250	0		0
			Average	**750**	**0**	**Subtotal**	**0**
1	S10-T1-EFH-TSS	1.26713	1.26721	250	0.32		0.08
2	S10-T2-EFH-TSS	1.24542	1.2457	250	1.12		0.28
3	S10-T3-EFH-TSS	1.25545	1.25593	250	1.92		0.48
			Average	**750**	**1.12**	**Subtotal**	**0.84**
				Average	**1.913333**	**Total**	**7.25**

Appendix – 9: Compressive Strength of Pervious Concrete Tests Results

Compressive Strength of Pervious Concrete
Specimen 11

Table A9-1. Pervious Concrete Specimen 11 Properties

Specimen	Specimen Diameter	Specimen Height	Specimen Weight	Specimen Unit Weight	Peak Load	Unconfined Compression Strength
No	in	in	lb	lb/ft3	lb	psi
11	4	8.17	5.324	91.57	6040	480.65

Table A9-2. Compressive Strength of Pervious Concrete Specimen 11

Reading	Dial Gauge Reading	Division Unit	Deflection	Strain	Load	Stress
		in	in	in/in	lb	psi
1	5	0.001	0.005	0.000625	160	12.7324
2	10	0.001	0.01	0.00125	240	19.09859
3	15	0.001	0.015	0.001875	300	23.87324
4	20	0.001	0.02	0.0025	400	31.83099
5	25	0.001	0.025	0.003125	540	42.97183
6	30	0.001	0.03	0.00375	760	60.47888
7	35	0.001	0.035	0.004375	1060	84.35212
8	40	0.001	0.04	0.005	1620	128.9155
9	45	0.001	0.045	0.005625	2680	213.2676
10	50	0.001	0.05	0.00625	4160	331.0423
11	55	0.001	0.055	0.006875	5600	445.6338
12	60	0.001	0.06	0.0075	6040	480.6479
13	65	0.001	0.065	0.008125	5300	421.7606
14	70	0.001	0.07	0.00875	2280	181.4366
15	75	0.001	0.075	0.009375	1260	100.2676

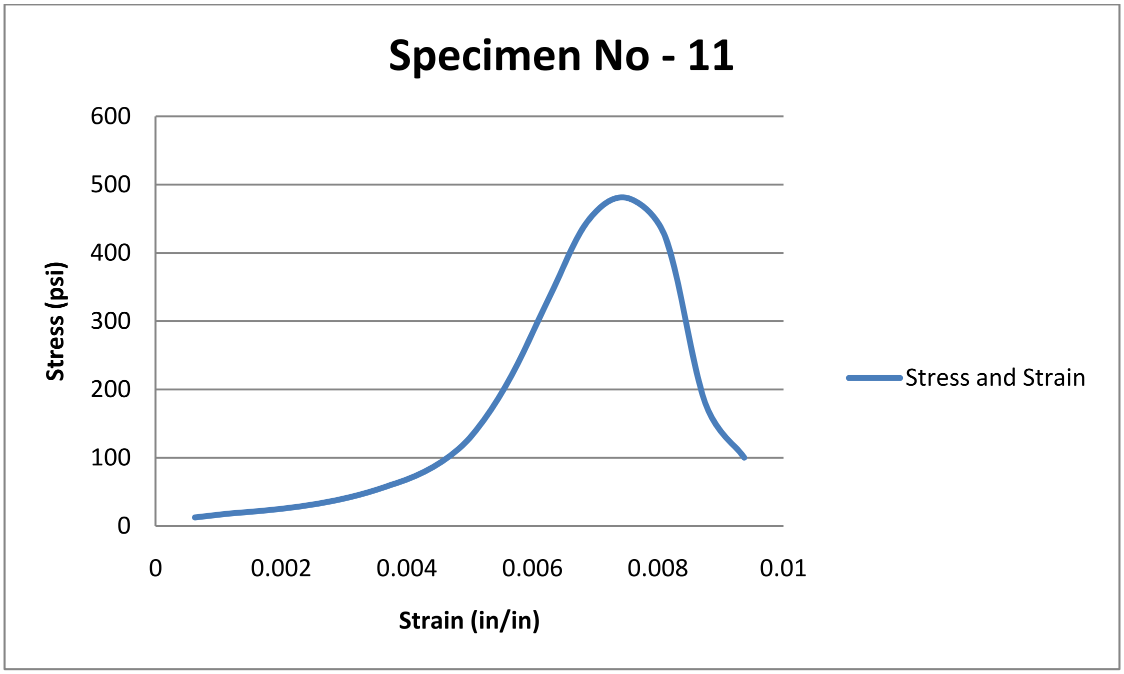

Figure A9-1. Compressive strength of pervious concrete specimen 11

Note: Specimen showed unpredictable behavior. The above data cannot be representative for the analysis.

Specimen – 12

Table A9-3. Pervious Concrete Specimen 12 Properties

Specimen	Specimen Diameter	Specimen Height	Specimen Weight	Specimen Unit Weight	Peak Load	Unconfined Compression Strength
	in	in	lb	lb/ft3	lb	psi
12	4	8.25	5.346	91.95	2940	233.96

Table A9-4. Compressive Strength of Pervious Concrete Specimen 12

Reading	Dial Gauge Reading	Division Unit	Deflection	Strain	Load	Stress
		in	in	in/in	lb	psi
1	5	0.001	0.005	0.000625	280	22.28169
2	10	0.001	0.01	0.00125	340	27.05634
3	15	0.001	0.015	0.001875	480	38.19719
4	20	0.001	0.02	0.0025	520	41.38029
5	25	0.001	0.025	0.003125	720	57.29578
6	30	0.001	0.03	0.00375	960	76.39437
7	35	0.001	0.035	0.004375	1420	113
8	40	0.001	0.04	0.005	2320	184.6197
9	45	0.001	0.045	0.005625	2940	233.9578
10	50	0.001	0.05	0.00625	1250	99.47184
11	55	0.001	0.055	0.006875	640	50.92958

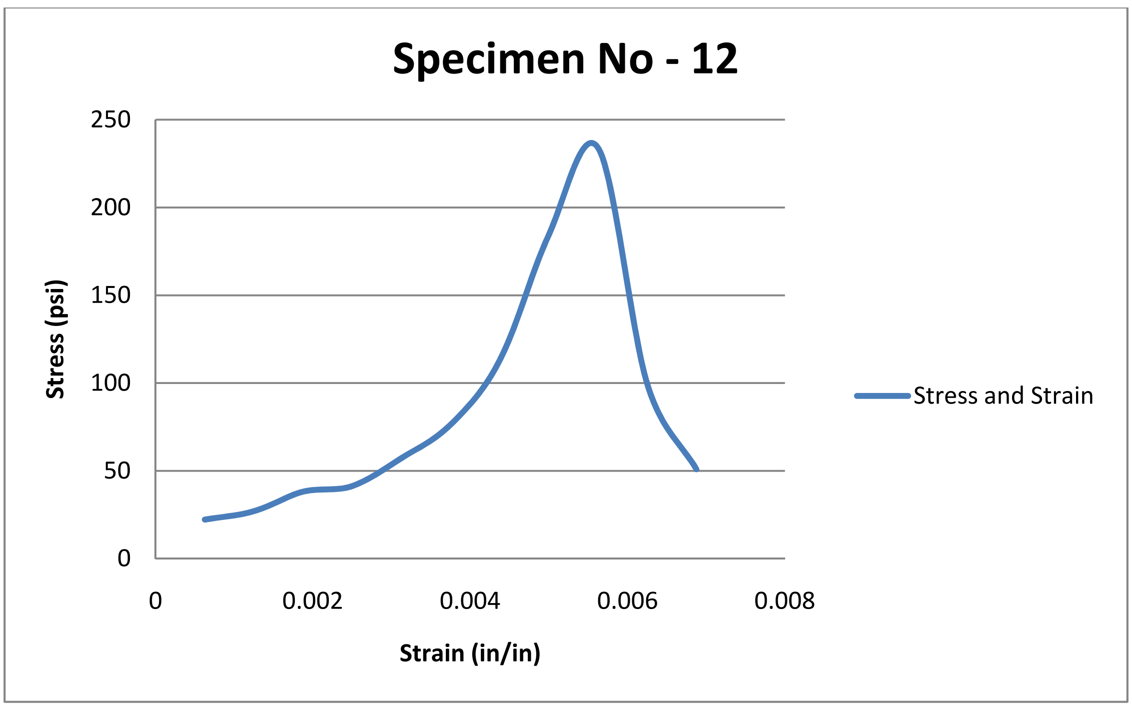

Figure A9-2. Compressive strength of pervious concrete specimen 12

Specimen – 13

Table A9-5. Pervious Concrete Specimen 13 Properties

Specimen	Specimen Diameter	Specimen Height	Specimen Weight	Specimen Unit Weight	Peak Load	Unconfined Compression Strength
	in	in	lb	lb/ft3	lb	psi
13	4	8.25	5.478	94.22	2620	208.49

Table A9-6. Compressive Strength of Pervious Concrete Specimen 13

Reading	Dial Gauge Reading	Division Unit	Deflection	Strain	Load	Stress
		in	in	in/in	lb	psi
1	5	0.001	0.005	0.000625	100	7.957747
2	10	0.001	0.01	0.00125	160	12.7324
3	15	0.001	0.015	0.001875	260	20.69014
4	20	0.001	0.02	0.0025	260	20.69014
5	25	0.001	0.025	0.003125	540	42.97183
6	30	0.001	0.03	0.00375	1000	79.57747
7	35	0.001	0.035	0.004375	1900	151.1972
8	40	0.001	0.04	0.005	2520	200.5352
9	45	0.001	0.045	0.005625	2620	208.493
10	50	0.001	0.05	0.00625	1520	120.9578
11	55	0.001	0.055	0.006875	520	41.38029

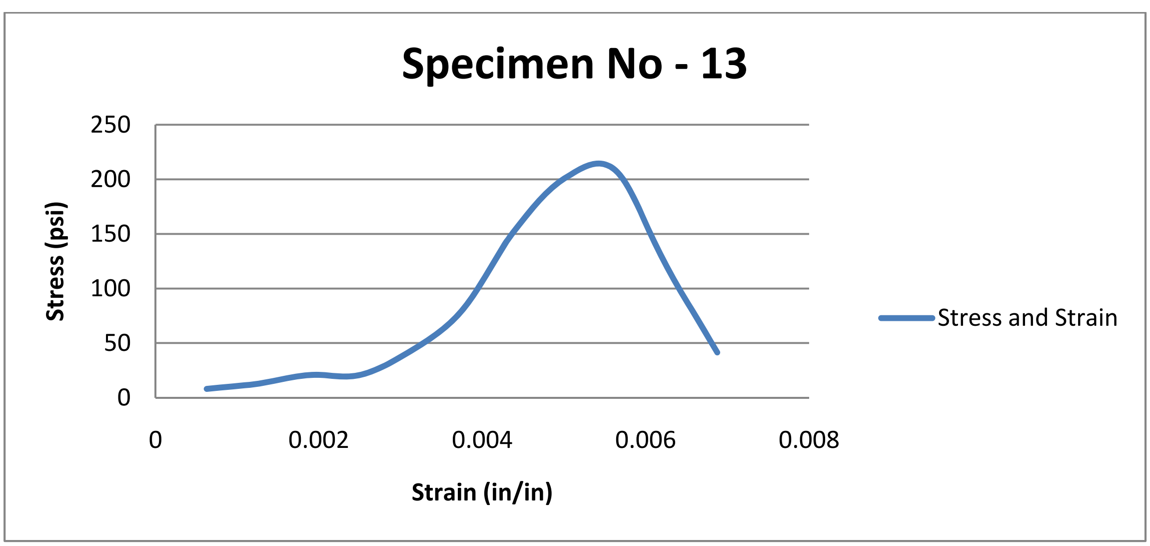

Figure A9-3. Compressive strength of pervious concrete specimen 13(A9-3)

Appendix – 10: Rapid Freeze and Thaw Tests Results

Rapid Freeze and Thaw Test of Pervious Concrete

Table A10-1. Initial Properties of Pervious Concrete Specimen for Rapid Freeze and Thaw Test

Specimen - II											
Initial Mass =	4639.3	g		**Initial Mass =**	4639.3	g		**Initial Mass =**	4639.3	g	
Length =	16	in		**Length =**	16.0	in		**Length =**	16.0	in	
	15.7	in			15.8	in			15.8	in	
	15.9	in			15.9	in			15.9	in	
Average =	15.9	in	40.3cm	**Average =**	15.9	in	40.4cm	**Average =**	15.9	in	40.4cm
Width =	4	in		**Width =**	4.0	in		**Width =**	4.0	in	
	3.8	in			3.8	in			3.8	in	
	3.9	in			3.8	in			3.8	in	
Average =	3.9	in	9.8cm	**Average =**	3.8	in	9.7cm	**Average =**	3.8	in	9.7cm
Thickness =	2.8	in		**Thickness =**	2.9	in		**Thickness =**	2.9	in	
	3.0	in			3.0	in			3.0	in	
	3.1	in			3.1	in			3.1	in	
Average =	3.1	in	7.7cm	**Average =**	3.1	in	7.7cm	**Average =**	3.1	in	7.7cm

Table A10-2 Rapid Freeze and Thaw Test Result

Specimen	Initial Mass	Final Mass	Mass Loss	Mass Loss (%)	Number of Cycle
1	4639.3	3696.1	943.2	20.3	22
2	4480.5	3877.7	829	18.5	22
3	4702.7	3783.6	919.1	19.5	22

Appendix – 11: Backfill Type 3 Tests Results

Table A11-1. Backfill Type 3 Gravel Permeability and Total Suspended Solids Washed Specimen-I

Backfill Type 3 Gravel (Washed)						
Specimen	Test	$k_{@°C}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
I	1	4.25	1235.56	1.00	88	7.1223E-05
				1.00	117	9.46942E-05
				1.00	108.9	8.81385E-05
				1.00	114.7	9.28327E-05
				1.00	116.1	9.39658E-05
				1.00	124.9	0.000101088
				1.00	131.3	0.000106268
				1.00	126	0.000101978
				1.00	116.7	9.44514E-05
				1.00	220.1	0.000178138
				10.00	1263.7	0.001022779
I	2	4.19	1235.56	1.00	8.7	7.04137E-06
				1.00	9.5	7.68885E-06
				1.00	10.1	8.17446E-06
				1.00	8.5	6.8795E-06
				1.00	7.9	6.39389E-06
				1.00	10.0	8.09353E-06
				1.00	8.7	7.04137E-06
				1.00	5.9	4.77518E-06
				1.00	3.9	3.15647E-06
				1.00	9.8	7.93165E-06
				10.00	83.0	6.71763E-05
I	3	4.25	1235.56	1.00	4.6	3.72302E-06
				1.00	6.2	5.01799E-06
				1.00	4.3	3.48022E-06
				1.00	4.7	3.80396E-06
				1.00	3.4	2.7518E-06
				1.00	3.6	2.91367E-06
				1.00	4.2	3.39928E-06
				1.00	4.8	3.88489E-06
				1.00	3.2	2.58993E-06
				1.00	8.4	6.79856E-06
				10.00	47.40	3.83633E-05
					Grand Total	0.001128318

Table A11-2. Backfill Type 3 Gravel Permeability and Total Suspended Solids Washed Specimen-II

Backfill Type 3 Gravel (Washed)						
Specimen	Test	$k_{@°C}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
II	1	4.51	1235.56	1.00	152.2	0.000123183
				1.00	162.4	0.000131439
				1.00	165.4	0.000133867
				1.00	127	0.000102788
				1.00	207.6	0.000168022
				1.00	156.7	0.000126826
				1.00	159.9	0.000129415
				1.00	190.9	0.000154505
				1.00	101.1	8.18255E-05
				1.00	138.9	0.000112419
				10.00	1562.1	0.00126429
II	2	4.56	1235.56	1.00	18.0	1.45683E-05
				1.00	12.1	9.79317E-06
				1.00	10.2	8.2554E-06
				1.00	2.6	2.10432E-06
				1.00	9.8	7.93165E-06
				1.00	7.1	5.7464E-06
				1.00	4.6	3.72302E-06
				1.00	5.0	4.04676E-06
				1.00	6.2	5.01799E-06
				1.00	10.2	8.2554E-06
				10.00	85.8	6.94424E-05
II	3	4.56	1235.56	1.00	2.9	2.34712E-06
				1.00	2.9	2.34712E-06
				1.00	5.4	4.3705E-06
				1.00	3.5	2.83273E-06
				1.00	2.6	2.10432E-06
				1.00	3.6	2.91367E-06
				1.00	4.8	3.88489E-06
				1.00	5.3	4.28957E-06
				1.00	2.5	2.02338E-06
				1.00	3.2	2.58993E-06
				10.00	36.70	2.97032E-05
					Grand Total	0.001363435

Table A11-3. Backfill Type 3 Gravel Permeability and Total Suspended Solids Washed Specimen-III

Backfill Type 3 Gravel (Washed)						
Specimen	Test	$k_{@°c}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
III	1	4.4	1184.07	1.00	128.1	0.000108186
				1.00	118.9	0.000100416
				1.00	94.1	7.94714E-05
				1.00	115.9	9.78824E-05
				1.00	118.9	0.000100416
				1.00	113.7	9.60244E-05
				1.00	106.1	8.96059E-05
				1.00	119.7	0.000101092
				1.00	113.3	9.56866E-05
				1.00	146.8	0.000123979
				10.00	1175.5	0.000992759
III	2	4.4	1184.07	1.00	7.2	6.0807E-06
				1.00	4.6	3.88489E-06
				1.00	4.5	3.80044E-06
				1.00	6.1	5.1517E-06
				1.00	4.9	4.13825E-06
				1.00	5.3	4.47607E-06
				1.00	5.2	4.39162E-06
				1.00	4.8	4.0538E-06
				1.00	4.4	3.71598E-06
				1.00	6.1	5.1517E-06
				10.00	53.1	4.48452E-05
III	3	4.44	1184.07	1.00	1.8	1.52018E-06
				1.00	1.5	1.26681E-06
				1.00	2.8	2.36472E-06
				1.00	2.0	1.68908E-06
				1.00	1.4	1.18236E-06
				1.00	1.5	1.26681E-06
				1.00	1.9	1.60463E-06
				1.00	1.8	1.52018E-06
				1.00	1.3	1.0979E-06
				1.00	3.7	3.1248E-06
				10.00	19.70	1.66375E-05
					Grand Total	0.001054242

Table A11-4. Backfill Type 3 Gravel Permeability and Total Suspended Solids Unwashed Specimen-I

Backfill Type 3 gravel(Unwashed)						
Specimen	Test	$k_{@°C}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
I	1	3.66	1132.59	1.00	466.8	0.000412152
				1.00	560	0.000494441
				1.00	544.7	0.000480932
				1.00	487	0.000429987
				1.00	492.6	0.000434931
				1.00	325.7	0.00028757
				1.00	486.1	0.000429192
				1.00	483.8	0.000427162
				1.00	456	0.000402616
				1.00	574.4	0.000507155
				10.00	4877.1	0.004306138
I	2	3.66	1132.59	1.00	42.7	3.77011E-05
				1.00	27.4	2.41923E-05
				1.00	26.6	2.34859E-05
				1.00	29.6	2.61347E-05
				1.00	27.2	2.40157E-05
				1.00	25.0	2.20733E-05
				1.00	27.7	2.44572E-05
				1.00	26.7	2.35742E-05
				1.00	26.2	2.31328E-05
				1.00	37.1	3.27567E-05
				10.00	296.2	0.000261524
I	3	3.66	1132.59	1.00	7.9	6.97515E-06
				1.00	8.2	7.24003E-06
				1.00	6.6	5.82734E-06
				1.00	7.1	6.2688E-06
				1.00	6.0	5.29758E-06
				1.00	7.2	6.3571E-06
				1.00	3.7	3.26684E-06
				1.00	5.4	4.76782E-06
				1.00	5.0	4.41465E-06
				1.00	10.0	8.8293E-06
				10.00	67.10	5.92446E-05
					Grand Total	0.004626907

Table A11-5. Backfill Type 3 Gravel Permeability and Total Suspended Solids Unwashed Specimen-II

Backfill Type 3 gravel(Unwashed)						
Specimen	Test	$k_{@°C}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
II	1	4.4	1132.59	1.00	451.6	0.000398731
				1.00	471.8	0.000416566
				1.00	370.9	0.000327479
				1.00	489.6	0.000432283
				1.00	477.9	0.000421952
				1.00	468.9	0.000414006
				1.00	608.5	0.000537263
				1.00	459.2	0.000405441
				1.00	455.4	0.000402086
				1.00	511.8	0.000451884
				10.00	4765.6	0.004207691
II	2	4.3	1132.59	1.00	16.0	1.41269E-05
				1.00	18.9	1.66874E-05
				1.00	13.5	1.19196E-05
				1.00	16.1	1.42152E-05
				1.00	30.5	2.69294E-05
				1.00	14.9	1.31557E-05
				1.00	14.8	1.30674E-05
				1.00	14.2	1.25376E-05
				1.00	14.5	1.28025E-05
				1.00	11.5	1.01537E-05
				10.00	164.9	0.000145595
II	3	4.3	1132.59	1.00	7.5	6.62198E-06
				1.00	8.5	7.50491E-06
				1.00	8.7	7.68149E-06
				1.00	7.3	6.44539E-06
				1.00	5.9	5.20929E-06
				1.00	6.9	6.09222E-06
				1.00	11.5	1.01537E-05
				1.00	8.2	7.24003E-06
				1.00	6.0	5.29758E-06
				1.00	2.4	2.11903E-06
				10.00	72.90	6.43656E-05
					Grand Total	0.004417652

Table A11-6. Backfill Type 3 Gravel Permeability and Total Suspended Solids Washed Specimen-III

Backfill Type 3 gravel(Unwashed)						
Specimen	Test	$k_{@°C}$	Volume of Concrete Specimen	Volume of Water per filter	TSS per Liter	Amount of TSS per Volume of Concrete Specimen
No.	No.	(cm/s)	Cm^3	L	(mg/L)	(gr/cm^3)
III	1	4.52	1192.65	1.00	527.2	0.000442039
				1.00	513.5	0.000430552
				1.00	531.5	0.000445645
				1.00	574.5	0.000481699
				1.00	606.9	0.000508865
				1.00	645.7	0.000541397
				1.00	565.2	0.000473901
				1.00	703.9	0.000590196
				1.00	640.1	0.000536702
				1.00	652.6	0.000547183
				10.00	5961.1	0.004998179
III	2	4.54	1192.65	1.00	12.6	1.05647E-05
				1.00	9.3	7.79773E-06
				1.00	48.9	4.1001E-05
				1.00	16.7	1.40024E-05
				1.00	28.4	2.38124E-05
				1.00	13.6	1.14031E-05
				1.00	39.9	3.34548E-05
				1.00	50.6	4.24264E-05
				1.00	83.3	6.98442E-05
				1.00	88.0	7.3785E-05
				10.00	391.3	0.000328092
III	3	4.56	1192.65	1.00	6.2	5.19849E-06
				1.00	7.0	5.86926E-06
				1.00	11.6	9.7262E-06
				1.00	11.3	9.47467E-06
				1.00	11.6	9.7262E-06
				1.00	8.4	7.04311E-06
				1.00	9.0	7.54619E-06
				1.00	7.5	6.28849E-06
				1.00	6.3	5.28234E-06
				1.00	29.1	2.43994E-05
				10.00	108.00	9.05543E-05
					Grand Total	0.005416825

Table A11-7. Backfill Type 3 Gravel Total Suspended Solids Comparison between Washed and Unwashed Specimen

Tests	Data summary and comparison washed and unwashed backfill type 3 gravel					
	Washed 1st Specimen	Washed 2nd Specimen	Washed 3rd Specimen	Unwashed 1st Specimen	Unwashed 2nd Specimen	Unwashed 3rd Specimen
	Amount of TSS per Volume of Concrete Specimen	Amount of TSS per Volume of Concrete Specimen	Amount of TSS per Volume of Concrete Specimen	Amount of TSS per Volume of Concrete Specimen	Amount of TSS per Volume of Concrete Specimen	Amount of TSS per Volume of Concrete Specimen
	(gr/cm3)	(gr/cm3)	(gr/cm3)	(gr/cm3)	(gr/cm3)	(gr/cm3)
1st	0.001022779	0.00126429	0.000992759	0.004306138	0.004207691	0.004998179
2nd	0.001082023	0.001325477	0.001032452	0.004534905	0.004343133	0.005252486
3rd	0.001113588	0.00135259	0.001045965	0.004585321	0.004405379	0.005318641
Total	**0.00321839**	**0.003942356**	**0.003071176**	**0.013426364**	**0.012956204**	**0.015569306**

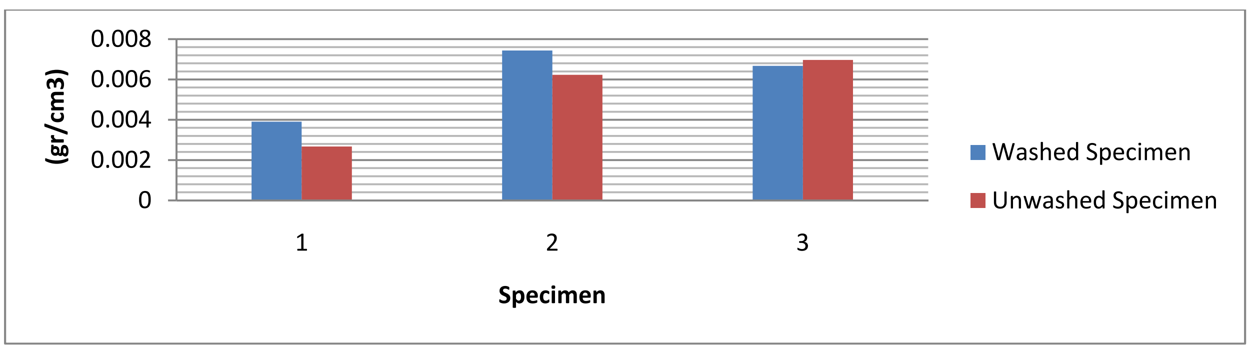

Figure A11-1. Type 3 gravel washed and unwashed TSS comparison

Appendix – 12: Greensand Tests Results

Constant head permeability of Greensand (tap water)
Diameter = 7.6 cm
Area = 45.6 cm2
Length = 7.6 cm

Table A12-1. Greensand Permeability

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	77	54.5	22.5	1080	60	0.394705	0.3386667	24	0.133673
2	85	64	21	1075	60	0.392878	0.3628571	24	0.142558
3	88	62	26	1130	60	0.412978	0.2930769	24	0.121034
4	90.5	64.5	26	1100	60	0.402014	0.2930769	24	0.117821
5	90	62	28	1100	60	0.402014	0.2721429	24	0.109405
6	89.5	61	28.5	1060	60	0.387396	0.2673684	24	0.103577
								Average =	0.121345

Constant head permeability of Greensand with A6 Soil (A6 soil clogging)
Test # 1
Diameter = 7.6 cm Area = 45.6 cm^2
Length = 7.6 cm A6 soil introduced = 15 g
Cumulative water = 5 liter

Table A12-2. Greensand Permeability with A6 Soil Test - I

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
I	1.2745	1.3221	0.0476	1000	47.60
II	1.2565	1.3007	0.0442	1000	44.20
III	1.2241	1.2713	0.0472	1000	47.20
IV	1.2491	1.2944	0.0453	1000	45.30
V	1.2444	1.3216	0.0772	1000	77.20
			Sum	5000.00	52.3

Table A12-3. Permeability after Clogging - I

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	45	28.5	16.5	630	60	0.230245	0.461818182	24	0.106331
2	44	23	21	575	60	0.210144	0.362857143	24	0.076252
								Average =	0.091292

Table A12-4. Greensand Permeability with A6 Soil Test - II

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
I	1.2519	1.2655	0.0136	1000	13.60
II	1.2527	1.2645	0.0118	1000	11.80
III	1.2387	1.249	0.0103	1000	10.30
IV	1.2389	1.2515	0.0126	1000	12.60
V	1.244	1.2624	0.0184	1000	18.40
			Sum	5000.00	13.34

Table A12-5. Permeability after Clogging - II

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	37	16	21	500	60	0.182734	0.362857	24	0.06631
2	32	13.5	18.5	475	60	0.173597	0.411892	24	0.0715
3	28.5	11	17.5	400	60	0.146187	0.435429	24	0.06365
								Average =	0.06715

Table A12-6. Greensand Permeability with A6 Soil Test - III

Filter #	Mass Filter	Mass Filter + Residue	Mass Residue	Sample Size	TSS
	(g)	(g)	(g)	(mL)	(mg/L)
I	1.2077	1.2122	0.0045	1000	4.50
II	1.2418	1.2471	0.0053	1000	5.30
III	1.2598	1.2649	0.0051	1000	5.10
IV	1.2396	1.2448	0.0052	1000	5.20
V	1.2663	1.2669	0.0006	1000	0.60
			Sum	5000.00	4.14

Table A12-7. Permeability after Clogging - III

Run No.	Manometers		ΔH	Q	t	Q/At	L/h	Temperature	k@20
	H_1	H_2							
	(cm)	(cm)	(cm)	(cm^3)	(s)	(cm/s)		(°C)	(cm/s)
1	33.5	25	8.5	210	60	0.076748	0.896471	24	0.068803
2	33	25	8	190	60	0.069439	0.9525	24	0.066141
3	33	24	9	190	60	0.069439	0.846667	24	0.058792
								Average =	0.064578

Data summary

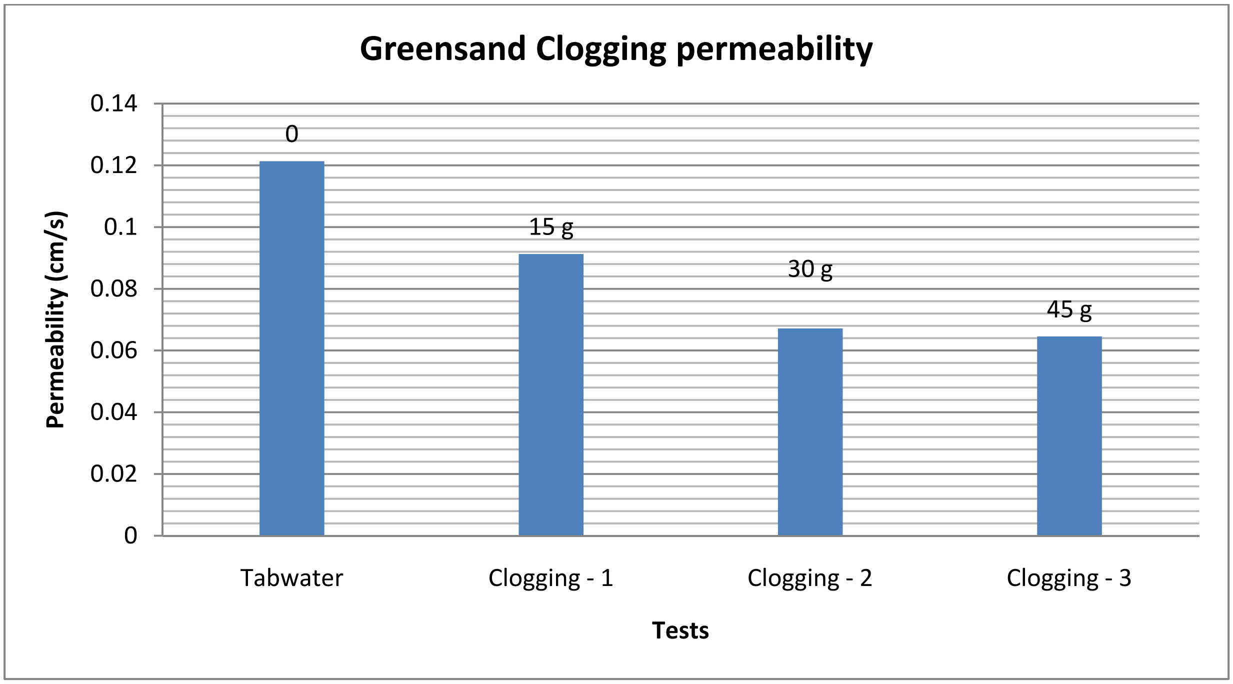

Figure A12-1. Greensand clogging

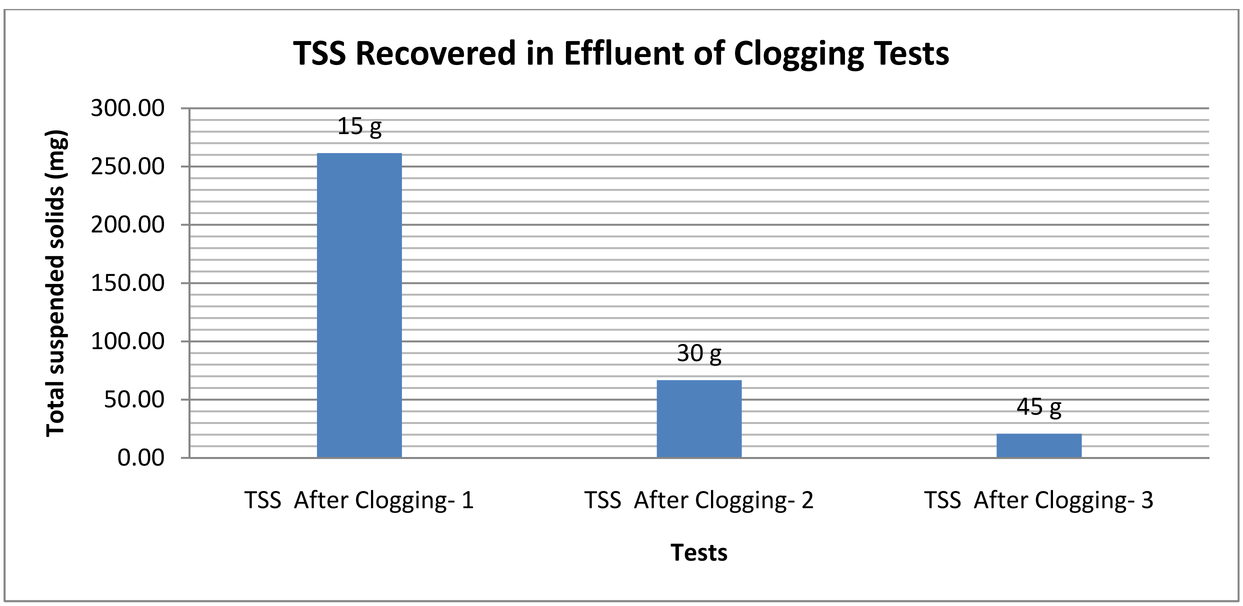

Figure A12-2. Total suspended solids