A Laboratory and Field Scale Evaluation of Compost Biofilters for Stormwater Management

Interim Report 2007

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Prepared for:

- Alltreat Farms
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1 EXECUTIVE SUMMARY

It is widely acknowledged that construction site stormwater runoff is a significant source of sediments and sediment-bound pollutants to urban streams. Receiving water quality concerns associated with increased construction activities in recent years in the Greater Toronto Area (GTA) has prompted government agencies and academia to research new stormwater treatment technologies that can be used in the thousands of construction sites across the GTA.

Simultaneously, Federal and Provincial governments are encouraging 60% recycling within municipalities and regions. A large quantity of compost is being produced, but not efficiently utilized. A sustainable, green technology has been developed that uses large volumes of compost material as engineered compost biofilters for stormwater runoff treatment. These compost biofilters provide a novel, effective, economical, and sustainable solution for treatment of stormwater runoff.

However, test results are practically non-existent for compost biofilters from Canadian producers for stormwater treatment application. Preliminary tests indicate that compost biofilters can effectively filter out contaminants from runoff and improve the sustainability of compost operations by identifying a valuable use for the compost. The objectives of this research include: to determine through-flow properties and to develop relationships for hydraulic design of the biofilter; to determine the effectiveness of the biofilter in removing contaminants from stormwater runoff; to determine the longevity of the biofilters; and to develop a user-friendly design tool to facilitate the application of this new technology.

During the spring and summer 2006 extensive laboratory and field experiments were conducted and hundreds of runoff samples were collected and analyzed. The maximum flow through rate without overtopping per unit width of the 8″ sock for the three compost materials (overs) tested was approximately 1.5 L s^{-1} m^{-1}. The flow through capacities of the 12″, 18″ and the 24″ socks were approximately 50%, 200%, and 300% higher than the flow through capacity of the 8″ sock. The average sediment removal efficiency of the 8″ socks for 5, 10, and 15 rolls was 34%, 48%, and 60%, respectively. The average sediment removal efficiency of the 18″ socks for 5, 10, and 15 rolls was 69%, 84%, and 95%, respectively. The average sediment removal efficiency of 5 rolls of the 18″ sock steadily and gradually reduced from 70% to 62% to 58% to 56% and to 54% after 1, 5, 10, 15, and 20 consecutive runs. Sediment removal efficiency of clay size material was only 30% while for fine silt was around 50% and for course silt around 80%. Application of Polyacrylamide polymers (PAM) were shown significantly enhance sediment removal efficiencies (more than 90%). The optimum application rate for liquid PAM was around 5 mg/L.

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NOMENCLATURE

ASTM – American Society for Testing and Materials

ATF – Alltreat Farms

BMP – Best Management Practices

EPA – Environmental Protection Agency

GTA – Greater Toronto Area

IC – Inorganic Carbon

MOE – Ministry of the Environment

MOEE – Ministry of the Environment and Energy

PWQO – Provincial Water Quality Objectives

SWMPs – Storm water Management Ponds

TC – Total Carbon

TMECC –Test Methods for the Examination of Composting and Compost

TOC – Total Organic Carbon

TRCA – Toronto and Region Conservation Authority

UV – Ultraviolet

2 PROBLEM STATEMENT

Soil loss rates from urban areas under construction can be 10 to 20 times that of agricultural lands (Faucette, et al., 2006). For example, forested lands lose an average of 0.36 tonne ha^{-1} per year; agricultural land loses an average of 5.5 tonne ha^{-1} per year while construction sites lose an average of 73.3 tonne ha^{-1} per year (GA SWCC, 2002). Various methods and techniques currently exist to control soil erosion and the transportation of contaminants by stormwater runoff. Although these measures reduce the amount of pollutants from entering the streams, they generally do not meet the required guidelines and standards (MOEE, 2004).

Water quality concerns of urban streams, coupled with increased construction activities in Ontario have prompted government agencies and academia to research new stormwater treatment technologies (Bradford and Gharabaghi, 2004; and Gharabaghi et al., 2006). In particular, stormwater runoff from construction sites often has high concentrations of deleterious substances such as fine sediments, heavy metals, and petroleum hydrocarbons that discharge through storm sewers and open ditches into nearby urban streams and rivers. Silt-laden runoff from these construction sites has potential adverse effects on streamwater quality and aquatic habitat and is a perpetual problem on construction projects.

To address solid waste issues, the Ontario government has proposed a 60% waste diversion strategy to divert non-hazardous solid waste from landfill sites (MOE 2004). The initiative has created a surplus of yard waste compost within the province. This compost is suitable for use as a soil amendment, topdressing or as an erosion control and sediment filtering agent. One sustainable solution for construction site runoff is the use of a compost biofilter. These biofilters provide a cost-effective solution for treatment of stormwater runoff (Gharabaghi et al., 2007).

A review of literature on pollution caused by highway runoff and highway construction by Barrett et al. (1995) notes that the most commonly-cited water quality impacts of road building are increased turbidity and suspended solids concentrations in stormwater runoff. In the

United States, the National Pollutant Discharge Elimination System (NPDES) has mandated strict erosion and sediment control of all construction sites one acre or larger. A survey of state Departments of Transportation (DOT's) by Mitchell (1997), indicated that 19 state DOT's had developed specifications for compost use. Thirty-four DOT's reported routine use of compost on roadsides for purposes such as: improved vegetation cover; erosion control; reduced moisture loss; filter berms; and bio-remediation of soils contaminated by petroleum compounds (Kunz, 2001; Demars, et al., 2004; Persyn, et al., 2005; Johnson et al., 2006).

Traditional methods for controlling erosion and reducing sediment transport from construction sites include; silt fence or straw bale barriers, straw bale or rock flow checks and sediment basins. A silt fence is a sediment-trapping practice utilizing a geotextile fence and has been used for erosion control on slopes and around the edges of construction sites for years (Tyler, 2001). Although these applications have been utilized frequently enough in the past that many regional regulations have incorporated them as a requirement, they often do not provide ample environmental protection (Gharabaghi et al., 2000).

Compost has been used in highway projects in order to control and treat stormwater runoff that is often contaminated with petroleum hydrocarbons (e.g. motor oil) and metals (Glanville, 2004). The humus content of compost catalyzes the hydrocarbon degradation process and microbial activity is 10 times greater in compost than in soils (USEPA, 1998). Compost is a rich source of micro-organisms, which can degrade petroleum hydrocarbons to innocuous compounds such as carbon dioxide and water (Khan, et al., 2006).

However, the use of compost as a biofilter for treatment of stormwater runoff (as a through-flow medium to remove contaminants) is a relatively new idea and there have been limited studies to determine the effectiveness of these control measures. USEPA (1997) tested a compost biofilter made of specially tailored leaf compost and reported sediment removal efficiency of 90%, oil and grease removal efficiency of 85%, and heavy metals removal efficiency of 82-98%.

This novel sustainable, green technology uses large volumes of compost material filled in mesh tubes also known as “sock” (in various diameters from 8" to 24"). Compost from Canadian landfills has not yet been tested for its effectiveness in stormwater runoff treatment since using compost as a biofilter for removal of suspended sediments and sediment-bound contaminants is a relatively new idea. In addition to assisting in sediment runoff control, these biofilters may also provide benefits to the agricultural sector by additionally recycling most of the raw organic wastes left after harvesting. This new application for compost will be of significant environmental and economic benefit to society.

3 OBJECTIVES

The specific objectives of this research project include:

1. To determine through-flow properties of the biofilter and to develop relationships for hydraulic design of the biofilter;
2. To determine the effectiveness of the biofilter in removal of suspended sediments from stormwater runoff;
3. Determine if addition of polymer further assists in removal of fine sediments;
4. To determine the longevity of the biofilters; and
5. To develop a user-friendly design tool to facilitate the application of this new technology.

4 COMPOST MATERIAL

The compost that makes up the biofilters is essentially made up of the various yard waste including twigs, bark and wood chips. On January 5, 2006, the composting facilities of Alltreat Farms (Arthur, Ontario), the Region of Peel (Caledon, Ontario), and the Region of Waterloo (Cambridge, Ontario) were visited. This visit was conducted in order to understand the three methods of making compost, to learn about the key ingredients of various certified compost types available in Ontario and to become educated about the overall differences between them. Three different methods were explored including; the Gore System, the Bio-reactor unit system and the Open Windrow system. A tour was completed at each site and samples of various compost materials were taken for lab analysis and testing. The following summarizes each location, their composting method, notable compost properties and the scale of each operation.

4.1 Alltreat Farms

Alltreat Farms produces approximately 100,000 tonnes of compost on a yearly basis that is sold in retail environments and in bulk form. The compost that is of interest in this research is the "overs" (> 0.5″) that are filtered out of the compost materials (roughly 20% of the produced compost) and not usually sold (i.e. sent to a landfill). Alltreat Farms uses a Gore cover composting system on windrows. This system consists of 10 rows, each of 50 m in length. They are windrows of compost, approximately 3 m high covered by a Gore Cover Laminate. At the end of each windrow, a fan is attached that supplies air flow throughout the pile (Figure 1). As well, aeration channels are present below each row of compost. The site uses a computer system to constantly measure temperature and oxygen levels. The duration and frequency of aeration is dependant on the monitored oxygen and temperature levels.

Figure 1: Aeration Fans of the Gore System

Figure 2 shows a compost windrow covered by a Gore Cover Laminate at Alltreat Farms. The windrows are static for most of the composting duration, but are turned after two weeks. The monitoring system allows for the proper timing of maturity, typically around four weeks. After the four weeks, the Gore Cover is removed and the composted material is cured for two weeks without a cover. The wedge system consists of a very large pile of compost. The material is monitored for temperature and dissolved oxygen regularly, and rotated constantly with large front-end loader machines. These machines simply drive over the compost and push it back and forth, to prevent the pile from becoming anaerobic.

Figure 2: The Gore System

4.2 The Region of Peel

The Region of Peel Composting Facility is located at the Caledon Sanitary Landfill site in the town of Caledon, Ontario. The facility accepts leaf and yard waste as well as organics from over 10,405 households from the town of Caledon and some regions of Brampton. This facility produces one type of generic compost. The facility has been in operation since December of 1994 (Peel, 2006). In 2001 the site processed 3,190 tonnes of organic material. Some of the compost is distributed to the community for free during special events, and can also be purchased at the Caledon Sanitary Landfill site or in bags at the Region's Community Recycling Centers and Recycling Depots (Peel, 2006). Figure 3 is a picture of the composting facility.

Figure 3: Region of Peel Composting Facility

Organic material that is collected from curb sides is brought into the facility by trucks and dumped onto the floor of the composting facility. The material is first visually checked for contamination e.g. nonorganics such as plastic bags. The material is then loaded by a front end loader into a shredder which cuts the material into smaller pieces. Figure 4 shows the shredding of the compost. After the material is shredded, it is loaded into the composting unit (Bruno, 2006). An example of the unit is seen in Figure 5.

Figure 4: Shredding of Organic Material at Region of Peel

Figure 5: Composting Inside Bio-cell Reactor Unit

The composting unit used by the Region of Peel Composting Facility is a Herhof Bio-cell. The facility has eight bio-cell reactors that are basically a reinforced concrete box, each with a capacity of 60 m^3 (Peel, 2006). Each of these cells can process about 1,500 metric tonnes of compost per year (BioCycle, 2000). The material stays in this unit for seven to ten days while the decomposition process takes place. This includes an initial warming stage for several days at 45° to 55°C, and a few more days at 60°C for pathogen control (BioCycle, 2000).

Each unit is computer controlled with a 15-min interval record and continuous readout (BioCycle, 2000). Inside the unit, air is circulated through the organic material via holes in the floor. Attached to each unit is a biofilter to control the odour in the exhaust that is produced during the decomposition process. The bio-filtration system consists of three stacked units laid out at 1.0 m by 1.2 m in cross section, with each level 0.66 m high. The three sections of the filter contain approximately 0.3 m each of cured compost, wood chips, and bark. The exhaust that exits the biofilter does so through a stack. The compost material located inside the filters is changed about every six months (BioCycle, 2000).

The facility operators like to keep the temperature of the material at about 60˚ C (Bruno, 2006). During biological degradation, leachate tends to form. This is collected in the floor and then re-circulated on the inside walls of each unit where it will evaporate from the heat. The facility operators like to keep the moisture level inside the unit between 45 to 60% (Peel, 2006). After the seven to ten days within the bio-cell, the compost is then removed and stored in open windrows outside for a curing period of about 30-45 days. These windrows are turned weekly (Bruno, 2006). After that, the final compost is screened through a half-inch wire screen. The screened compost is then sold, and the "overs" are used for daily landfill cover. The collected sample of "overs" includes mainly sticks and some fine material. Visual observation indicates that perhaps due to high moisture content of compost at the time of screening, a larger than usual percentage of fine material (< 0.5″) remained in the sample.

4.3 The Region of Waterloo

The Region of Waterloo site, located in Cambridge Ontario uses an open windrow system. Yearly incoming compostable material in 2000 was approximately 9,700 tonnes (RMW, 2001). The composted material at the Waterloo site is given away to the public during Giveaway Events held once or more throughout the year. The leftover material is often sold in bulk to contractors, or given away as a charitable donation. Bulk compost is sold at a rate of $15.00 per tonne of screened material, and $9.00 per tonne of unscreened material (RMW, 2001).

In the open windrow system, the incoming organic waste is first prepared by plastic bag removal and grinding. The windrows are placed in parallel rows of 2 to 4 m in height. The height is determined by the need to prevent compaction of the material. Three concrete pads serve as the floor of the compost area. The piles are turned regularly, about every three weeks, and monitored for temperature weekly. The desired temperature remains between 55°C and 65°C for a period of 15 cumulative days to control pathogens. After the compost has matured, it is cured for a minimum of 21 days, and temperatures are not allowed to exceed 20°C over the ambient air temperature. The final material is then screened. Figure 6 shows open windrows of leaf and yard waste on the concrete pad at the Region of Waterloo Composting facility.

Figure 6: Open Windrow (Leaf and Yard) at Waterloo

The wood chip compost will be suitable for providing high flow through rate due to large void space within the compost to filter the storm water runoff. This type of compost is not always readily available, as it depends on the time of year, i.e. after Christmas. The main sample we collected from the Waterloo site was a leaf and yard waste mixture.

5 METHODOLOGY

Laboratory and field experiments have been conducted to evaluate the effectiveness of the biofilters in removing contaminants from stormwater runoff. First, the three compost materials were tested to quantify the differences between the products. Next, through-flow runs were conducted in a controlled laboratory setting and a numerical model was developed for hydraulic design of the system. Clean water runs were conducted and water quality was tested to determine if the biofilter would have any adverse effects on the environment. A set of field experiments was conducted to determine the effect of compost material, sock diameter, number of socks, and flow rate on sediment removal efficiency and longevity of the biofilter. Lastly, limited polymer tests were conducted to determine if higher sediment removal efficiencies can be achieved and the optimum dosage rate of the polymer. The following section provides the details of the experimental setup, sample collection and analysis.

5.1 Physical Tests on Compost Material

Physical tests were performed on the three composts under consideration. These tests included particle size analysis, bulk density, and void ratio. Full methods can be found in Appendix A: Methods and Materials.

5.2 Flow Through Tests

Flow rate tests were conducted to determine the flow through capacity of the biofilter. The laboratory tests were completed on an 8″ diameter biofilter and a numerical model was used to extend the results for larger diameter filters. Each compost material was tested using three different samples. Flow rate tests were done using the flume shown in Figure 7. The flume was 1.5 m long by 0.69 m in width and 0.3 m deep with a constant head tank at the inlet end and collection channel at the outlet. The biofilters of 8″ in diameter were placed across the center of the flume. Water was evenly distributed by using the water taps in the lab. The water enters at the inlet, flows through the biofilter during the filtration process, and continues toward the collection channel where the samples are collected (Figure 7).

Figure 7: Flume for Flow Rate Testing

A detailed methodology can be found in Appendix A: Methods and Materials. To ensure accuracy of the collected laboratory data, each runs was repeated three times to capture natural variability in the results.

5.3 Clean Water Tests

The Ministry of the Environment (MOE) has set Provincial Water Quality Objectives (PWQO) for receiving water standards. They provide an extensive list of chemicals found in water, and state the allowable concentrations that can be discharged into receiving waters. The purpose of the clean water tests was to determine if the biofilter would have adverse effect on water quality due to wash-off of the compost material out of the sock. The pH, total suspended solids, turbidity and conductivity in the soils lab were all tested at the University of Guelph. Methods for each test are described in Appendix A: Methods and Materials.

5.4 Field Experiments

Field experiments were conducted in the summer of 2006 at the Guelph Turf Grass Institute, University of Guelph to evaluate sediment removal efficiency of biofilters. A set of controlled field test were conducted, as described below, to determine the effect of compost material, sock diameter and number of socks on sediment removal efficiency.

The initial setup at the Guelph Turf Grass Institute and Environmental Research Station, University of Guelph required construction of two 10 m long, 1.2 m wide channels. Initially the sod layer was removed in the two plot sites and the ground was leveled. An end channel was constructed using sheet metal formed into a triangular spout with upright walls to direct the water. Sheet metal walls were then placed upright and perpendicular to each other to form the water column. The channels were then covered in plastic sheet wrap.

Water was supplied from pressurized irrigation system using fire hoses to a large constant head tank, which supply a steady flow rate of 1 L/s and measured at both upstream and downstream ends of the channels using HS flumes. A 1.2 m wide weir box was used at the inlet to distribute the flow evenly across the plot. A steady-state flow and sediment concentration was introduced uniformly at the inlet of the channel. A mixing column was used to mix soil and water to prepare slurry. A high clay content soil was dried, grounded, and sieved. For each run a soil-slurry was prepared by mixing a 2 kg mass of sieved soil with 40 L of clean water in the mixing column. A sump pump was used in the mixing column for continuous stirring of slurry during the experiment. The prepared slurry was mixed with the clean water and was delivered at the inlet of the channel at a set rate using peristaltic pumps into a 1.2 m wide perforated PVC pipe where it was first diluted and then well mixed with the steady-rate inflow of clear water at the weir box upstream of the plots.

Figure 8: Weir Box at the Inlet of the Channel

The preliminary tests preformed used both runs using ten 8” diameter socks in series (Figure 9). After initial setup, clean water was allowed to flow for 10 min to clean the socks. The soil solution was then introduced and allowed to run for 40 min to allow steady state conditions to be reached. Samples were taken after 40 min at the input and outlet of the channel.

Figure 9: Ten 8″ sock run

Four runs were conducted on Plot A using the Region of Waterloo’s compost. Six samples were collected per run (3 inputs and 3 outputs) for a total of 12 samples collected. One run was done on Plot B, using the Alltreat sample of compost, for a total of six samples collected.

After the ten sock tests were completed, the runs were altered to create a three-tier/level run. This was constructed using plywood and gravel to level and define each of the levels. This allowed a flowing stream for four different locations on the run so samples could be collected and the differences could be measured. Five 8” socks were placed on each tier for a total of fifteen socks (Figure 10). Plot A tested the three different types of compost. Six runs were conducted on each sample of compost. Four samples were taken from each sampling location for a total of sixteen samples from each run. Therefore, there were a total of 288 samples collected from Plot A for the 15 sock tests.

Figure 10: Three Tier Setup

Plot B tested all three types of compost for testing the overall longevity of the system. Peel compost was placed on the first tier as it consisted of the finest materials. Waterloo compost was placed in the middle, as its material was coarser. Alltreat was placed at the bottom as its compost was the coarsest. Again four samples were taken from each sampling location (Figure 11). Seventeen runs were conducted in total on Plot B for a total of 272 samples collected.

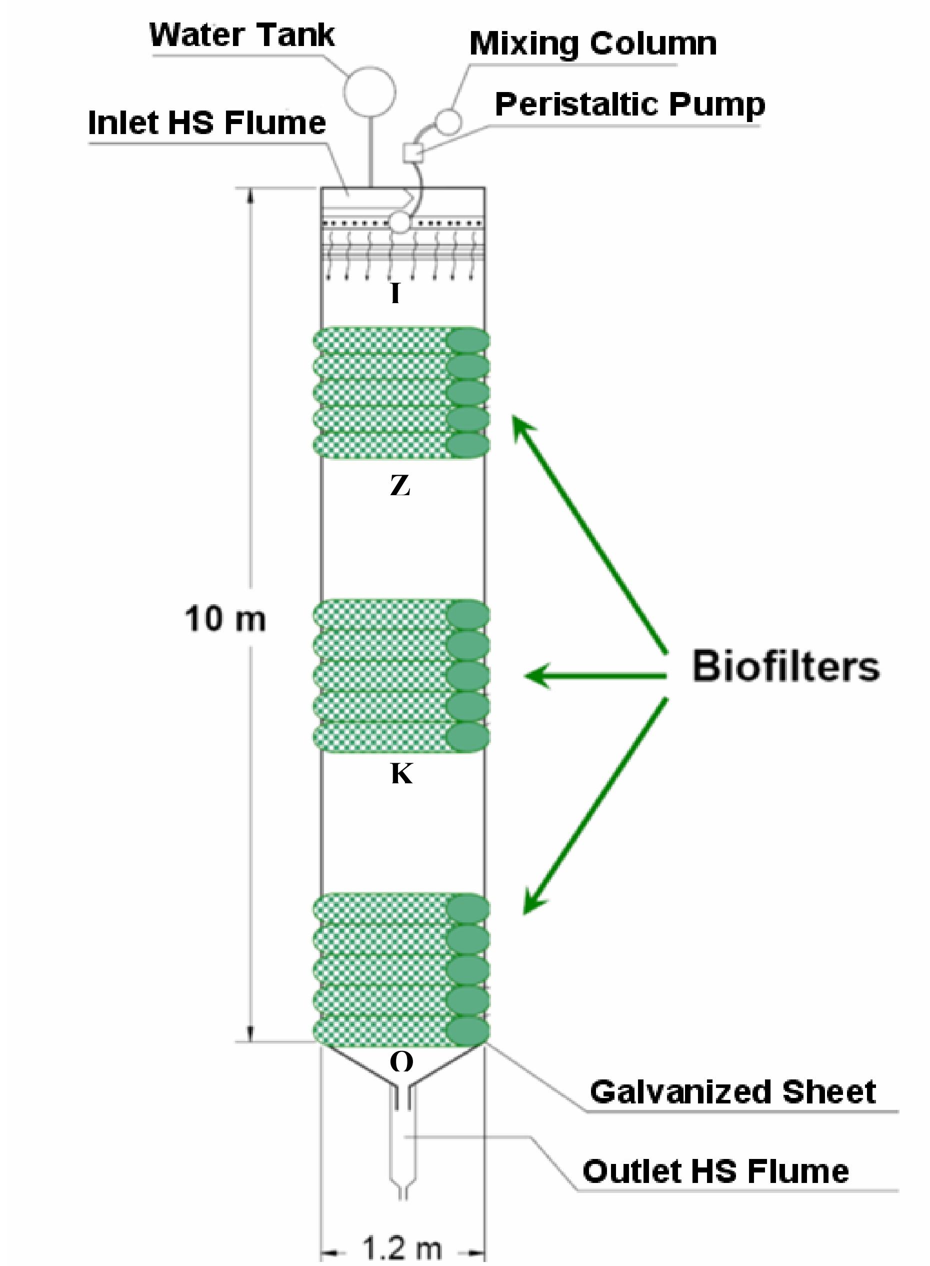

Figure 11: Sample Collection Sites (I, Z, K, and O)

For the final experiments the runs were changed back to being the original uniformly and five 18"socks were placed at the bottom of the run starting where the run tapers and going up. Two different experiments were preformed on the 18' socks. The first involved different flow rates including: 0.5, 1.0, 1.5 and 2.0 L/s and the second was a longevity test. The flow rate runs, performed on Plot A consisted of performing two runs per flow rate and collecting four samples from both the Input and the Output locations for a total of 64 samples collected. The second test was also preformed on Plot A and consisted of running 30 longevity runs. Again four samples were collected on each location for at total of 120 samples.

5.5 Runoff Sample Analysis

The total suspended solids (TSS) for runoff samples were analyzed in the Fluids lab of Thornborough building in the University of Guelph. The initial lab setup consisted of attaching plastic tubing from a vacuum pump to a series of Erlenmeyer flasks, feeding each flask from a t-joint connecter (Figure 12). Four glass filtration funnels were placed inside a rubber stopper and then secured on the top of the Erlenmeyer flasks.

Figure 12: Initial Lab Setup

Once the setup was complete, four samples were selected for analysis and recorded on a lab sheet. Four metal weighing tins were obtained, labeled and individually wrapped micropore filters were placed inside each of the weighing tins. These tins were weighed for the initial masses and then, using tweezers the filters were carefully removed from the tins and placed on top of the filtration funnels. A filtration filter cup was secured over the filter and was then clamped together to seal the filtration unit. Once the chosen samples were adequately mixed, 150 milliliters were obtained in a clean 250-milliliter graduated cylinder and was poured into the filtration unit. The vacuum pump was turned on and the water was drawn out of the filter into the Erlenmeyer flasks. Once all the water was removed from the samples, the vacuum was turned off and the filters were carefully removed using tweezers. The filters were placed back into the weighing tins and placed in the oven at 98-108 degrees Celsius for 24 hours. Once the sample had dried, the tins were re- weighed and placed in appropriate storage.

Statistical analysis was conducted on sediment removal efficiencies using SAS version 9 and proc mixed which fits a variety of mixed linear models to data and enables statistical inferences about the data. The response variable was outlet sediment removal efficiency. The four fixed effect treatments were sock size, compost type, number of socks and flow rate.

Using a particle size analysis machine (Mastersizer 2000) the fourth sample taken from each of the runs was run through the machine to verify any trends in the particle size distribution as the solution was passed through each filtration sock. In order to use this machine, the initial particle size needed to be determined, in order to ensure the proper optical properties of the soil could be identified. Three hydrometer tests were conducted using 50 kilograms of the dried clay and silt particles from the soil obtained in Windsor.

The Mastersizer works by using the optical unit to capture the actual scattering pattern from a field of particles. It then calculates the size of the particles that create that pattern using the Fraunhofer model as well as the Mie theory. The Fraunhofer model can predict the scattering pattern that is created when a solid, opaque disk of a known size is passed through a laser beam and the Mie Theory predicts the way light is scattered by spherical particles and deals with the way light passes through, or is adsorbed by, the particle.

5.6 Polymer Tests

The outflows of storm-water management ponds have become a source of some concern with municipalities and conservation authorities. High volumes of suspended solids, too fine to settle out in the ponds, are entering the receiving waters in amounts far exceeding legislated limits. This problem is incredibly evident during construction phases, when topsoil is stripped, and erosion is a very large problem. An effective method for removing these fine suspended particles is called coagulation. This is the process of increasing the settling velocity of these particles by causing them to clump together into larger particles that settle faster.

Polymers act as a flocculent in water, sewage, and stormwater treatment applications. The flocculation mechanism is based on soil particle-polymer bonding. Polyacrylamide polymer (PAM) products work by attracting fine particles making for a larger aggregate, which can then be caught in a filter. The flocculation process is a function of charge density, molecular weight, and nature of the PAM product. The extension of polymer strands in an aqueous environment plays a large role in the adsorption of particles. This is a reflection of the nature of the polyacrylamide used. Coagulation is the neutralization of charge of a particle and flocculation is the linking of two or more particles by a particle of polymer. These two processes comprise the means of soil particle-polymer bonding.

Zeta potential is the difference in electric potential at the particle-liquid interface of a colloidal dispersion. Particles with positive zeta potential provide a means of attracting and thereby removing very fine negatively charged particles from a medium. This occurs via electrostatic attraction and is practical in water of pH 5-8. PAM's function by destabilizing the electrostatic layer that causes the fines to repel each other, allowing them to flocculate. However, the PAM must be matched to the soil type for best removal efficiency. One of the objectives of this study was to determine the optimum concentration of an anionic Polyacrylamide polymer (PAM) that was most effective in removing fine sediments from storm-water outflows and to determine the effectiveness of PAM in liquid form versus solid form in removal of sediments.

See Figure 13, Figure 14 and Figure 15 for a detailed visual description of the setup.

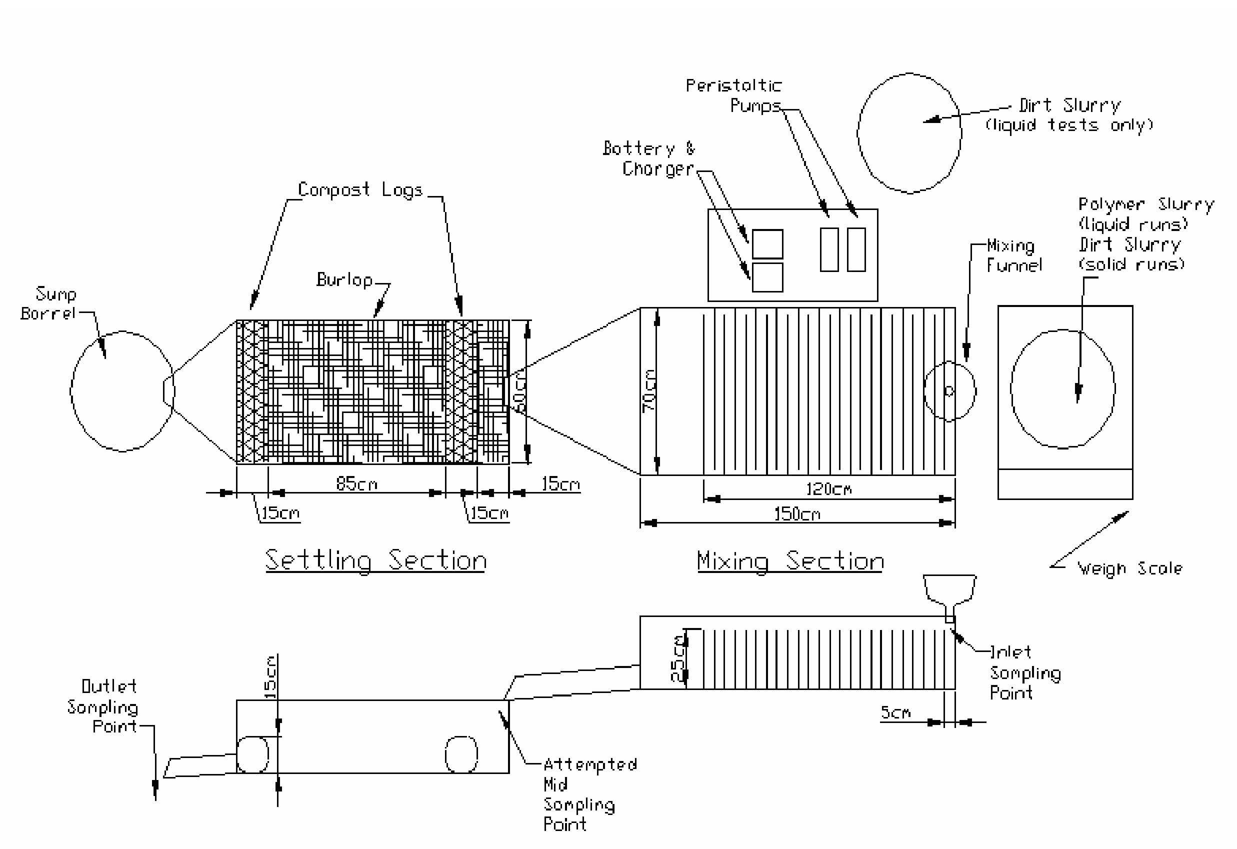

Figure 13: Diagram of Polymer Testing Setup

Figure 14: Polymer Testing Setup

Figure 15: Polymer run: mixing setup and settling run.

The total flow rate was calibrated to approximately 20 L/min. This was comprised of flow from the water tap, the soil solution, and the polymer solution. The concentration of polymer used changed with every second trial. Concentrations of 1, 5, 15, 25, 50, 100, and 500 mg/L were used. The concentration of soil solution remained at roughly 800 mg/L. In the solid polymer tests, surface areas of 360 cm^2 and 720 cm^2 were used, with the flow rate coming from the water tap and soil solutions only. The temperature was recorded, along with date, time, and concentration of polymer and soil solution.

Each run began with 30 min of clean water running through the run at a flow rate of approximately 18.2 L/min for the liquid, and 19.2 L/min for the solid. This cleaned out the compost socks of organics and dirt residual from the composting process. After 30 min of clean water, soil solution was added and the test ran for 30 min. A sample was taken after 30 min after the soil solution had run in order to achieve steady state. Three outlet samples were taken, followed by three inlet samples. Next, polymer solution was run through the setup for 30 min and then another set of four samples were taken at the outlet and inlet. A total of 18 samples will have been collected for each run, each with a small amount of sulfuric acid added. At the completion of each sampling run, the compost logs and burlap were disposed of into a dumpster and the tables were rinsed with tap water to clean out leftover sediment. The logs and burlap were then replaced for another run.

6 RESULTS

6.1 Physical Tests

Several physical tests were conducted including physical tests, void space ratio tests and flow rate tests. Performing these tests allowed for further understanding of the compost and its characteristics. Fieldwork results were also obtained through sample analysis in the lab and the results were interpreted in several ways for a complete understanding of the trend that this technology offers.

6.1.1 Particle Size Distribution

From the particle size analysis completed and displayed Figure 16 approximately, 92.14% - 99.78% passed through a sieve of 25.4 mm. Also, 81.70% - 94.25% was able to pass through a sieve of 19 mm. Finally, 58.43% - 84.10% was able to pass through a sieve of 9.42 mm. A full table of results is available in Appendix C. The calculated uniformity and gradation coefficients both show that the composts are fairly well graded.

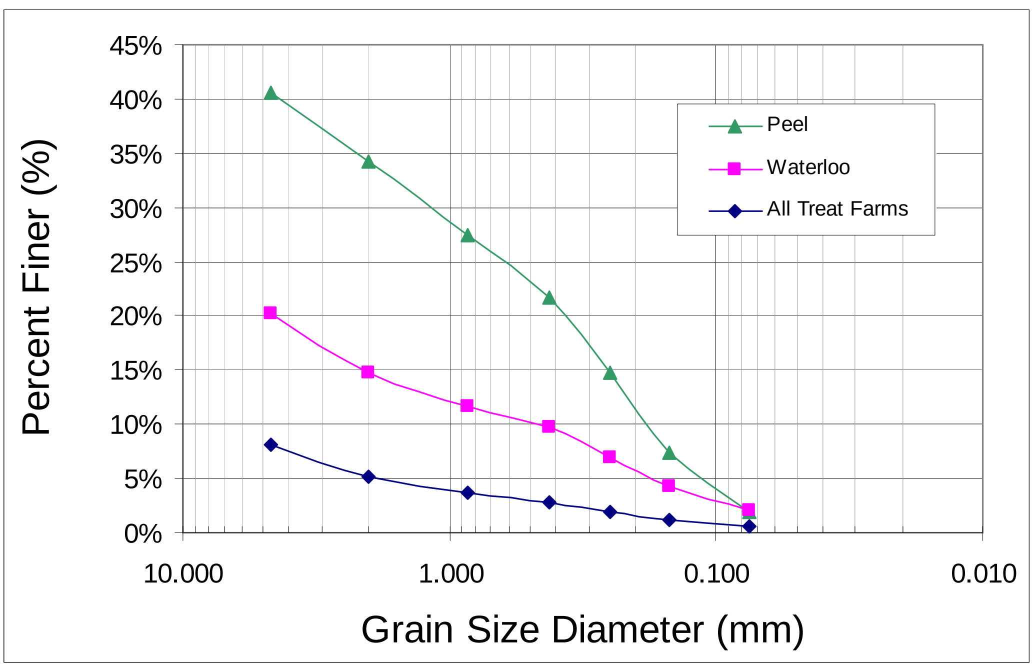

Figure 16: Average Particle Size Analysis

6.1.2 Void Space Ratio

Void space is used to determine flow through properties of the porous media. More compacted compost will result in a lower hydraulic conductivity. However, compost with too much void space will not be as effective in removing sediments. For all three samples, void ratio ranged from 60% to 70%.

6.2 Flow Through Tests

Figure 17 displays the results of the flow rate tests after averaging (for three replications). All three compost types showed similar trend in their results. The sample from the Peel Region had a lower flow through capacity due to higher percentage of fine particles in the sample. Fine particles create denser compost, thus decreasing hydraulic conductivity.

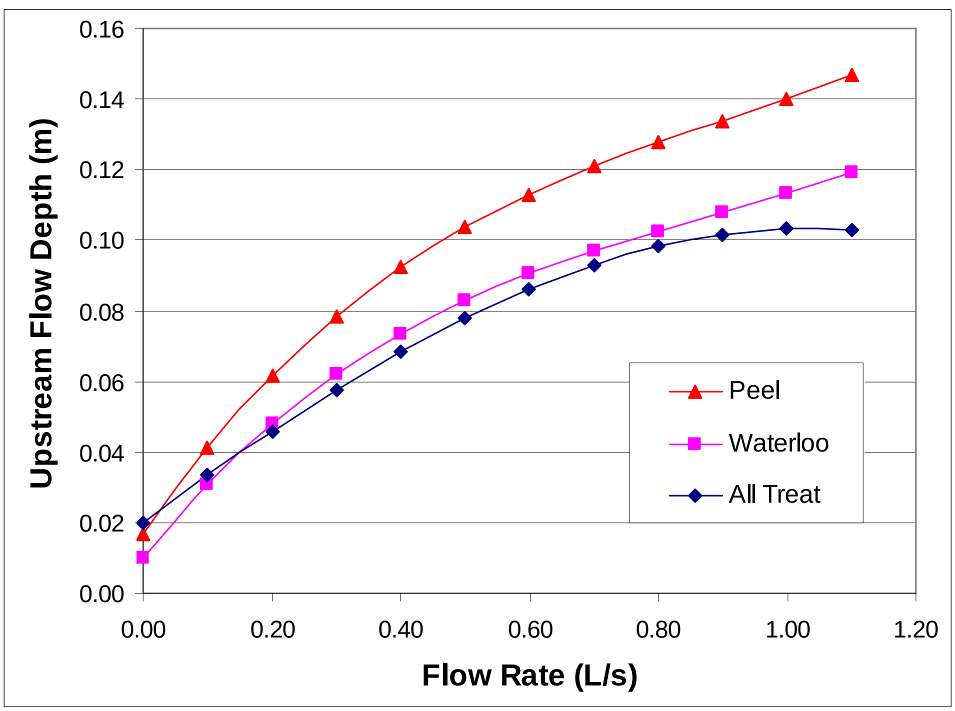

Figure 17: Water Depth vs. Flow Rate Comparison

Following the laboratory flow through tests, a state-of-the art finite element numerical model called SEEP/W was used for simulation of flow through the biofilter. In Seep/W, using gravity driven water pressure in terms of head, flow of water through a porous media with complex geometry can be modeled (Krahn, 2004). Using the data obtained in the lab, a model for each sock was developed. The 2D cross section for each sock was drawn, and its depth modeled. Boundary conditions, specifying head and water table data obtained from the lab results were then specified within a finite element mesh outlining the cross section of the sock. The model was calibrated for hydraulic conductivity so that the modeled flow rates were matched to that of the experimental data. The highest three lab flows for each sock type were averaged for each upstream head level, and used in this back-calculation of the hydraulic conductivity. Once the model was calibrated for each sock, different sock sizes (12”, 18”, and 24”) were modeled.

Hydraulic conductivity (k) is otherwise known as the coefficient of permeability (Das, 2005). In 1856, Henri Darcy developed a simple empirical relationship for the discharge velocity of water through saturated soils (Das, 2005):

$$v = ki$$

Where; v = the discharge velocity, or the quantity of water flowing in unit time, through a cross sectional area of soil at right angles to the direction of flow

k = the hydraulic conductivity

i = the hydraulic gradient

The hydraulic conductivity depends on many factors, including but not limited to; fluid viscosity, pore-size and particle-size distribution, void ratio, and roughness of particles (Das, 2005).

Particle size distribution curves, determined in sieve analysis, may be used to determine the effective size, compare different soils, and classify soils (Das, 2005). The effective grain size corresponds to the diameter of the particles on the grain size distribution curve that represent 10% finer (Das, 2005). This value, alongside D_{60} (which corresponds to the diameter which 60% are finer on the particle size distribution chart) is useful to determine the uniformity gradient. Once the uniformity gradient has been determined, it allows for a classification of the quality of grading of the soil in question. The hydraulic conductivity may also be empirically estimated by the Hazen method (Thorbjarnarson, 2006). In this method, D_{10} is used alongside an empirical coefficient to estimate the hydraulic conductivity. As the effective size decreases in magnitude, so does the hydraulic conductivity, in an exponential manner.

$K = C (D_{10})^2$ (Thorbjarnarson, 2006)

K = hydraulic conductivity (cm/s)

d_{10} = effective grain size; grain-size diameter at which 10% by weight are finer (cm)

C = coefficient based on:

Very fine sand, poorly sorted	40-80
Fine sand with appreciable fines	40-80
Medium sand, well sorted	80-120
Coarse sand, poorly sorted	80-120
Coarse sand, well sorted, clean	120-150

6.2.1 Flow Through Modeling Results and Discussion

The Seep/W, models for each sock type were used, and the four highest flow depths from the laboratory were developed to obtain average hydraulic conductivity values for Alltreat Farms, Peel, and Waterloo composts, shown in, and a sample (Figure 18) below.

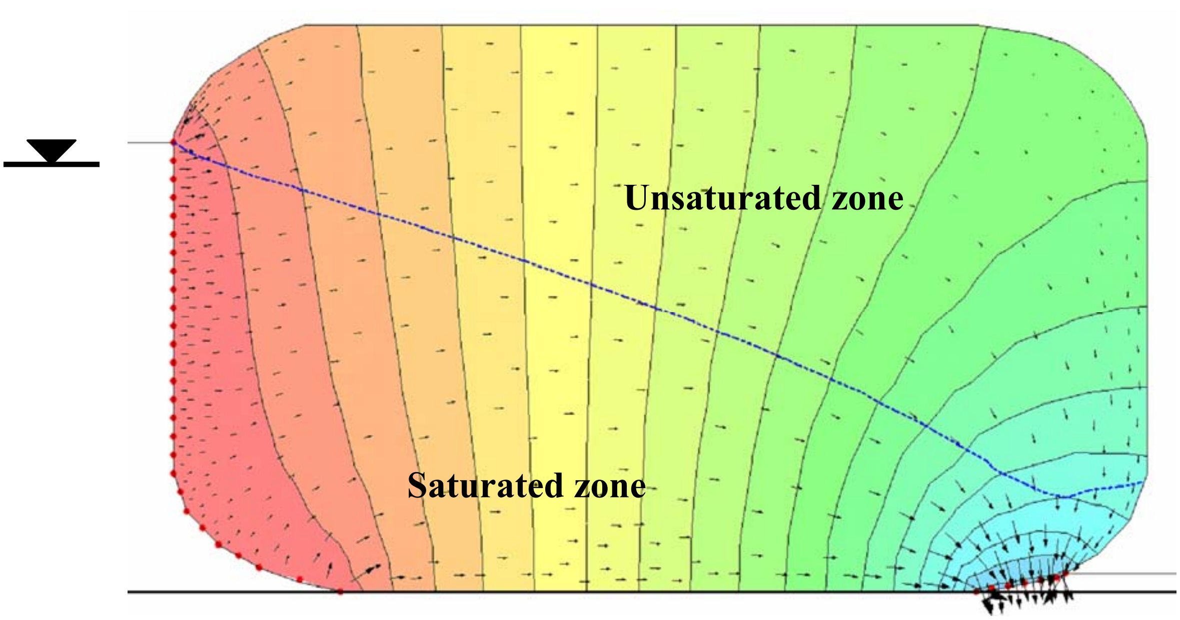

Figure 18: Alltreat Compost Model at 100 mm Upstream Water Depth

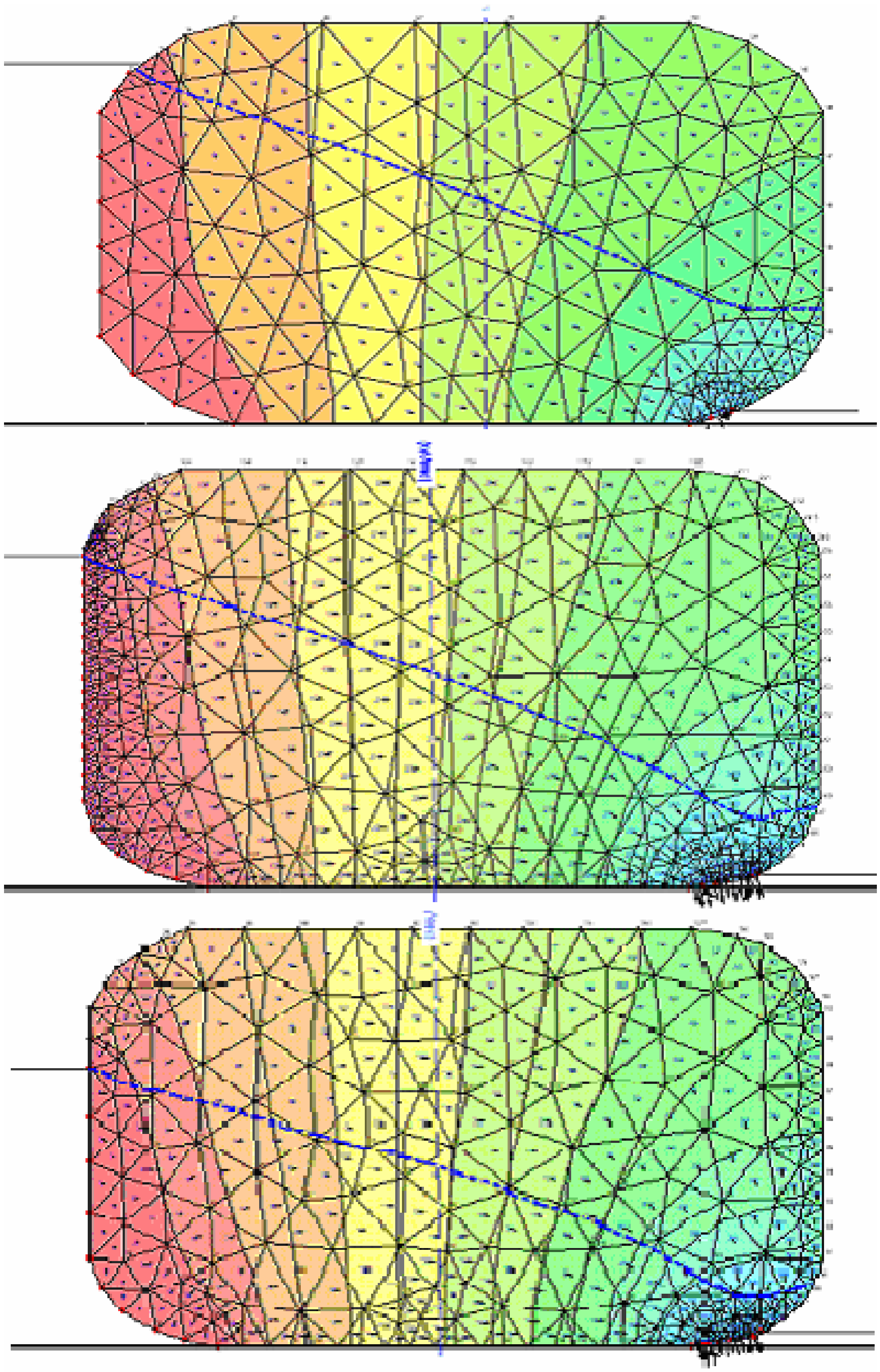

Figure 19: Flow through model for the 8″ sock;
(a) 110 mm upstream head; (b) 100 mm upstream head; (c) 80 mm upstream head.

Hydraulic conductivity of samples ranged from 1.51 to 1.85 cm/s. It should be noted that hydraulic conductivities of compost fall within the classification of coarse sand (Das, 2005).

6.3 Clean Water Flow Quality Tests

Clean water runs were conducted and water quality was tested to determine if the biofilter would have any adverse effects on the environment.

6.3.1 Total Suspended Solids (TSS)

The suspended solid concentrations of the Alltreat and Waterloo composts are quite similar. Peel has slightly higher TSS concentration in the first 30 min. This could be due to the release of fine particles. Figure 20 displays these results clearly.

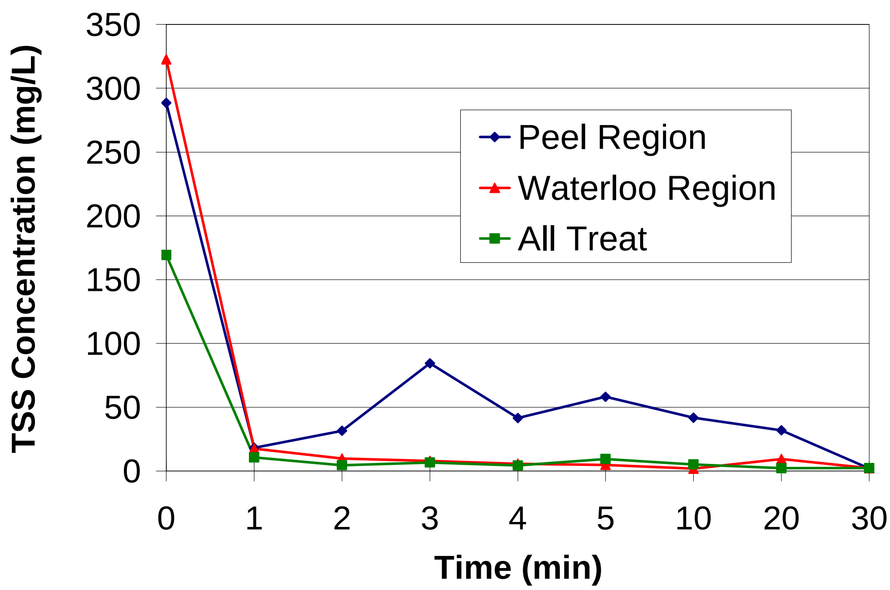

Figure 20: Suspended Solid Concentration vs. Time Comparison

The water quality guideline value for protection of aquatic life for TSS is 25 mg/L for chronic exposure and 80 mg/L for acute short-term exposure (EIFAC, 1965). As shown in Figure 21, a 10 min flush period will be required to meet these guidelines for short-term exposure.

6.3.2 Turbidity

Turbidity is a measure of the cloudiness of water. The turbidity may be composed of organic and/or inorganic constituents, which may carry high concentrations of bacteria and viruses. Turbidity is measured in units of Nephelometric Turbidity Units (NTU) by a turbidimeter. The higher the NTU, the greater the number of suspended solids present in the water sample. After the first 10 min all turbidity approaches zero. Figure 21 shows the relationship between turbidity and time for each compost.

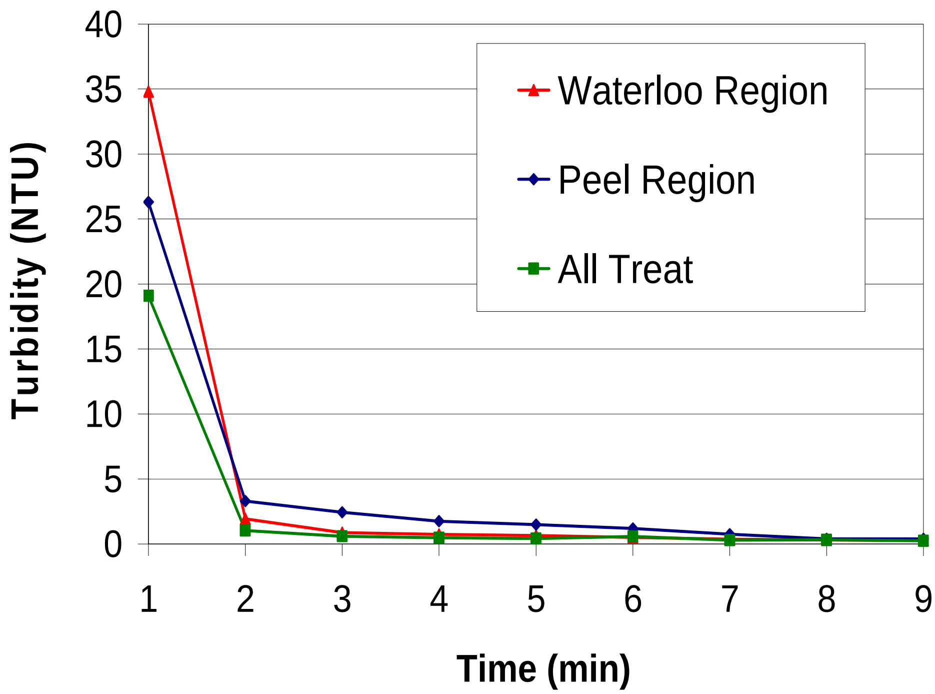

Figure 21: Turbidity vs. Time Comparison

6.3.3 Electrical Conductivity

Conductivity is a measure of the soluble salt content in the compost. In this case, a soluble salt refers to the concentration of soluble ions in the compost. Conductivity will vary with both the number and type of ions contained in the compost (USCC, 2002). Electrical conductivity gives an indication of the total ion concentration in the water (USCC, 2002). As is shown in Figure 22, the conductivity values ranged from 600 to 800 S/cm, which translates to approximately 76 to 138 mg/L of Chloride concentration. The United States Environmental Protection Agency (US EPA) has a water quality guideline value for protection of aquatic life of 230 mg/L chlorides for chronic exposure and 860 mg/L for acute short-term exposure. Figure 22 shows this trend. The conductivity for each compost seems to level out after 10 min.

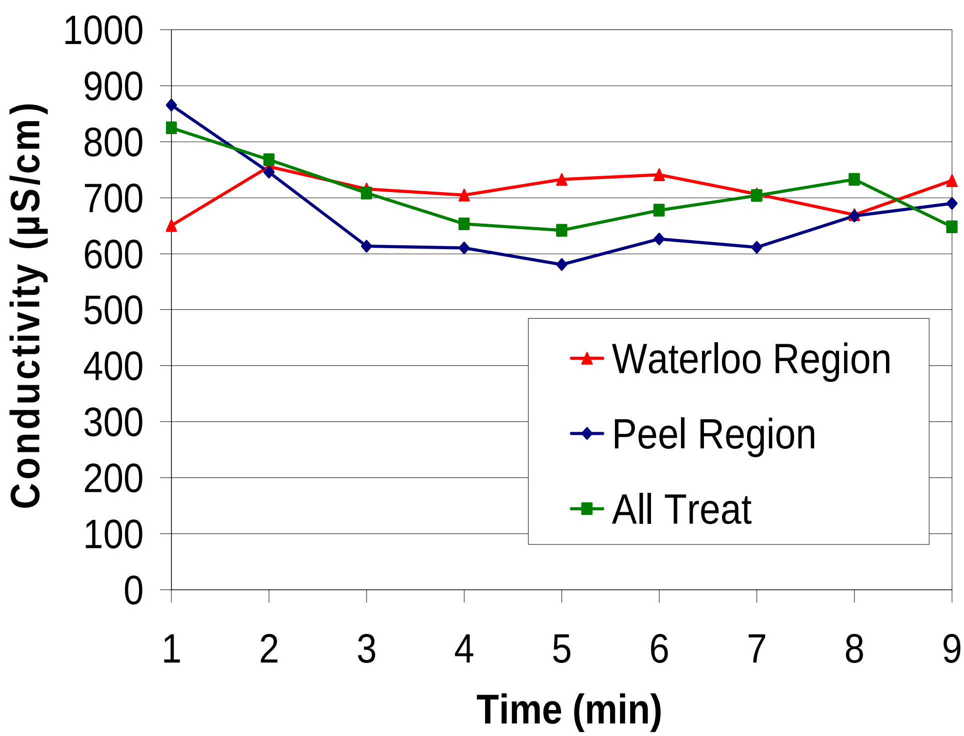

Figure 22: Conductivity vs. Time Comparison

6.3.4 pH

pH is a measurement of the degree of acidity or alkalinity of a solution. It is measured on a scale of 0 to 14. Acids have a pH of fewer than seven, alkalis have a pH of over seven, and neutral solutions have a pH value of seven. Both high and low values of pH can have negative effects on the aquatic life. However, as seen in Figure 23, the pH measurements for all three compost types are within the acceptable range set by the PWQO.

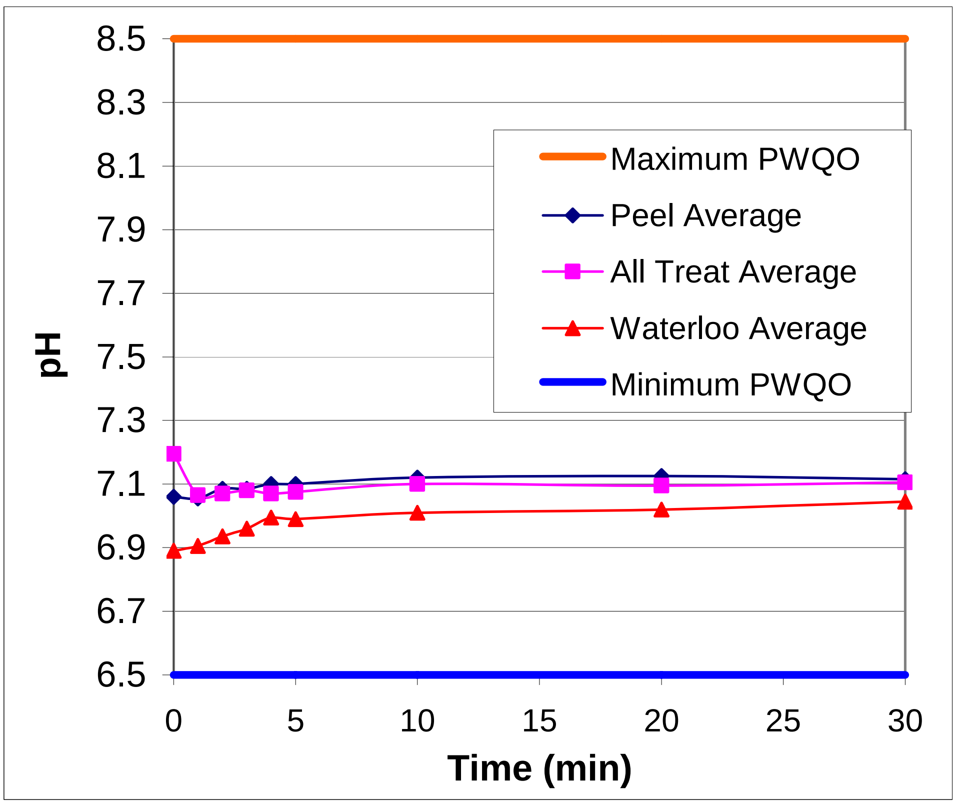

Figure 23: pH vs. Time Comparison

6.3.5 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl Nitrogen is the sum of the organic nitrogen plus ammonia nitrogen (NH_4+N) that is present in the sample (USCC, 2002). The results for TKN found in the discharge water can be seen in Figure 24. TKN concentration approached zero after about 5 min of clean water wash.

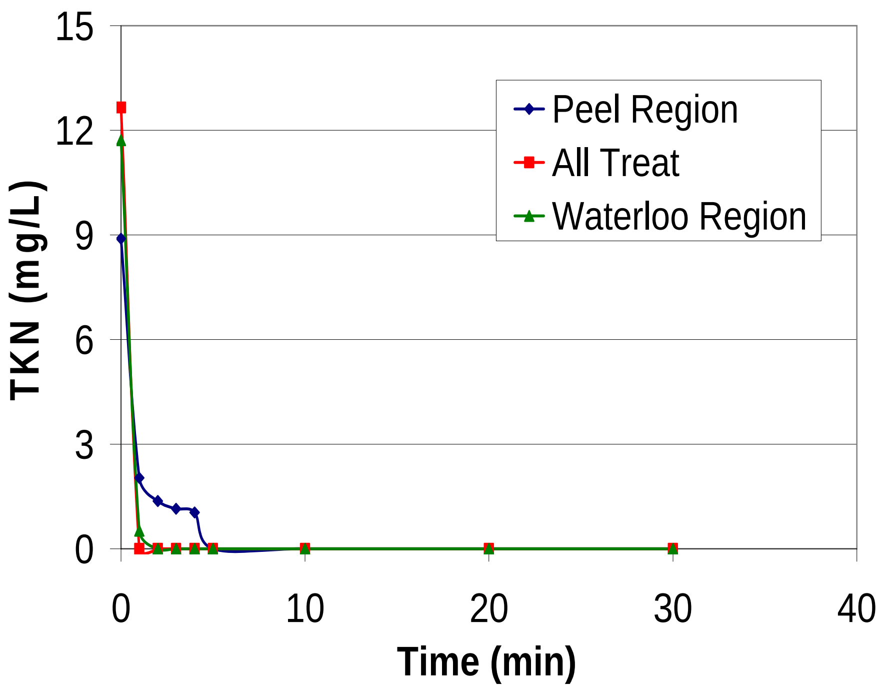

Figure 24: TKN Comparison

6.3.6 Total Phosphorous (TP)

To control eutrophication of lakes, rivers and streams, the PWQO has a limit of 0.030 mg/L on the amount of TP that can be discharged. As shown in Figure 25, TP concentration dropped below detection limit (<0.050 mg/L) after about 5 min of clean water flush through biofilter.

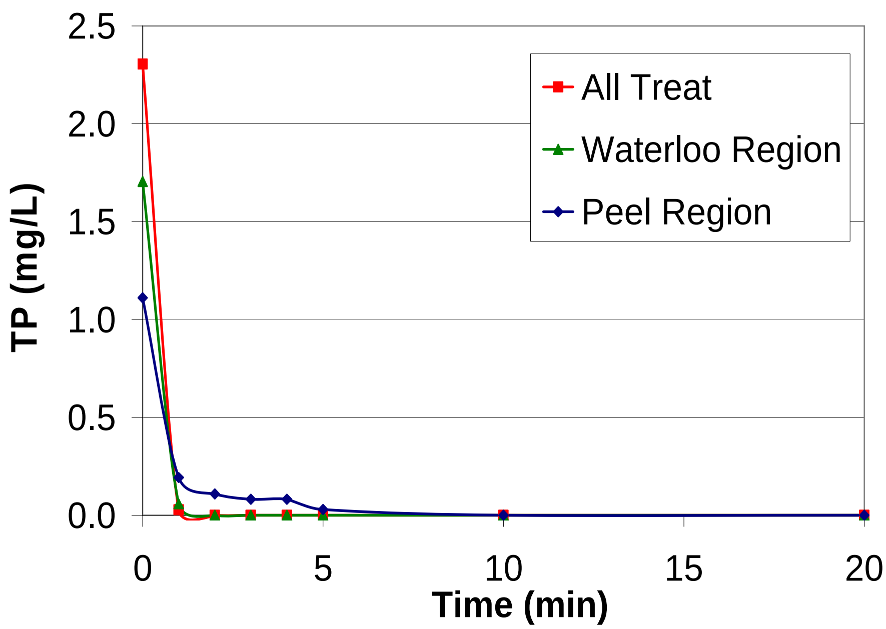

Figure 25: Total Phosphorous Comparison

6.3.7 Total Organic Carbon, Inorganic Carbon and Total Carbon

The total organic carbon content (TOC) of compost comes from sugars, starches, proteins, fats, hemicellulose, cellulose and lignocellulose that are degraded during composting and curing (USCC, 2002). The three different composts follow the same trend for TOC, as shown in Figure 26.

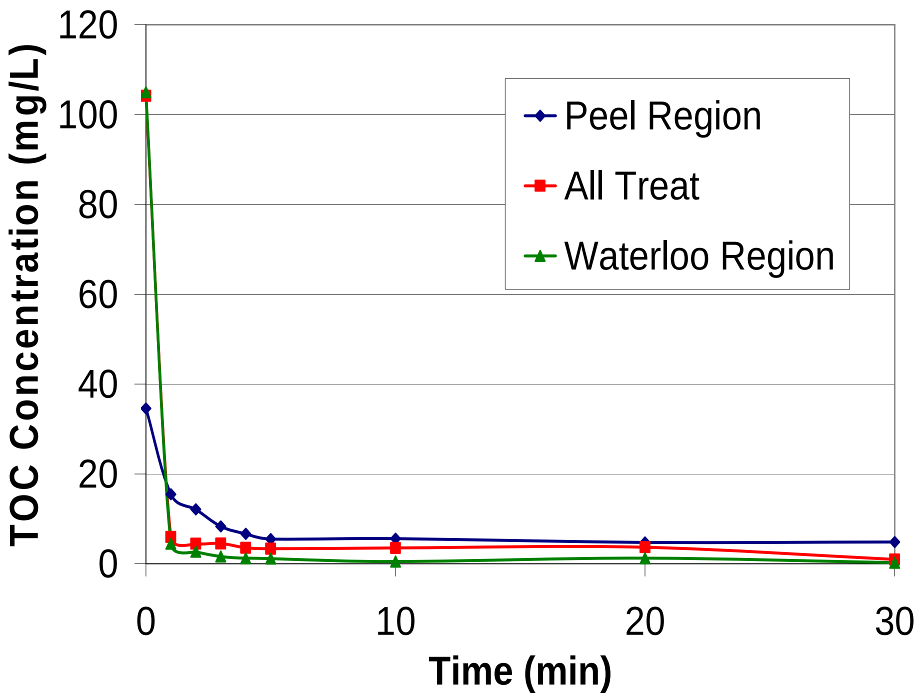

Figure 26: Total Organic Carbon Comparison

6.4 Field Experiment Results

6.4.1 New Filter Test Results

As is shown in Figure 27, the sediment removal efficiency increased with the number of socks. The average sediment removal efficiency of the 8″ socks for 5, 10, and 15 rolls were (20% to 40%), (40% to 60%), and (60% to 80%), respectively.

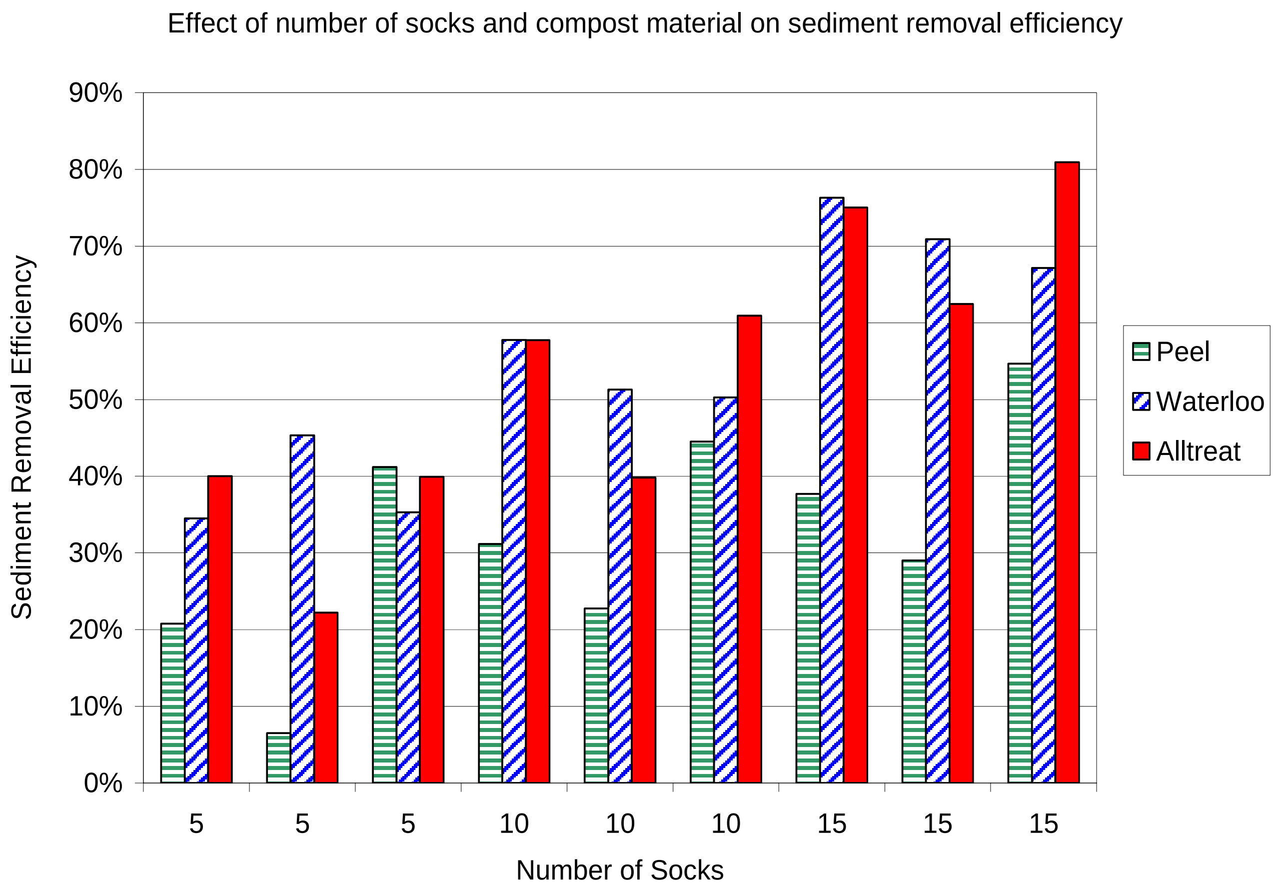

Figure 27: Effect of Number of Socks on Sediment Removal Efficiency

6.4.2 Longevity Test Results

It was observed that, over time, as the sediments started to accumulate in the biofilter, the flow through rate decreased (Figure 28). The maximum flow through rate per unit width of the 8" sock for the three compost materials, without overtopping, (overs) tested was 1.5 L s^{-1} m^{-1}.

It was found that the larger diameter socks provided a larger filter media and were more effective than the smaller diameter socks when filtering out the clay and silt particles from the soil solution. The flow through capacity without overtopping of the 18″ sock was approximately double the flow through capacity of the 8″ sock.

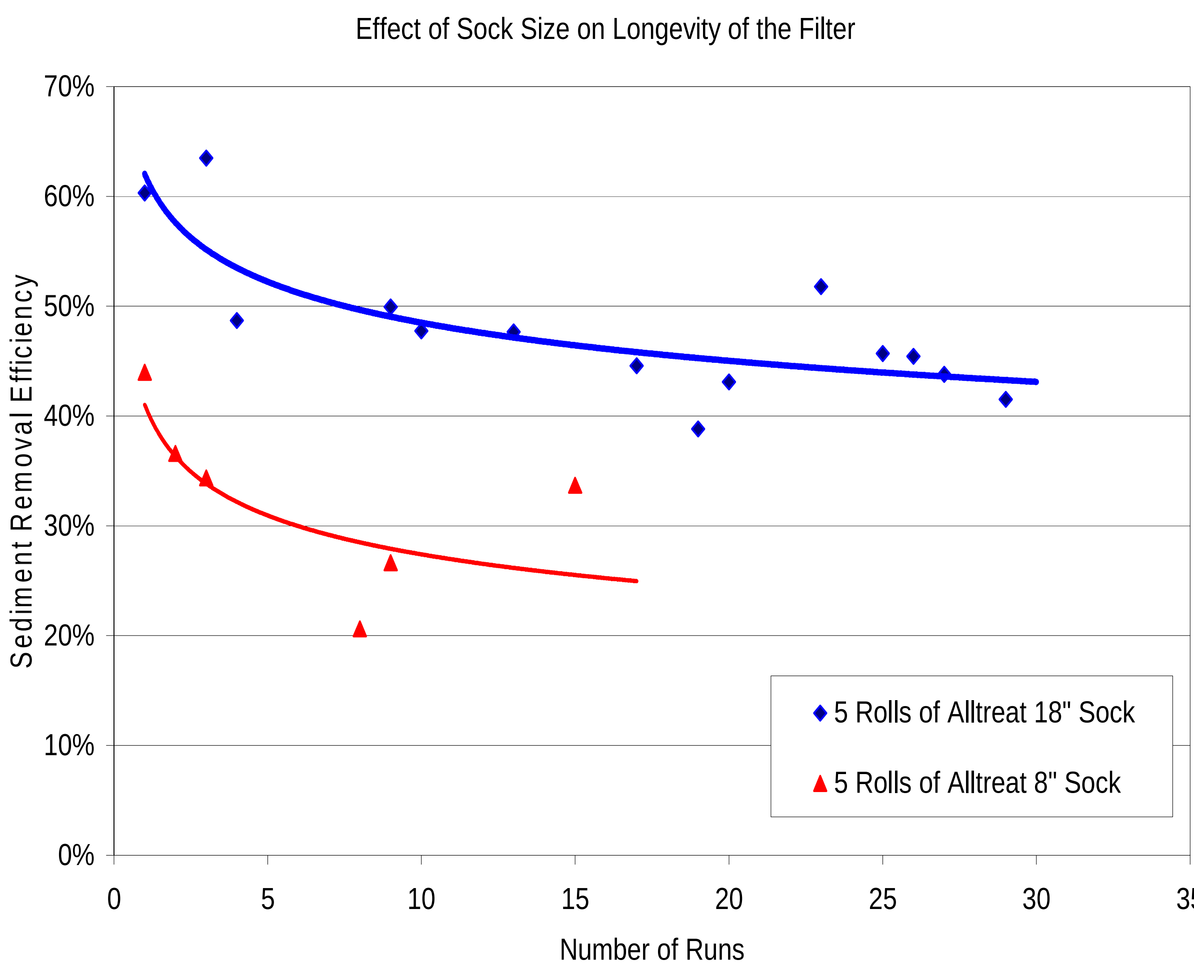

Figure 28: Longevity Test Results

6.4.3 Void Space and Porosity

Figure 29 presents change in compost porosity (percent void space) for the three sets of compost biofilter socks. The first five rolls near the inlet are labeled Z in Figure 29, the middle five rolls are labeled K and the last five rolls (near the outlet) are labeled O. The first set accumulated the highest amount of sediments and experienced the greatest decrease in void space after 16 consecutive runs.

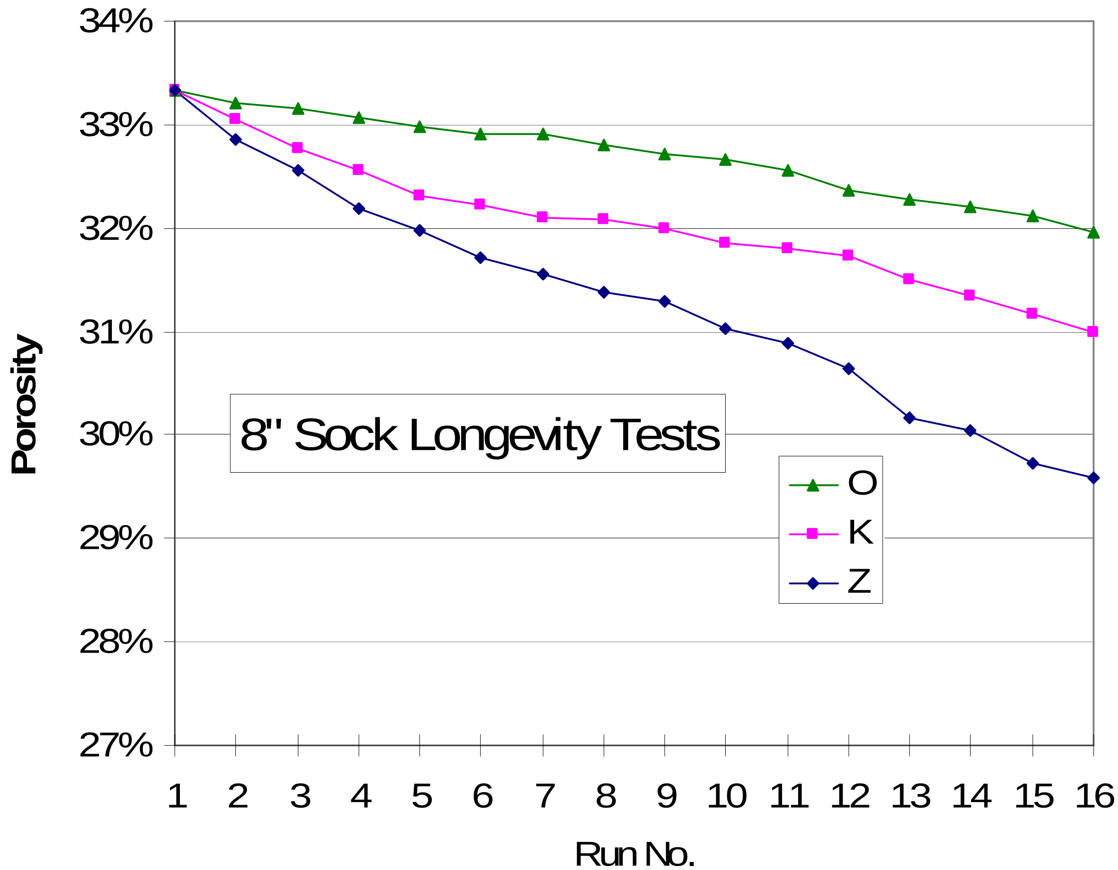

Figure 29: Sediment Accumulation Effect on Porosity

6.4.4 Effect of Flow Rate

In regards to the overall longevity of the socks, the sediment removal efficiency of the new sock reduces to roughly half its initial value over its life time and it is concluded that the removal efficiency did not increase at lower flow rates (Figure 30).

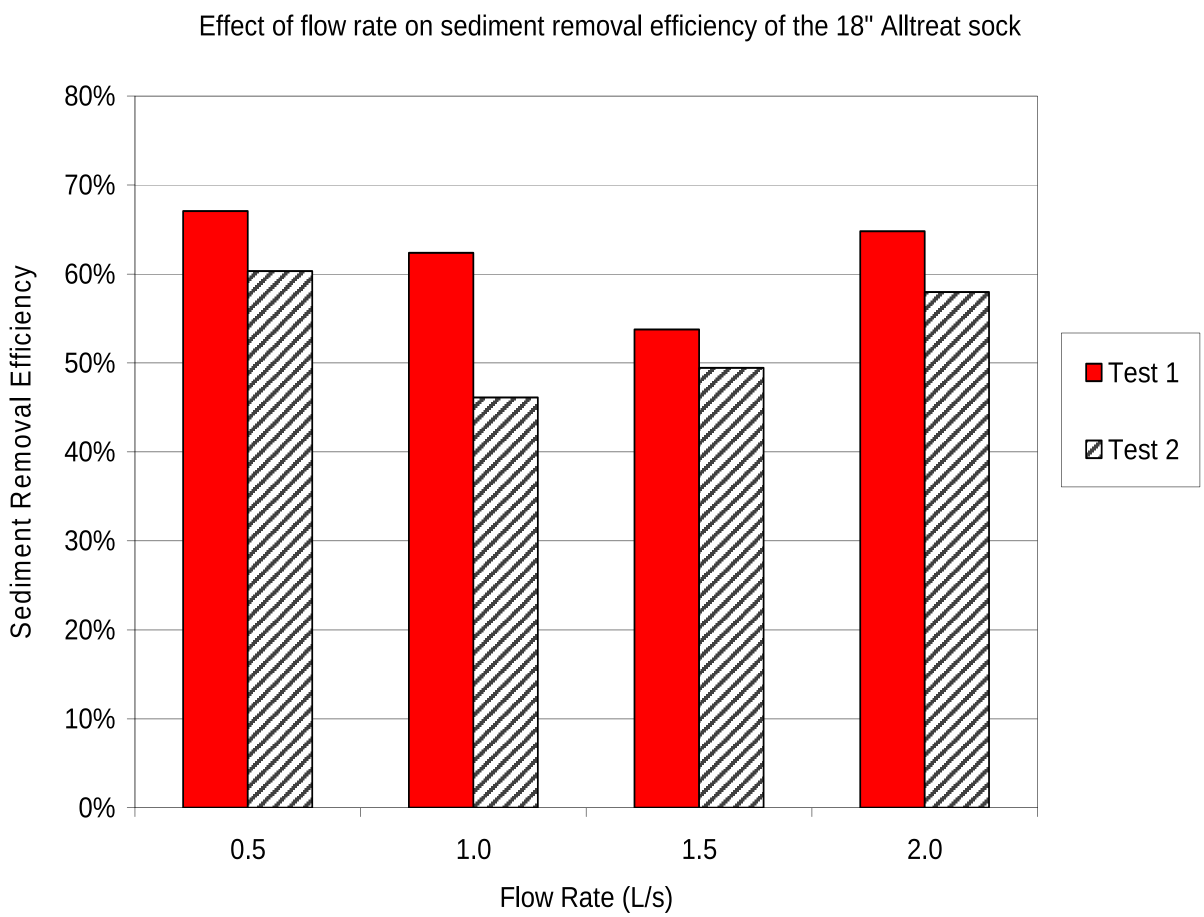

Figure 30: Sediment Removal vs. Flow Rates

6.4.5 Statistical Analysis Results

There are two sets of experiments conducted as part of this study. The first set was conducted in plot A location from May 10th to June 5th 2006. The objective for this set of experiments was to investigate the effect of different design factors on the sediment removal efficiency of the biofilter. The effects of four factors on sediment removal efficiency were considered: sock size (8″ or 18″), compost type (Waterloo, Alltreat, and Peel), number of socks (5, 10 or 15) and flow rate (0.5, 1 and 2 L/s). The sediment removal efficiency was calculated as the ratio of sediment concentration difference (inlet – outlet) over the inlet concentration.

As shown in Table 1, the main effect compost type and flow rate were not significant. Although compost type did not show statistical relativity when comparing the three different types it is important to note that they had similar consistencies and therefore this came out in the statistical results. The flow rates also have a large impact as the flow rates tested were in the 0.5 – 2 L/s range that is limited. When tested on a larger scale the flow rates were a major factor as overtopping can occur. The main effect of sock size and number of socks were significant. The non-significance of compost type was an important finding in this analysis.

Table 1: Effects of parameters

Effects	DF	F value	P value
Number of socks	2	38.94	<0.0001
Sock size	1	4.66	0.0355
Inlet Concentration	1	3.20	0.0796
Flow Rate	3	0.93	0.4348
Compost Type	2	0.13	0.8825

The second set of experiments was conducted in plot B location during May 10th to June 16th 2006. The objective was to study the longevity of different type of socks on the sediment removal efficiency. The treatments considered, included: sock size (8″ or 18″) and number of socks (5, 10 or 15). Compost type was Alltreat and flow rate was fixed at 1 L/s. For each treatment combination, 17 to 29 consecutive runs were completed.

Two separate statistical models were used in analyzing the above data sets. The linear mixed model for experiment 1 included four fixed effect treatments of sock size, compost type, number of socks, flow rate and their interaction. The inlet sediment concentration was included as continuous covariate and the date and the run number were taken as random blocks. The residuals of the final model were normally distributed. The model was simplified by removing those non-estimable interactions and non-significant main effects.

The estimated mean sediment removal efficiency of the new filters as well as the 95% confidence interval at different sock size and number of socks are present in Table 2.

Table 2: New Filter Tests

Sock size	Number of socks	Means	95% Confidence Interval	
			CI lower	CI upper
8"	5	34%	12%	55%
8"	10	48%	27%	69%
8"	15	60%	38%	81%
18"	5	69%	39%	99%
18"	10	84%	54%	100%
18"	15	95%	64%	100%

For, example, with five rolls of the 18″ sock the estimated mean sediment removal efficiency was 69% with 95% confidence interval as (39%, 99%).

The longevity test data from plot B was analyzed by fitting time curves for different treatment combination groups. The response variable was sediment removal efficiency. The residual examination of log transformed response model, log transformed both response and run number, as well as original scale model showed that original scale model had normally distributed residuals and was adopted. It was also found that the time trend was best described by quadratic curve, indicating that the removal efficiency decreased fast for the first several runs but gradually stabilized at a certain level. Based on the model, the estimated mean and 95% confidence interval for 5, 10, 15, and 20 runs is presented in Table 3.

Table 3: Longevity Tests on Five Rolls of the 18″ Alltreat Socks

Sock size	Run number	Means	95% Confidence Interval	
			CI lower	CI upper
18"	1	70%	59%	73%
18"	5	62%	57%	67%
18"	10	58%	53%	63%
18"	15	56%	50%	61%
18"	20	54%	49%	59%

For example, the predicted mean sediment removal efficiency for five rolls of the 18″ sock gradually decreased from 70% when the filter was new to 62% after 5 runs, to 58% after 10 runs, to 56% after 15 runs, and to 54% after 20 runs.

6.4.6 Particle Size Analysis Results

Samples were analyzed using the Mastersizer to determine their particle size distribution. Sediments were classified into 4 particle size classes: class 1 consisted of particles finer than 5.75 microns (clay size particles), class 2 consisted of particles between 5.75 and 19.95 microns (fine silt), class 3 consisted of particles between 19.95 and 60.23 microns (medium silt) and class 4 consisted of particles larger than 60.36 microns (course silt). Removal efficiency at each point was calculated for all four classes. Sample calculations are shown in Figure 31.

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
Inlet	50.5	36.5	10.6	2.4	418	301	88	20				
Outlet	56.5	36.8	5.0	1.7	212	138	19	7	49%	54%	79%	67%

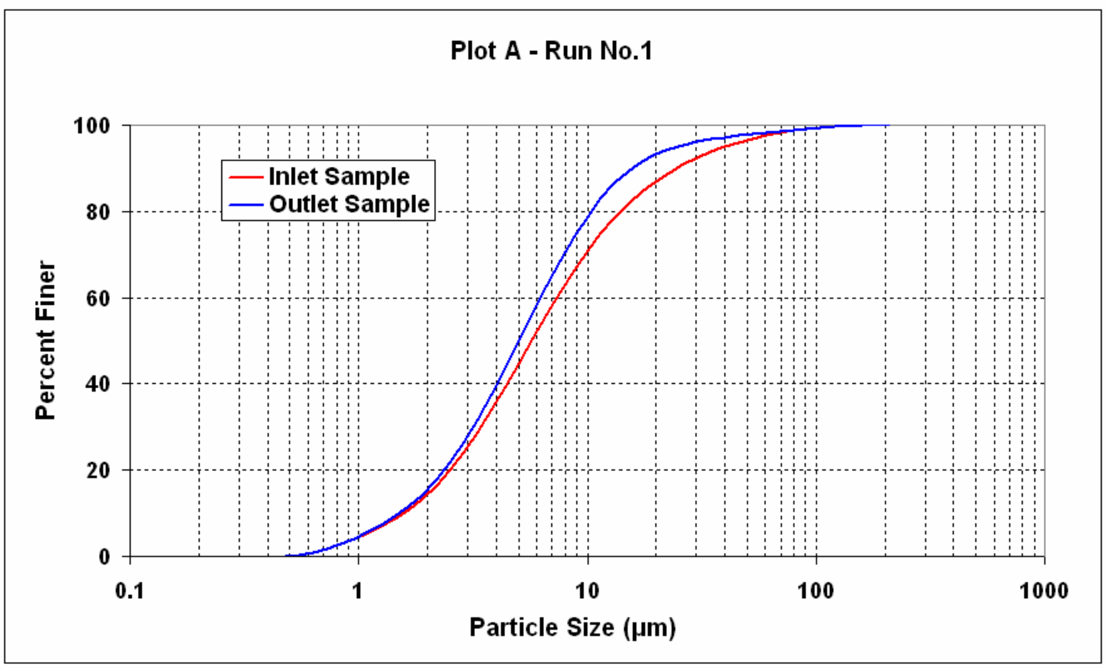

Figure 31: Particle size distribution

As is shown in Figure 32 for longevity tests, sediment removal efficiency was about 30% for clay size particles (Class 1), about 50% for fine silt (Class 2), and about 80% for medium and course silt (class 3 & 4). Sediment removal efficiency for clay size particles gradually decreased while the for medium and course silt increased. Results of particle size distribution analysis are shown in appendix F.

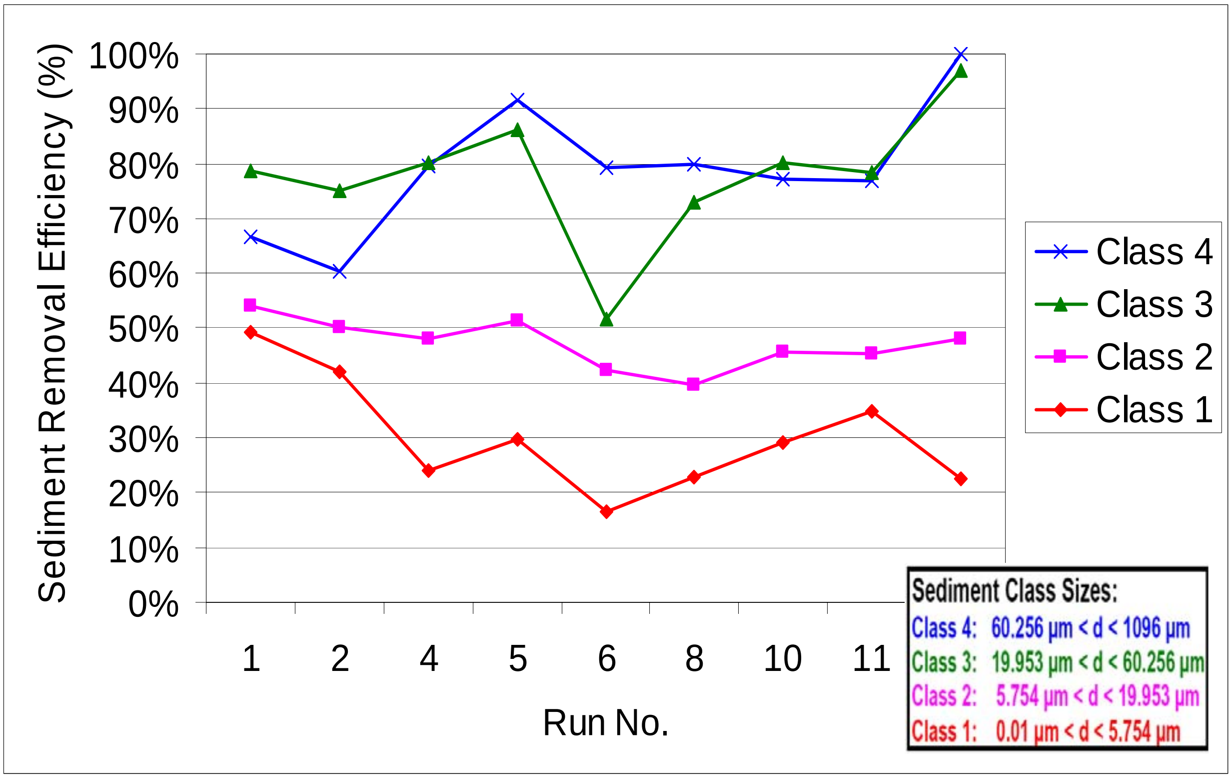

Figure 32: Particle size distribution

6.4.7 Polymer Tests

In order to determine the ideal concentration of polymers required for to obtain optimum settling velocities of the particles six hydrometer tests were conducted using 25, 50, 100, 200, 300 and 300 mg/L. It was found that the fastest settling velocities were obtained when the concentration of the polymers exceeded 100 mg/L. These results contradicted the larger scale polymer experiments preformed as the hydrometer lab tests used a mixer that mixed the polymer solution much more thoroughly than what could be preformed on a life size scale.

Testing of the PAM took place in a contained run comprised of two primary parts, a mixing section and a settling section. The mixing section consisted of multiple baffles, to create the turbulence required for the PAM to properly mix with the soil. The settling section contained two compost logs wrapped in burlap, along with layers of burlap draped through the run.

As with all testing, one of the ultimate concerns is always consistency. Be it the consistency in sampling, in environmental variables, or in the items being tested. This was the main source of difficulty with the original planned testing of PAM. There was no effective way to tell how much of the polymer was being used when in solid form. Therefore, there was no way to tell if it was consistently the same amount for each run.

This was solved by dissolving the PAM into a liquid slurry of known concentration, which was then pumped into the flow at a known rate. A concentration of 5mg/L was first run, during which, jar tests were performed at several concentrations. These jar tests showed 500mg/L to be most effective. This was contrary to most other research previously performed however. Following these results of these jar tests however; 500mg/L was the next concentration run.

It was observed that the 500 mg/L polymer concentration had a much lower rate of sediment removal than the 5 mg/L polymer concentration. This was contradictory to the jar test results, which showed settling, time for 500 mg/L polymer concentration and for the 5 mg/L polymer concentration.

It was also observed that the TSS test for the 500 mg/L concentration that the samples would not filter. The high concentrations of polymer remaining in the outlet samples clogged the filters so quickly that very little water was drawn out. This problem also arose in the attempted mid point samples. The polymers in the sample quickly clogged the filter, making it impossible to get a TSS value.

The solid tests were performed after the liquid tests, and two surface areas were tested. The 360 cm² and 720 cm² tests showed results of lesser removal than the liquid tests at any concentration run. Troubles also arose when attempting to remove the polymer pucks in between runs as well as storage. When removing pucks from the run, large globules of polymer were falling off, as well as sticking to the sides of the baffles. Storing the pucks also led to problems, and ultimately, not allowing the pucks to be employed for reuse.

Figure 33 - Storage of the Pucks after use, ad removal of pucks during testing

The liquid polymer test results proved more promising, showing consistent removal rates as high as ~93% for the 5 mg/L tests.

7 FULL SCALE TESTS

Full scale tests of the biofilter at the outfall of an erosion and sediment control pond were conducted in November 2006 by the Toronto and Region Conservation Authority under the Sustainable Technologies Evaluation Program (STEP). The purpose of the tests was to measure the capacity of biofilters to remove fine particulate matter and to determine how variations in pond outflow rates affect suspended solids removal. This chapter was adapted from a separate more detailed report on the full scale tests prepared by TRCA in March 2007.

7.1 Study Location

The study area is located in the Humber River Watershed and drains to the east branch of the river (Figure 34). The site is a 21.9 ha construction site located in a low tableland area near the intersection of Highway 27 and Islington Avenue in the Humberplex Community, Kleinburg, Ontario (Figure 35).

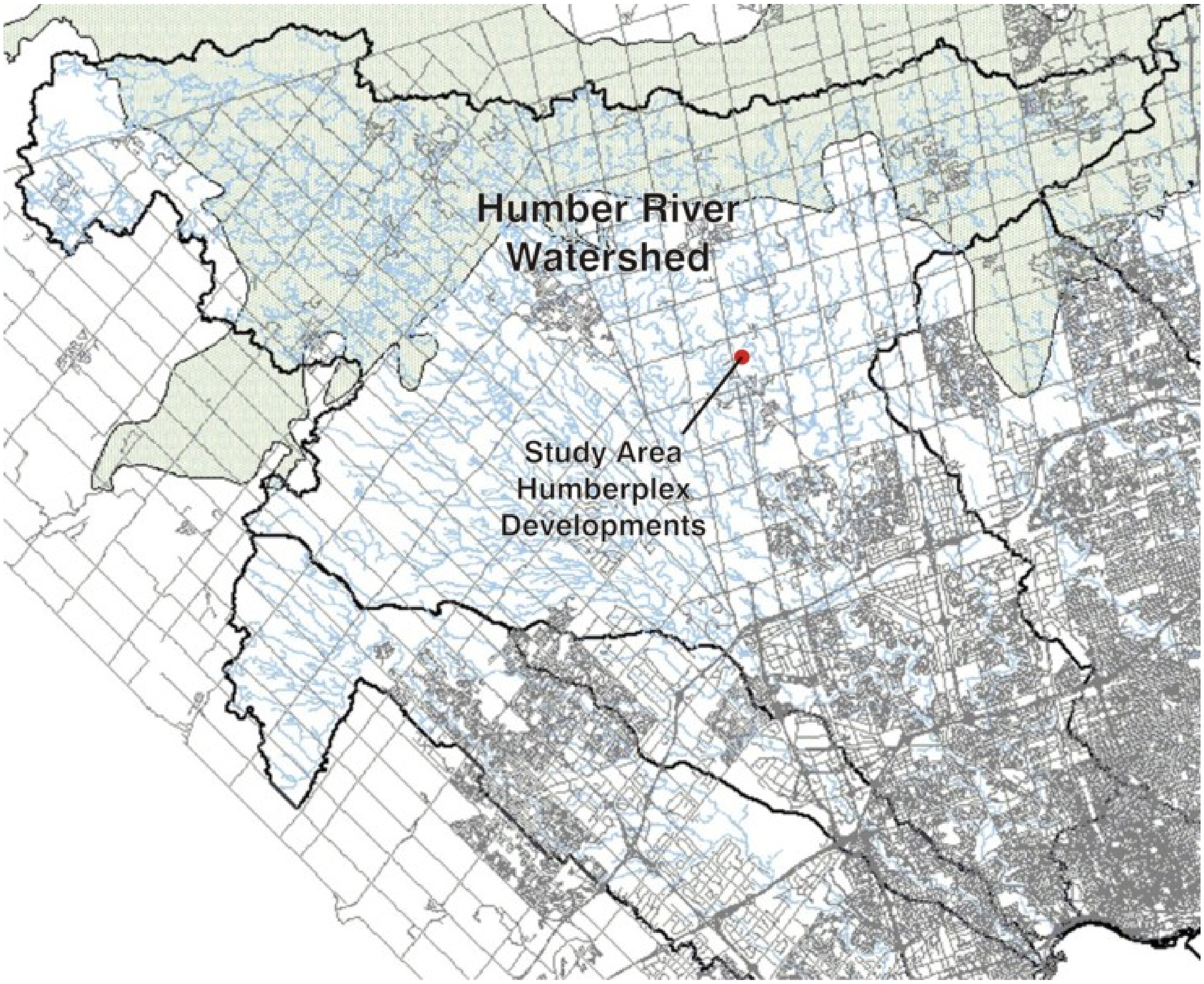

Figure 34 – Study area, Humber river watershed

Figure 35 – Study location within the Humberplex Development

The pond is designed to provide 'Level 1' quality control with permanent and extended detention storage volumes of 148 m^3/ha and 123 m^3/ha respectively. Drawdown times for a 25 mm event were less than 24 hours. The biofilter ditch-check berm system was installed downstream of the south outlet structure (Figure 36).

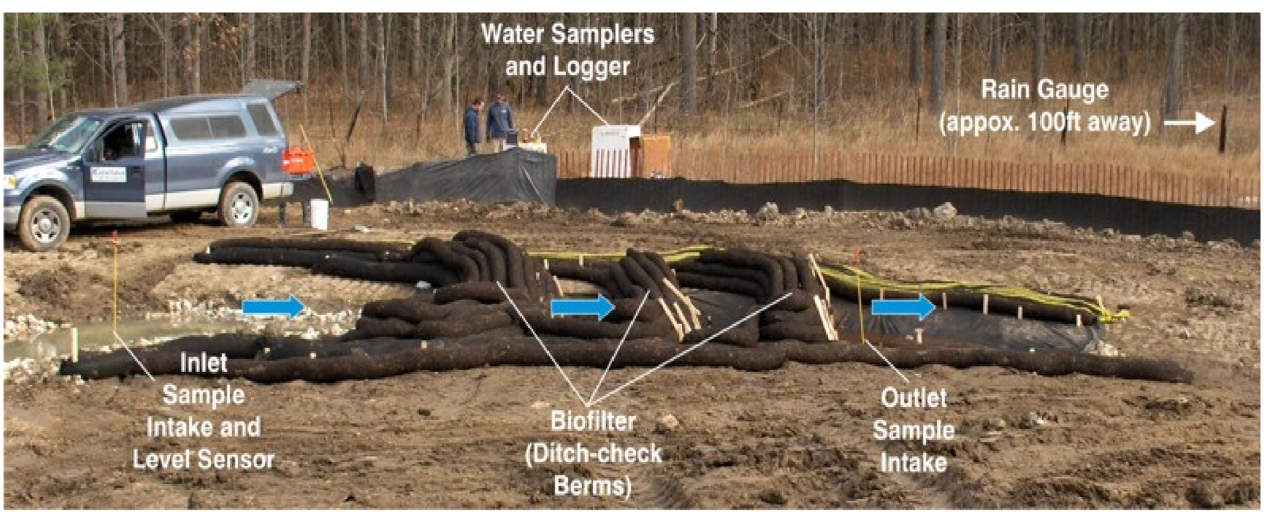

Figure 36 – Biofilter system and monitoring equipment locations.
(Blue arrows depict the direction of flow)

7.2 Runoff Sampling

The biofilter system was monitored from November 5th to December 5th, 2006. A tipping bucket rain gauge and logger was installed on site. Rainfall measurements were recorded at 5 minute intervals and downloaded bi-weekly. An ISCO 4150 flow meter and area/velocity sensor was installed in the pond outlet flow splitter, upstream of the biofilter, and was programmed to record water level, flow, and velocity every 5 minutes (Figure 37).

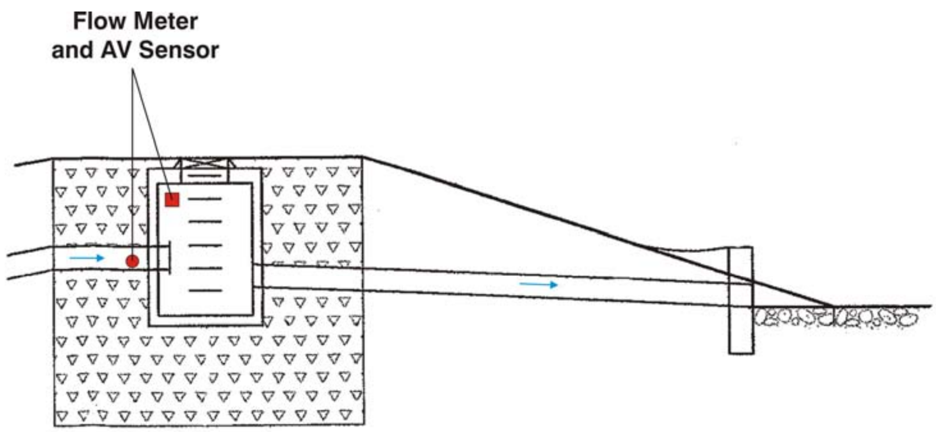

Figure 37: Location of outlet flow meter.

Water samples were collected as grabs, time proportioned composites, and discrete aliquots. Samples collected before and after the biofilter are referred to as "influent" and "effluent". Influent and effluent water samples were collected using two ISCO 6700 automated water samplers and triggered via water level by the ISCO 4150 flow meter and area/velocity sensor. Using a "Y" split connection cable, both samplers were triggered simultaneously with the effluent sampler starting 30 minutes after the influent-biofilter sampler. The samplers were fitted with 24, one liter bottle carousels which permitted both discrete and composite sampling. The samplers were programmed to take one 500 ml sample per bottle every 30 min over a period of 24 hrs. Sample intakes were installed at both the inlet and outlet of the biofilter system and each sampler was housed in a weatherproof enclosure. Samples were processed offsite and submitted to the Ontario Ministry of the Environment laboratory services for analysis.

7.3 Biofilter through-flow capacity

The through-flow capacity of the biofilter system depends on the hydraulic conductivity of the compost material, the dimensions of the ditch-check berms and the head loss in the water level (upstream versus downstream of the berm). The laboratory and field tests (as shown in Fig. 17, 18, and 19) indicated that the through-flow capacity of the biofilters is approximately 1 L/s per 1 m width and 0.1 m head loss; the field experiments on the 18" sock (Table 9, run number PA-A2.0-R1) also confirmed a through-flow capacity of 2 L/s per 1 m width and 0.2 m head loss. The measured width of flow and head loss of the filter socks installed for the full-scale test (Fig. 38) was approximately 2 m and 0.3 m, respectively. Hence, the initial flow through capacity was approximately 5 L/s.

The biofilter was visually observed during rain events to determine the flow rate at which overtopping begins to occur. Comparison of the visual observations with measured flow rates indicates that the through-flow capacity of the system was approximately 3 L/s, which is less than the theoretical flow through capacity determined from the pilot scale tests.

Figure 38: Biofilter overflow caused by high flow rates, December 1, 2006 13:05 pm.

7.4 Results and Discussion

Seven rainfall events occurred during the study period ranging in size from 1 mm to 31 mm. Influent and effluent water samples were collected during 5 of the 7 events. Water samples were analyzed discretely for suspended solids, and as composites for selected groups of pollutants, including metals, nutrients, and general chemistry. During 2 of the 5 events, samples were collected during only a portion of the event because of equipment malfunction. Table 4 summarizes the rainfall, flow, and total suspended solids (TSS) concentrations and loads for the three events with discrete samples collected over the duration of the event. The following sections examine each of these three events in more detail.

Table 4: Suspended solids removal efficiency of biofilter.

Event Date		11-Nov-06	30-Nov-06	1-Dec-06	Total
Rain	Depth (mm)	7.7	19.6	31.5	-
Flow	Maximum (L/s)	3.6	22.7	81.8	-
	Mean (L/s)	2.1	6.3	18.2	-
TSS Influent	Max Concentration (mg/L)	55.2	392.0	2580.0	-
	Maximum Load (kg/hr)	0.5	29.1	768.5	-
	Mean Concentration (mg/L)	29.1	148.1	660.9	-
	Total Load (kg)	5.7	106.1	3345.2	3457
TSS Effluent	Max Concentration (mg/L)	23.4	247.0	2520.0	-
	Maximum Load (kg/hr)	0.3	18.4	692.9	-
	Mean Concentration (mg/L)	18.1	97.8	592.6	-
	Total Load (kg)	3.2	67.7	3131.8	3203
TSS Removal	Removal Efficiency (%)	42.8	36.2	6.4	7.3

7.4.1 The November 11th, 2006 Event

The November 11th, 2006 event was a typical mid-sized storm event. During this event, only slight overtopping was observed. Over the sampling period, the load-based TSS removal efficiency was 43% and the average and maximum effluent concentrations were below the 25 mg/L threshold for the protection of aquatic life. Removal efficiencies decline as influent concentrations approach 'background' TSS levels (Figure 39), a phenomenon that has also been demonstrated in stormwater ponds and wetlands (SWAMP, 2005).

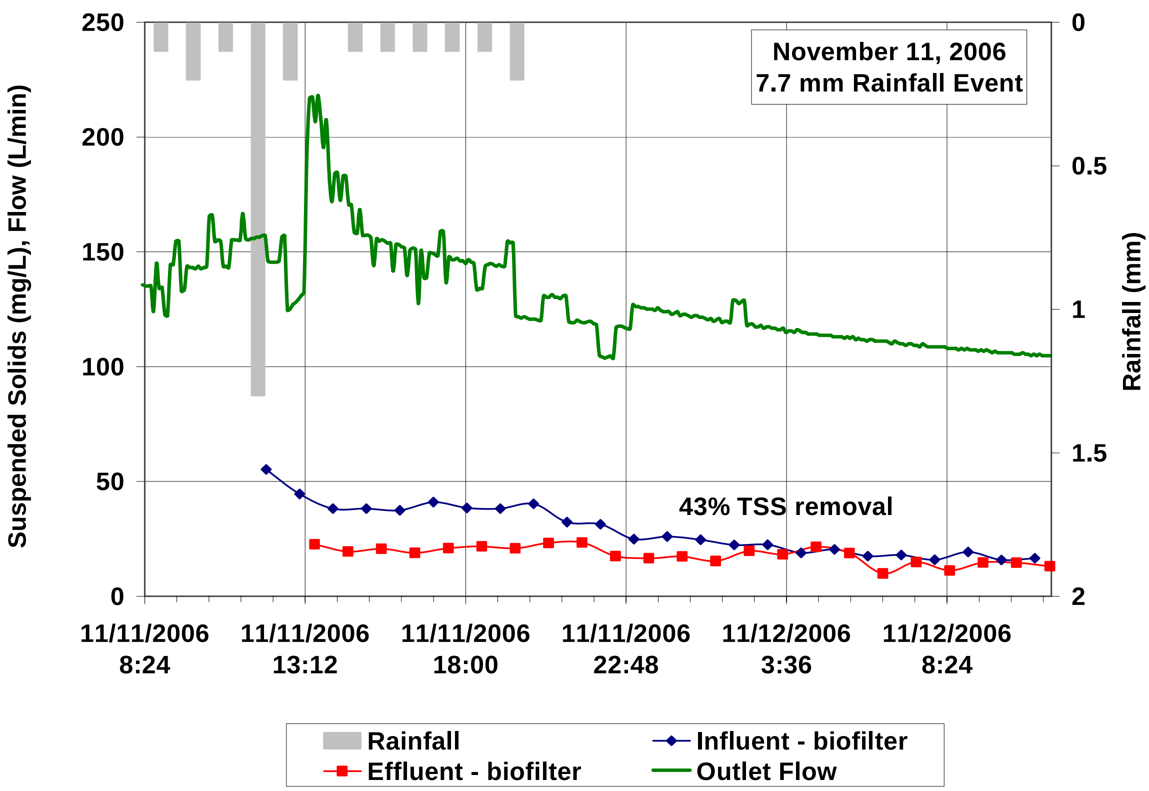

Figure 39: Flow, Rainfall and TSS Concentrations, November 11th, 2006.

7.4.2 The November 30th, 2006 Event

The November 30th, 2006 event was a larger event (19.6 mm). Flow during this storm exceeded the through-flow capacity of the biofiter system most of the time. Effluent concentrations during this event were elevated and much higher than the 25 mg/L threshold for the protection of aquatic life. Even though a significant volume of runoff overtopped the biofilter and was not treated, the biofilter was able to remove 36% of influent TSS loads. As shown in Figure 40, during the peak of the November 30th, 2006 event the influent TSS concentration was 400 mg/L and the effluent TSS concentration was 250 mg/L (*i.e.* 40% TSS removal efficiency).

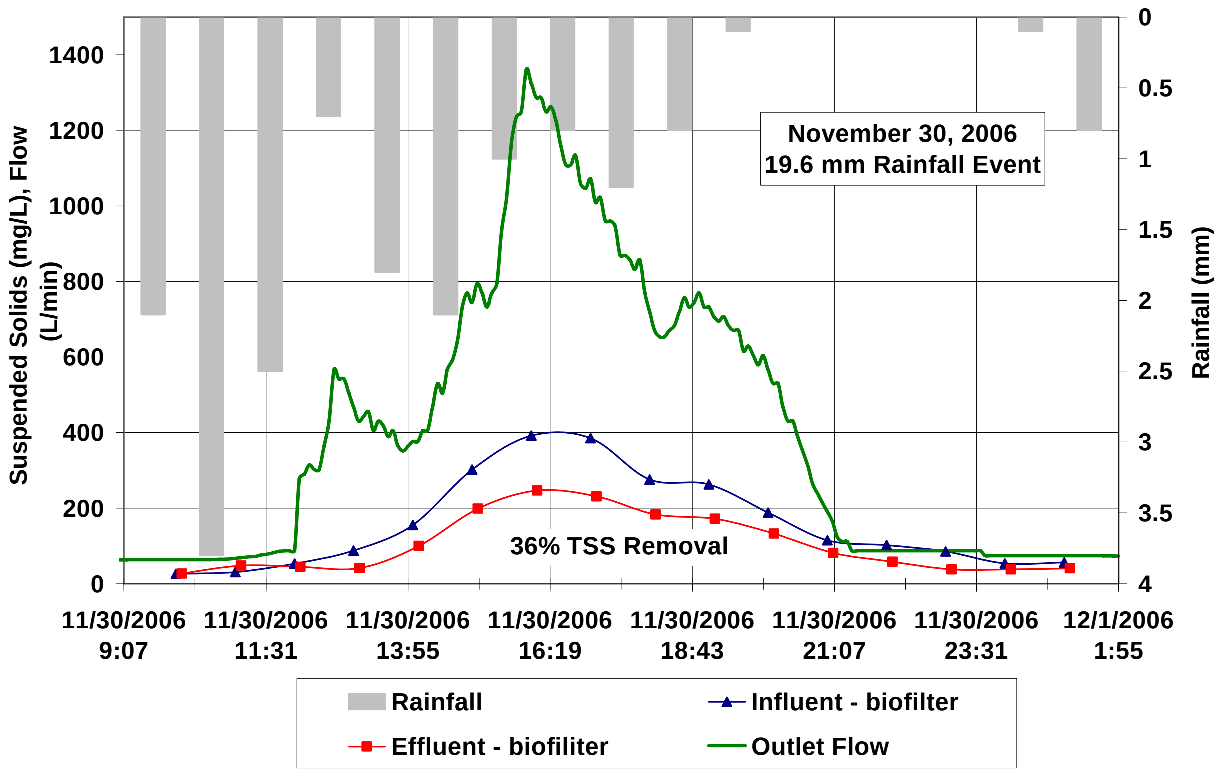

Figure 40: Flow, Rainfall and TSS Concentrations, November 30th, 2006.

7.4.3 The December 1st, 2006 Event

The December 1, 2006 event occurred on the heels of the November 30th event and produced 31.5 mm of rain over roughly 16 hours. The soil was already saturated when this storm arrived and due to infiltration-excess, or Hortonian overland flow, this event resulted in significant runoff and soil erosion. Peak flows approached 5,000 L/min, compared to only 216 L/min and 1,362 L/min peak flows for the Novermber 11th and 30th storms. The bulk of the stormwater runoff overtopped the biofilter and was not treated, resulting in a very low TSS removal efficiency (6.4%).

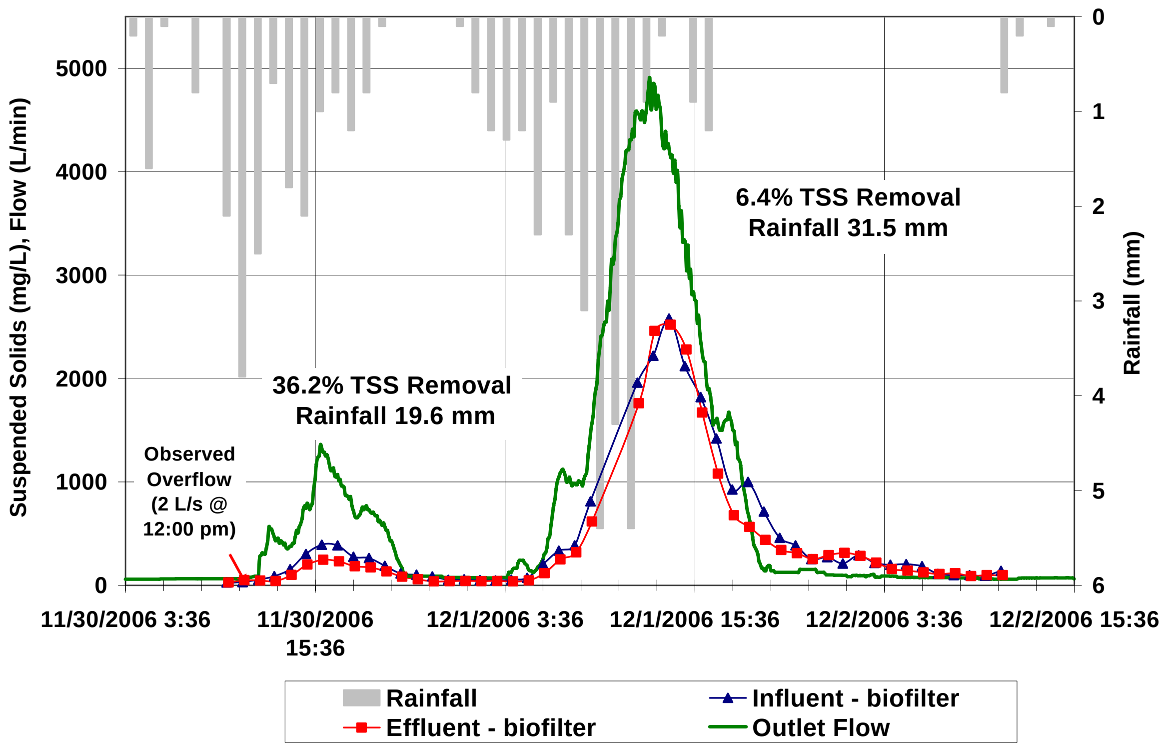

Figure 41: Flow, Rainfall and TSS Concentrations, November 30th and December 1st, 2006.

Total sediment load during the November 11th, November 30th, and December 1st events were 5.7 kg, 106 kg, and 3,345 kg, respectively. Since close to 95% of the total TSS load for the three events was discharged during the December 1st event, during which most of the flow was not treated, the overall load-based TSS removal efficiency for the biofilter over the three events was only 7.3%.

7.4.4 Sediment accumulation capacity of the system

Figure 29 shows that porosity of a new compost material is roughly 33% void space and the longevity field tests indicate that when this number goes down to about 23% it is time to replace the biofilter. That is, the biofilter can hold about 10% of sediments by volume. The total effective volume of the biofilters was roughly 3000 L of compost and therefore the sediment holding capacity of the system was roughly 300 L or approximately 300 kg (assuming the density of freshly deposited sediments is roughly 1 kg/L of solids).

During the Nov. 11th event, total sediment load at inflow was 5.7 kg and 2.5 kg of that was trapped in the biofilter; the November 30th event resulted in 106 kg of influent sediment load and 39 kg trapped was trapped in the biofilter; however, the December 1st storm event resulted in 3,345 kg influent sediment load and 210 kg was trapped in the biofilter. During this event the cumulative sediment load trapped in the biofilter exceeded the capacity of the filter. Figure 41 shows that near the end of the December 1st storm, when flow rates parallel those of the November 30th storm, influent and effluent concentrations remain similar.

An important design consideration for the biofilter system is to estimate the total sediment load that needs to be trapped during the lifetime (typically one year) of the system and install enough of the ditch-check berms in series to provide the necessary volume and void space capacity to trap the sediments. The volume of the biofilter should be approximately 10 times the volume of the sediments that needs to be trapped. In this field trial, the TSS load exiting the pond was vastly underestimated, resulting in early clogging of the system.

7.4.1 Particle Size Analysis

Average influent and effluent particle size distributions (n=9) are presented in Figure 45. The average distributions were almost identical indicating that size-selective removal of particles was not occurring. The median particle size (d_{50}) was less than 2 µm (or clay sized) and the 10^{th} percentile diameter particle (d_{10}) was 7 µm. That is, 90% of suspended solids in runoff were smaller than 7 µm (fine silt and clay size). It is remarkable that the biofilter was able to remove 36% to 43% of particles this size during low flow events. These results are consistent with the results presented in Figure 32 for sediments sizes in Class 1 (consisted of particles finer than 5.75 µm).

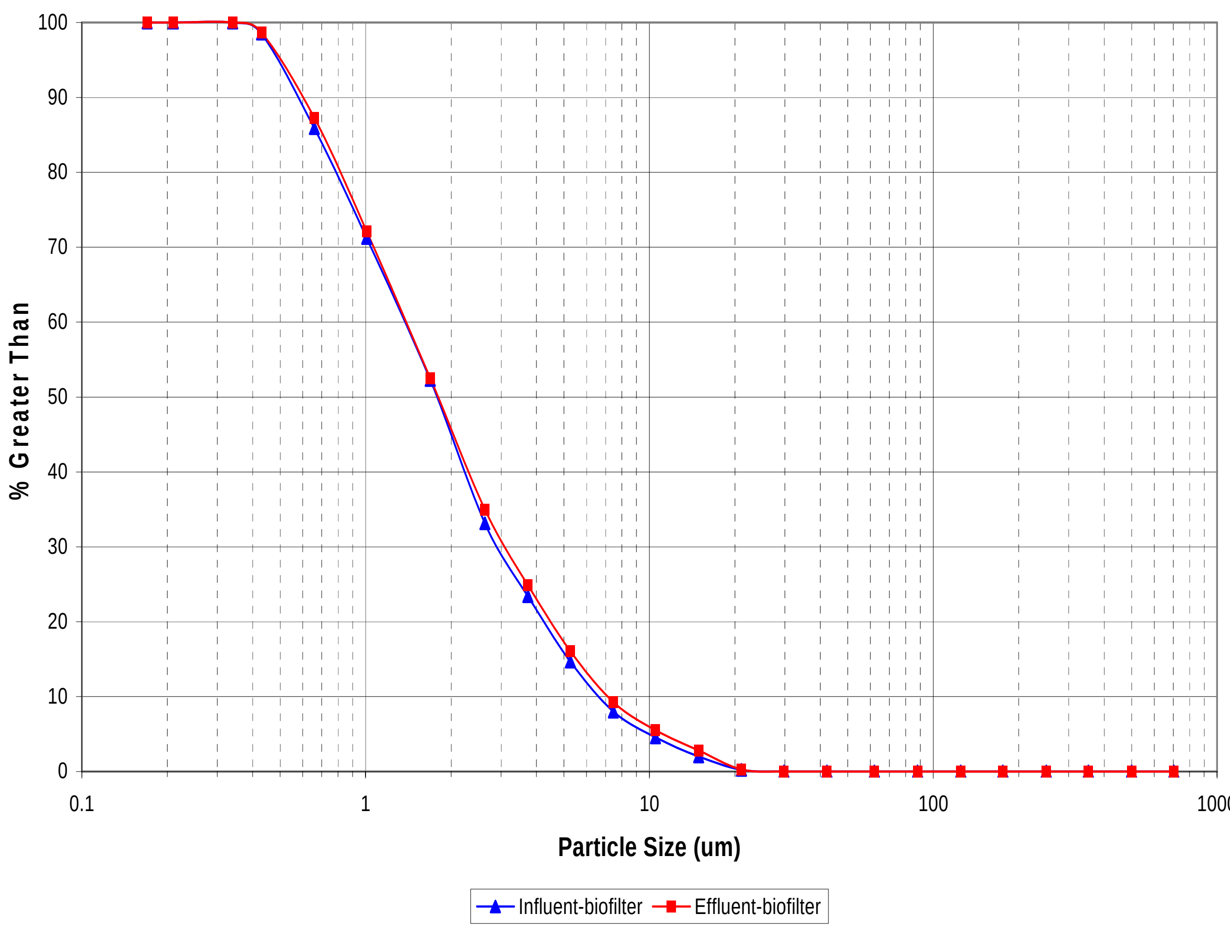

Figure 42: Average Influent and Effluent Particle size distribution (n=9)

7.4.2 Nutrients and Heavy Metals

Sample results for heavy metals indicate that the biofilter is effective in reducing the average concentration of most metals (Figure 43), although on a load basis these removal rates would be much lower. Copper was the only metal in which removal performance was poor (-12.3%). Aluminium, cadmium, copper, and iron all exceeded provincial water quality guidelines. In both cases, this may be a result of trace amounts of metals in the compost material or native soils, and a need for improved suspended solids removal.

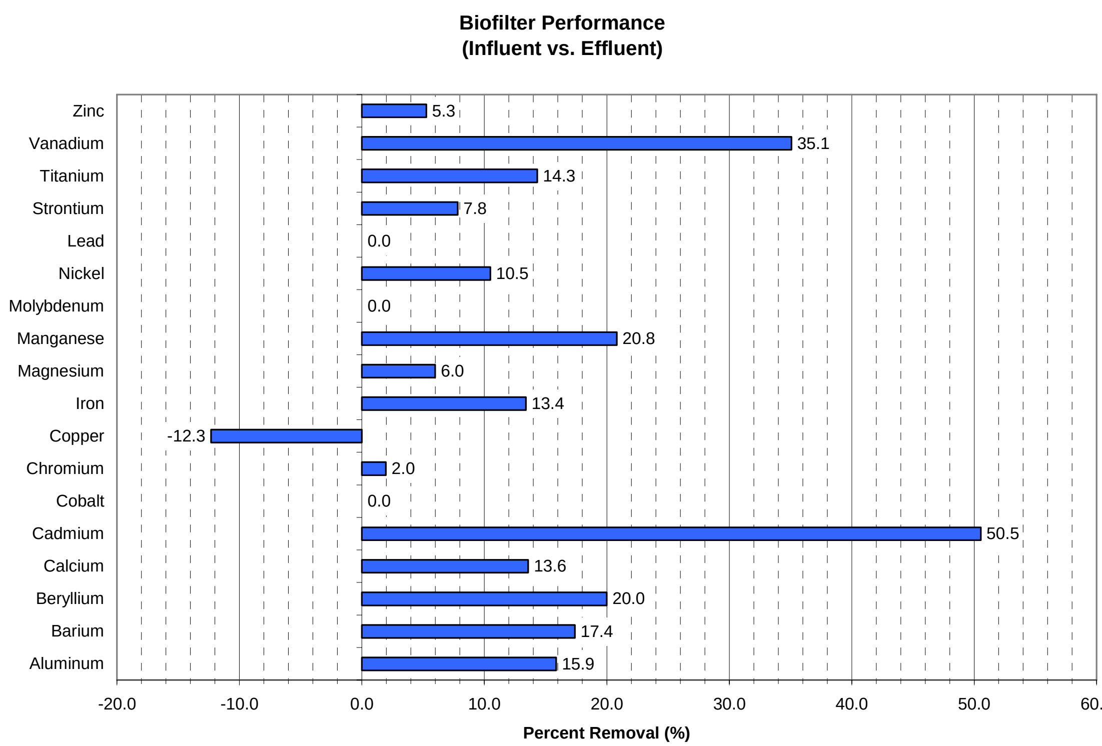

Figure 43: Metal Removal Efficiency

As shown in Table 5, Nutrients such as TKN and total phosphorus experienced improvements similar to that of suspended solids (roughly 25%), and comparable to that of metals. This is not a surprising result as these constituents readily bind to suspended solids (although a portion of TKN is also transported in dissolved form). Dissolved nutrients such as nitrite and phosphate experienced little or no treatment by the biofilter as these constituents are not subject to settling or filtration. Dissolved organic carbon increased by about 50%, likely due to leaching from the filter sock.

Table 5: Biofilter water quality performance results.

				Influent-biofilter					Effluent-biofilter					Performance		
														Mean		
	Parameter	Units	Guideline	# of Samples	Min	Max	Mean	Median	# of Samples	Min	Max	Mean	Median	Influent-Biofilter	Effluent-biofilter	Influent vs. Effluent
General Chemistry	Chloride	mg/L	250	3	11.800	17.700	15.567	17.200	4	12.600	18.900	16.000	16.250	15.6	16.0	-2.8
	Arsenic	mg/L	0.1	3	0.001	0.001	0.001	0.001	4	0.001	0.001	0.001	0.001	0.0	0.0	0.0
	Selenium	mg/L	0.1	3	0.001	0.001	0.001	0.001	4	0.001	0.001	0.001	0.001	0.0	0.0	0.0
	Solids; suspended	mg/L	20	3	**26.500**	**859.000**	**356.500**	**184.000**	4	**28.700**	**740.000**	**268.175**	**152.000**	356.5	268.2	24.8
	Solids; suspended, ash	mg/L	20	3	**21.900**	**754.000**	**312.300**	**161.000**	4	**22.700**	**648.000**	**233.675**	**132.000**	312.3	233.7	25.2
	Solids; suspended, LOI	mg/L	20	3	4.600	**105.000**	**44.400**	**23.600**	4	6.000	**92.300**	**34.450**	**19.750**	44.4	34.5	22.4
	Conductivity	uS/cm		3	219.000	358.000	303.000	332.000	4	227.000	371.000	306.250	313.500	303.0	306.3	-1.1
	Carbon; dissolved organic	mg/L		3	2.000	2.500	2.233	2.200	4	2.900	4.200	3.325	3.100	2.2	3.3	-48.9
	Carbon; dissolved inorganic	mg/L		3	15.500	18.400	17.033	17.200	4	16.800	19.400	17.900	17.700	17.0	17.9	-5.1
	Silicon; reactive silicate	mg/L		3	1.600	2.500	2.160	2.380	4	1.720	2.560	2.155	2.170	2.2	2.2	0.2
	pH	None	6.5 - 9.5	3	8.120	8.180	8.150	8.150	4	8.090	8.150	8.118	8.115	8.2	8.1	0.4
	Alkalinity; total fixed endpt	mg/L CaCO3		3	77.100	90.400	84.100	84.800	4	76.200	93.900	84.675	84.300	84.1	84.7	-0.7
	Turbidity	FTU	5	3	**59.000**	**1880.000**	**748.000**	**305.000**	4	**226.000**	**2000.000**	**1077.250**	**1041.500**	748.0	1077.3	-44.0
Nutrients	Nitrogen; ammonia+ammonium	mg/L	1.4	3	0.001	0.031	0.017	0.019	4	0.001	0.157	0.078	0.078	0.0	0.1	-360.3
	Nitrogen; nitrite	mg/L	0.06	3	0.034	0.045	0.041	0.044	4	0.035	0.067	0.051	0.052	0.0	0.1	-25.0
	Nitrogen; nitrate+nitrite	mg/L		3	1.280	2.140	1.833	2.080	4	1.280	2.100	1.818	1.945	1.8	1.8	0.9
	Phosphorus; phosphate	mg/L		3	0.016	0.103	0.063	0.069	4	0.026	0.104	0.060	0.055	0.1	0.1	4.7
	Phosphorus; total	mg/L	0.03	3	0.059	0.946	0.419	0.253	4	0.055	0.863	0.308	0.157	0.4	0.3	26.6
	Nitrogen; total Kjeldahl	mg/L	3.2	3	0.470	1.160	0.797	0.760	4	0.150	1.130	0.623	0.605	0.8	0.6	21.9
Metals	Aluminum	ug/L	75	3	**431.000**	**3986.365**	**1942.525**	**1410.210**	4	**388.000**	**3588.513**	**1634.351**	**1280.446**	1942.5	1634.4	15.9
	Barium	ug/L		3	25.600	112.757	61.689	46.711	4	22.800	101.119	50.961	39.962	61.7	51.0	17.4
	Beryllium	ug/L	11	3	0.100	0.524	0.241	0.100	4	0.100	0.472	0.193	0.100	0.2	0.2	20.0
	Calcium	mg/L		3	47.300	110.553	71.602	56.954	4	46.300	93.074	61.881	54.074	71.6	61.9	13.6
	Cadmium	ug/L	0.1	3	**0.300**	**1.220**	**0.607**	**0.300**	4	**0.300**	**0.300**	**0.300**	**0.300**	0.6	0.3	50.5
	Cobalt	ug/L	0.9	3	0.650	0.650	0.650	0.650	4	0.650	0.650	0.650	0.650	0.7	0.7	0.0
	Chromium	ug/L	8.9	3	2.140	4.969	3.432	3.188	4	2.610	5.135	3.365	2.857	3.4	3.4	2.0
	Copper	ug/L	5	3	**7.620**	**18.865**	**13.360**	**13.596**	4	**12.262**	**21.858**	**15.005**	**12.950**	13.4	15.0	-12.3
	Iron	ug/L	300	3	**519.000**	**3106.973**	**1762.690**	**1662.098**	4	**407.000**	**2867.483**	**1526.639**	**1416.037**	1762.7	1526.6	13.4
	Magnesium	mg/L		3	7.773	8.700	8.338	8.540	4	6.740	8.740	7.839	7.938	8.3	7.8	6.0
	Manganese	ug/L		3	32.200	487.406	214.794	124.777	4	26.100	423.836	170.069	115.170	214.8	170.1	20.8
	Molybdenum	ug/L	10	3	0.800	0.800	0.800	0.800	4	0.800	0.800	0.800	0.800	0.8	0.8	0.0
	Nickel	ug/L	25	3	0.650	7.820	3.480	1.969	4	1.460	6.080	3.115	2.460	3.5	3.1	10.5
	Lead	ug/L	5	3	5.000	5.000	5.000	5.000	4	5.000	5.000	5.000	5.000	5.0	5.0	0.0
	Strontium	ug/L		3	235.114	259.000	246.469	245.292	4	200.000	252.000	227.172	228.343	246.5	227.2	7.8
	Titanium	ug/L		3	2.143	5.381	4.051	4.630	4	1.810	5.735	3.471	3.170	4.1	3.5	14.3
	Vanadium	ug/L	7	3	2.510	6.589	4.253	3.659	4	0.750	5.172	2.761	2.561	4.3	2.8	35.1
	Zinc	ug/L	20	3	4.200	**31.320**	16.415	13.725	4	5.950	**30.146**	15.549	13.050	16.4	15.5	5.3

Note: Provincial Water Quality Objective (PWQO) guideline exceedence.

8 DEVELOPMENT OF A DESIGN TOOL FOR COMPOST BIOFILTERS

A user-friendly design tool (software) is under development based on both field and laboratory test results and Ontario guidelines to facilitate the design and application of this new technology. Field and Laboratory experiments have provided information on through-flow properties and contaminant removal characteristics along with specific attributes of various compost biofilters. Software will be developed using this information in order for the user to enter the site conditions with respect to flow and sediment loading. The output will consist of the most suitable compost for the task along with the biofilter specifications such as the sock size, number of socks, and compost type to achieve stormwater treatment targets and water quality standards, taking into account the life expectancy and longevity of the biofilter and develop the optimum maintenance schedule for the system.

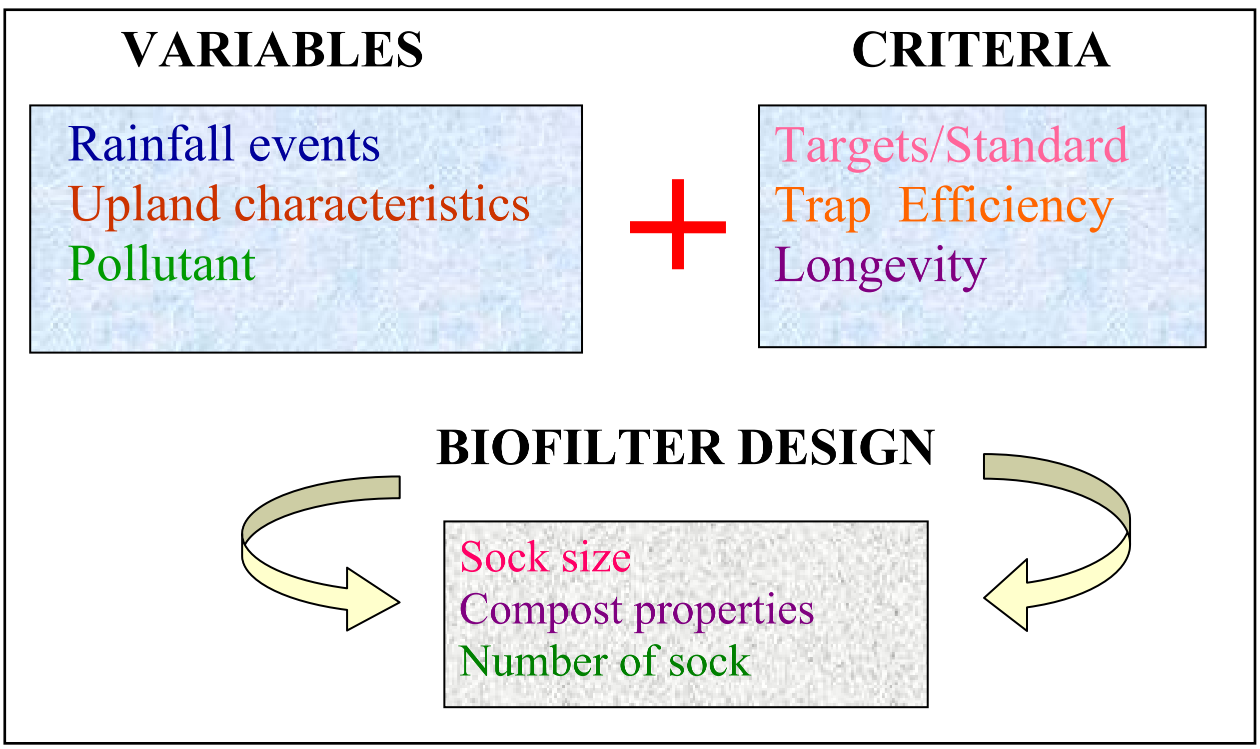

Figure 44: Design Tool

9 CONCLUDING REMARKS

The following concluding remarks are based on the preliminary results obtained from limited number of experiments and therefore should be considered with caution.

- The maximum flow through rate without overtopping per unit width of the 8″ sock for the three compost materials (overs) tested is approximately 1.5 L s^{-1} m^{-1}.
- The flow through capacity of the 12″, 18″and the 24″ socks are approximately 50%, 200%, and 300% higher than the flow through capacity of the 8″ sock.
- As the sediments start to cumulate in the biofilter over time the flow through rate will decrease to roughly half of its initial value. Further testing needs be completed to more accurately quantify this effect.
- Based on the preliminary results of this study, it is recommended to pre-wash the biofilter with clean water for about 10 min before installation.
- Sediment removal efficiency increased with the number of socks; The average sediment removal efficiency of the 8″ socks for 5, 10, and 15 rolls were 34%, 48%, and 60%, respectively.
- Larger diameter socks provided larger filter media and were more effective than the smaller diameter socks. The average sediment removal efficiency of the 18″ socks for 5, 10, and 15 rolls were 69%, 84%, and 95%, respectively.
- The sediment removal efficiency reduces significantly over time. The average sediment removal efficiency of 5 rolls of the 18″ sock steadily and gradually reduced from 70% to 62% to 58% to 56% and to 54% after 1, 5, 10, 15, and 20 consecutive runs.
- Sediment removal efficiency did not depend on flow rate as long as the stormwater runoff did not overtop the biofilter.
- Particle size distribution is an important design factor for the biofilter. Sediment removal efficiency of clay size material was only 30% while for fine silt was around 50% and for course silt around 80%.
- The results from the Polyacrylamide polymer (PAM) tests show significantly higher sediment removal efficiencies (more than 90%) and the optimum application rate for liquid PAM was around 5 mg/L.

- The results from full scale tests show that biofilters are not practical to treat stormwater runoff from temporary erosion and sediment control pond outflows with large drainage areas (approximately larger than 5 ha) because of their limited through-flow capacity.
- Overtopping can seriously compromise biofilter performance and therefore the biofilter system should be designed with proper dimensions to accommodate the full range of anticipated flows for a given site.
- An important design consideration for the biofilter system is the total sediment load that needs to be trapped during the lifetime (typically one year) of the system. Enough ditch-check berms should be installed to provide the necessary volume and void space capacity to trap the sediments. The volume of the biofilter should be approximately 10 times the volume of the sediments that needs to be trapped.
- Sheet flow from sloping lands, or channelized flow from small drainage areas such as highways are ideal applications for this technology. Despite very high flows from the pond, the filters remained in place and showed few signs of wear.
- The socks are inexpensive, completely biodegradable and provide a use for excess compost that would otherwise need to be sent to a landfill. Biofilters are an important part of an overall sediment and erosion plan on construction sites, but should be applied only where flows are within the range of the filter's maximum through flow rate.

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Appendix A: Methods and Materials

Particle Size Distribution

Sieve analyses are typical of any grain size distribution analysis. This analysis was performed on three different types of compost, All-Treat Farms, Peel, and Waterloo, with three representative samples per type of compost for a total of 9 tests. Using an automatic shaker and a stack of varying numbered sieves, a soil sample was mechanically separated and a plot of percent finer versus grain size was produced. The sieve analysis lab consisted of taking three representative samples of three different types of compost. Using a stack of sieves consisting of the below ten sieves, the compost sample was placed in the Sieve No. 1 sieve (at the top of the stack) and the cover was placed on top of the stack. This stack of sieves was then set into the automatic sieve shaker. The shaker was left on for 5 min to fully distribute the compost to the various sieves. Once complete, the stack was removed from the shaker, dismantled, and the weight of the compost on each individual sieve was measured. The results were recorded and the compost was disposed off.

Experimental Apparatus

1. Sieves, including bottom pan and cover

Sieve No.	Opening (*mm*)
1	25.400
2	19.000
3	9.423
4	4.699
10	2.000
20	0.850
40	0.425
60	0.250
100	0.150
200	0.075

2. A balance sensitive up to 0.1g
3. Mechanical sieve shaker

4. Tin plate

Experimental Procedure

The sieve analysis lab consisted of taking three representative samples of three different types of compost. Using a stack of sieves consisting of the above ten sieves, the compost sample was placed in the Sieve No. 1 sieve (at the top of the stack) and the cover was placed on top of the stack. This stack of sieves was then set into the automatic sieve shaker. The shaker was left on for 5 min to fully distribute the compost to the various sieves. Once complete, the stack was removed from the shaker, dismantled, and the weight of the compost on each individual sieve was measured. The results were recorded and the compost was disposed of.

Void Space Ratio

The void space was found by measuring 1000mL of compost to a graduated cylinder. Water was added to the cylinder to fill all the void spaces. The volume of water used to fill the spaces is equal to the volume of void spaces. The ratio was found by dividing the volume of water by 1000mL (compost volume).

Bulk Density

Bulk density was found by using a graduated cylinder that was filled with 1000mL of compost. It was compacted to a density similar to the compost socks. The mass of compost was then recorded. The bulk density was found by dividing the dry mass of a sample by its volume.

Methodology (Flow Rate Tests)

A pre-filled and measured compost sock was placed into the outlet of the flume and secured with a metal support to ensure that the sock would not float away. The sock was manipulated to fit snugly along the bottom and sides of the flume. This was done to minimize the amount of water that exits without passing through the compost filter. The water supplied to the flume was from sink taps in the Soil Mechanics lab of the Engineering building. The taps were turned on to maximum flow, without allowing the water to overtop the compost sock. A ruler was used to determine the depth of water both directly upstream and downstream of the compost sock. The upstream measured was essential to determine if the flow rates were constant. If the depth did not change for a period of five min, it was assumed that steady state had been reached and a flow measurement was taken.

To take a flow measurement, the pump was turned off and the siphon broken manually by moving the pipe around. A stopwatch was started at a known weight, as shown on the scale, and was recorded. The stopwatch was stopped after approximately a min and the final mass and exact time were recorded. The pump was then turned back on to drain the water from the bucket and the measurements were repeated two more times, for a total of three at every constant depth.

To achieve variable depths, the taps were turned down in stages to allow for readings at every 5 to 10 mm decrease in water depth. This test was performed three times for each compost, which each run using a different sample, to account for the variability of the compost material.

Methodology (Clean Water Tests)

During the flow through tests, samples were taken from the outflow water. The water was collected in 500 mL pre-labeled jars. Two 500 mL samples were taken every minute for the first five minutes, and at 10, 20, and 30 minutes. Two sets of samples were collected at each time, one to send to the University of Guelph Laboratory Services Division for chemical testing, and one to keep for our in lab testing, which will be discussed later in this section.

For this test however, we needed to ensure that the flow at time 0, was the same as that of time 30 minutes. To do this, a barrier was made by placing another compost sock inside a plastic bag and placing it directly upstream of the sock being tested. It was used to prevent water from running through the compost before a maximum water depth was achieved. The 2 cold water taps in the lab were turned on to full flow and the barrier sock was held in place until the water level reached close to the top of the sock, and steady state occurred. The pump was turned on at this point and the barrier sock removed from the flume.

pH and Conductivity

Testing for pH and conductivity is straight forward and done using digital readout probes. Before use, the probes were calibrated according to their respective manuals. To test the water sample, the probe is simply inserted into the sample and the value is read from the screen once the values stop fluctuating. The probe is then removed, and the end of the probe is rinsed with de-ionized water before testing the next sample.

Turbidity

The turbidimeter we used was the HACH 2100P Turbidimeter. The method of testing turbidity is similar to the probes mentioned above, but instead of putting a probe directly into the sample, a small vial is filled with the sample, wiped clean, and then inserted into the turbidimeter. The 'Read' button is then pushed, which starts the meter. Once the value stabilizes, the turbidity reading is taken. The lid of the meter is then opened, and the vial is rotated 45 degrees, and the measurement repeated. This is done to account for any discrepancies in the sample. This is done 4 times, and the lower of the readings is the turbidity that is said to be the turbidity of the sample.

Total Suspended Solids

The first step in determining the total suspended solids (TSS) in each sample is to weigh the filter paper and tin used to hold the paper. The size of filter paper used is 0.45 micron. The next step is to place the clean filter on to the vacuum pump and place the cup onto it and clamp it down. The pump is then started, and air flow to the vacuum container is opened up. The sample in the 500 mL jar is then poured into the cup, where it slowly filters through the filter paper. Once the water is completely filtered, the lid is removed, and the filter peeled off using sterilized tweezers. The filter is then placed into the tin, and placed into the drying oven. The sample is kept in the oven for at least 24 hours, at approximately $100^{o}C$ degrees. Once the sample is removed, it is weighed again, and the dried mass is subtracted from the initial mass. This will give a concentration of TSS in the water sample.

Appendix B: Compost Particle Size Analysis

Table 6: Cumulative Mass Retained on Sieves

	Sieve No.	1	2	3	4	10	20	40	60
Sample #	Opening (*mm*)	25.4	19	9.423	4.699	2	0.85	0.425	0.25
1	All Treat	99.74%	92.48%	73.73%	15.57%	7.39%	0.15%	0.001%	0.000%
2	All Treat	99.57%	89.51%	71.78%	8.93%	5.07%	0.20%	0.004%	0.000%
3	All Treat	99.78%	84.30%	58.43%	10.42%	4.50%	0.13%	0.002%	0.000%
4	Waterloo	97.92%	87.75%	73.79%	27.96%	10.91%	0.66%	0.019%	0.000%
5	Waterloo	98.39%	91.39%	84.10%	29.76%	15.73%	0.40%	0.008%	0.000%
6	Waterloo	97.75%	94.24%	71.77%	21.64%	7.92%	0.59%	0.024%	0.001%
7	Peel	92.14%	86.69%	79.42%	24.79%	10.72%	0.80%	0.061%	0.003%
8	Peel	93.59%	81.70%	62.26%	20.80%	9.20%	0.59%	0.042%	0.003%
9	Peel	95.69%	87.30%	70.52%	28.17%	12.10%	0.64%	0.034%	0.002%

Appendix C: Clean Water Tests

Table 7: Water Quality Tests (pH, Conductivity, Temperature, Turbidity, and TSS)

Compost Type	Time of Sample (min)	pH	Conductivity (µS/cm)	Temp (°C)	Turbidity (NTU)	Suspended Solids Concentration (mg/L)
Peel 1	**0**	7.11	817.4	20.3	10.40	145.73
	1	7.09	735.8	19.7	2.70	20.33
	2	7.10	628.9	18.9	2.62	52.33
	3	7.10	700.1	18.9	1.91	159.13
	4	7.11	460.2	18.7	1.42	65.93
	5	7.13	579.5	19.0	1.02	113.33
	10	7.14	491.2	18.9	0.81	85.93
	20	7.14	609.5	18.8	0.49	50.93
	30	7.12	604.6	18.5	0.51	6.93
Peel 2	**0**	7.01	913.2	16.7	42.20	431.33
	1	7.02	755.6	14.6	3.89	16.13
	2	7.07	597.7	12.5	2.24	10.93
	3	7.07	520.4	10.9	1.59	9.73
	4	7.09	701.3	10.9	1.55	17.13
	5	7.07	672.9	11.9	1.34	3.13
	10	7.10	731.8	11.0	0.70	2.27
	20	7.11	725.5	10.3	0.28	12.93
	30	7.11	774.9	9.9	0.28	17.07
All Treat 1	**0**	7.10	985.1	18.1	12.40	109.73
	1	6.92	794.5	15.4	0.73	7.33
	2	6.96	692.1	15.2	0.57	5.33
	3	6.99	602.1	14.9	0.40	5.33
	4	6.99	593.2	14.6	0.52	3.13
	5	7.02	652.2	14.6	0.41	2.73
	10	7.04	670.6	14.6	0.38	6.33
	20	7.05	736.0	14.7	0.34	3.13
	30	7.08	632.9	14.3	0.31	1.33
All Treat 2	**0**	7.29	664.3	20.0	25.80	228.93
	1	7.21	741.4	18.6	1.33	14.13
	2	7.18	724.6	19.0	0.62	3.93
	3	7.17	704.0	17.6	0.56	8.13
	4	7.15	690.5	17.4	0.33	5.53
	5	7.13	702.7	17.4	0.76	16.33
	10	7.16	736.9	17.4	0.21	4.13
	20	7.14	729.4	17.2	0.30	1.33
	30	7.13	663.2	17.7	0.17	3.53
Waterloo 1	**0**	6.86	618.1	19.0	30.80	310.93
	1	6.89	740.7	18.0	2.11	16.53
	2	6.94	693.8	18.0	0.95	7.73
	3	6.97	722.4	18.6	0.65	6.73
	4	6.99	728.5	18.0	0.69	5.93
	5	6.99	770.1	17.4	0.44	3.33
	10	7.00	699.3	17.7	0.37	0.53
	20	7.02	658.2	17.8	0.36	0.87
	30	7.05	753.2	17.8	0.34	2.33
Waterloo 2	**0**	6.92	683.0	16.0	38.80	334.33
	1	6.92	770.6	15.9	1.75	18.73
	2	6.93	737.3	15.4	0.78	11.93
	3	6.95	686.9	15.4	0.82	9.33
	4	7.00	736.7	14.9	0.62	5.53
	5	6.99	712.2	15.3	0.58	6.33
	10	7.02	713.4	14.6	0.36	3.33
	20	7.02	681.1	14.1	0.26	19.73
	30	7.04	708.1	14.1	0.22	2.13

Table 8: Water Quality Tests (TKN, TOC, and TP)

Sample ID	Compost	Time (min)	TKN (mg/L)	TOC (mg/L)	TOC (mg/L)	TOC (mg/L)	Total P (mg/L)
L06-008091							
06-0138054	Peel-1	0	9.84	111	71.2	39.3	1.270
06-0138055	Peel-1	1	2.28	85.4	65.3	20.1	0.194
06-0138056	Peel-1	2	1.32	79	62.5	16.5	0.110
06-0138057	Peel-1	3	1.23	75.3	65.6	9.7	0.076
06-0138058	Peel-1	4	1.09	73	65.1	7.9	0.099
06-0138059	Peel-1	5	<1.00	72.5	64.7	7.8	<0.050
06-0138060	Peel-1	10	<1.00	73.7	63.2	10.5	<0.050
06-0138061	Peel-1	20	<1.00	73.5	65.9	7.6	<0.050
06-0138062	Peel-1	30	<1.00	72.4	64.3	8.1	<0.050
L06-008508							
06-0142890	Peel-2	0	7.95	99.2	69.3	29.9	0.952
06-0142891	Peel-2	1	1.79	77.2	66.4	10.8	0.191
06-0142892	Peel-2	2	1.42	74.3	66.6	7.7	0.107
06-0142893	Peel-2	3	1.07	72.1	65.2	6.9	0.087
06-0142894	Peel-2	4	1.00	71.0	65.6	5.4	0.065
06-0142895	Peel-2	5	<1.00	69.1	65.9	3.2	0.059
06-0142896	Peel-2	10	<1.00	68.5	67.8	0.7	<0.050
06-0142897	Peel-2	20	<1.00	68.3	66.4	1.9	<0.050
06-0142898	Peel-2	30	<1.00	67.4	65.8	1.6	<0.050
L06-008092							
06-0138063	All Treat-1	0	8.90	90.1	68.8	21.3	1.290
06-0138064	All Treat-1	1	<1.00	65.3	64.8	0.5	<0.050
06-0138065	All Treat-1	2	<1.00	63.6	63.6	0	<0.050
06-0138066	All Treat-1	3	<1.00	65.0	65.0	0	<0.050
06-0138067	All Treat-1	4	<1.00	63.8	62.9	0.9	<0.050
06-0138068	All Treat-1	5	<1.00	63.0	62.8	0.2	<0.050
06-0138069	All Treat-1	10	<1.00	64.0	64.0	0	<0.050
06-0138070	All Treat-1	20	<1.00	62.6	62.0	0.6	<0.050
06-0138071	All Treat-1	30	<1.00	62.4	61.5	0.9	<0.050
L06-008489							
06-0140456	All Treat-2	0	16.41	262.0	74.8	187	3.320
06-0140457	All Treat-2	1	<1.00	84.2	72.8	11.4	0.055
06-0140458	All Treat-2	2	<1.00	81.4	72.5	8.9	<0.050
06-0140459	All Treat-2	3	<1.00	78.3	69.3	9	<0.050
06-0140460	All Treat-2	4	<1.00	76.9	70.7	6.2	<0.050
06-0140461	All Treat-2	5	<1.00	77.1	70.6	6.5	<0.050
06-0140462	All Treat-2	10	<1.00	77.3	70.3	7	<0.050
06-0140463	All Treat-2	20	<1.00	77.6	70.8	6.8	<0.050
06-0140464	All Treat-2	30	<1.00	69.3	68.3	1	<0.050
L06-008490							
06-0140465	Waterloo-1	0	14.36	202.0	76.3	125	2.130
06-0140466	Waterloo-1	1	<1.00	71.9	68.1	3.8	0.060
06-0140467	Waterloo-1	2	<1.00	70.6	69.0	1.6	<0.050
06-0140468	Waterloo-1	3	<1.00	68.6	68.6	0	<0.050
06-0140469	Waterloo-1	4	<1.00	68.8	67.1	1.7	<0.050
06-0140470	Waterloo-1	5	<1.00	68.9	68.9	0	<0.050
06-0140471	Waterloo-1	10	<1.00	68.8	68.8	0	<0.050
06-0140472	Waterloo-1	20	<1.00	67.7	66.9	0.8	<0.050
06-0140473	Waterloo-1	30	<1.00	67.7	67.2	0.5	<0.050
L06-008491							
06-0140474	Waterloo-2	0	9.07	159.0	74.0	85	1.280
06-0140475	Waterloo-2	1	1.04	72.8	67.7	5.1	0.056
06-0140476	Waterloo-2	2	<1.00	71.4	67.6	3.8	<0.050
06-0140477	Waterloo-2	3	<1.00	69.5	66.3	3.2	<0.050
06-0140478	Waterloo-2	4	<1.00	70.2	69.4	0.8	<0.050
06-0140479	Waterloo-2	5	<1.00	69.8	67.5	2.3	<0.050
06-0140480	Waterloo-2	10	<1.00	67.9	66.9	1	<0.050
06-0140481	Waterloo-2	20	<1.00	67.6	65.9	1.7	<0.050
06-0140482	Waterloo-2	30	<1.00	68.1	68.1	0	<0.050
06-0142899	**Clean**	**0**	**<1.00**	**69.9**	**66.5**	**3.4**	**<0.050**

Appendix D: Field Experiment Results

Table 9: New Filter Test Results

Run Code	Date	Plot	Sock size	Compost type	No. of Socks	Flow Rate	Inlet Conc	Z Conc	K Conc	Outlet Conc	Z	K	O
						(L/s)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	%	%	%
10W 1FP	May 10th	A	8"	Waterloo	10	1	335	N/A	N/A	94	N/A	N/A	72%
10W 2FP	May 10th	A	8"	Waterloo	10	1	1023	N/A	N/A	146	N/A	N/A	86%
10W 3FP	May 10th	A	8"	Waterloo	10	1	601	N/A	N/A	158	N/A	N/A	74%
10W 4FP	May 10th	A	8"	Waterloo	10	1	665	N/A	N/A	282	N/A	N/A	58%
PA W1 R1	May 17th	A	8"	Waterloo	15	1	1125	764	520	326	32%	54%	71%
PA W1 R2	May 17th	A	8"	Waterloo	15	1	1014	590	534	351	42%	47%	65%
PA W1 R3	May 17th	A	8"	Waterloo	15	1	1047	705	560	396	33%	47%	62%
PA W1 R4	May 18th	A	8"	Waterloo	15	1	935	696	649	524	26%	31%	44%
PA W1 R5	May 18th	A	8"	Waterloo	15	1	1244	726	581	461	42%	53%	63%
PA W1 R6	May 18th	A	8"	Waterloo	15	1	1036	774	607	449	25%	41%	57%
PA A1 R1	May 25th	A	8"	Alltreat	15	1	1133	712	524	342	37%	54%	70%
PA A1 R2	May 25th	A	8"	Alltreat	15	1	1120	745	575	342	33%	49%	69%
PA A1 R3	May 25th	A	8"	Alltreat	15	1	1088	863	685	526	21%	37%	52%
PA A1 R4	May 29th	A	8"	Alltreat	15	1	627	408	292	183	35%	53%	71%
PA A1 R5	May 29th	A	8"	Alltreat	15	1	477	380	303	234	20%	36%	51%
PA A1 R6	May 29th	A	8"	Alltreat	15	1	577	497	349	245	14%	40%	58%
PA P1 R1	May 23rd	A	8"	Peel	15	1	1080	873	769	703	19%	29%	35%
PA P1 R2	May 23rd	A	8"	Peel	15	1	925	870	732	679	6%	21%	27%
PA P1 R3	May 23rd	A	8"	Peel	15	1	1016	630	599	503	38%	41%	50%
PA P1 R4	May 23rd	A	8"	Peel	15	1	872	545	509	501	38%	42%	43%
PA P1 R5	May 24th	A	8"	Peel	15	1	978	663	528	472	32%	46%	52%
PA P1 R6	May 27th	A	8"	Peel	15	1	962	700	517	502	27%	46%	48%
PA-A0.5-R1	June 6th	A	18"	Alltreat	5	0.5	980	N/A	N/A	375	N/A	N/A	62%
PA-A1.0-R1	June 6th	A	18"	Alltreat	5	1.0	833	N/A	N/A	363	N/A	N/A	56%
PA-A1.5-R1	June 5th	A	18"	Alltreat	5	1.5	844	N/A	N/A	434	N/A	N/A	49%
PA-A2.0-R1	June 5th	A	18"	Alltreat	5	2.0	679	N/A	N/A	289	N/A	N/A	57%
PA-A0.5-R2	June 6th	A	18"	Alltreat	5	0.5	982	N/A	N/A	437	N/A	N/A	56%
PA-A1.0-R2	June 6th	A	18"	Alltreat	5	1.0	860	N/A	N/A	499	N/A	N/A	42%
PA-A1.5-R2	June 5th	A	18"	Alltreat	5	1.5	940	N/A	N/A	514	N/A	N/A	45%
PA-A2.0-R2	June 5th	A	18"	Alltreat	5	2.0	590	N/A	N/A	293	N/A	N/A	50%

Table 10: Longevity Test Results

Run Code	Date	Plot	Run No.	Sock size	Compost type	No. of Socks	Flow Rate	Inlet Conc	Z Conc	K Conc	Outlet Conc	Z	K	O
							(L/s)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	%	%	%
PB R1	May 17th	B	1	8"	Hybrid	15	1	1265	743	433	304	41%	66%	76%
PB R2	May 17th	B	2	8"	Hybrid	15	1	1139	814	519	464	28%	54%	59%
PB R3	May 17th	B	3	8"	Hybrid	15	1	1212	820	587	484	32%	52%	60%
PB R4	May 18th	B	4	8"	Hybrid	15	1	1004	773	516	427	23%	49%	58%
PB R5	May 18th	B	5	8"	Hybrid	15	1	885	600	497	420	32%	44%	53%
PB R6	May 18th	B	6	8"	Hybrid	15	1	738	564	424	410	24%	42%	44%
PB R7	May 23rd	B	7	8"	Hybrid	15	1	743	564	551	437	24%	26%	41%
PB R8	May 23rd	B	8	8"	Hybrid	15	1	788	698	601	511	11%	24%	35%
PB R9	May 23rd	B	9	8"	Hybrid	15	1	1184	890	733	683	25%	38%	42%
PB R10	May 23rd	B	10	8"	Hybrid	15	1	923	780	734	620	15%	20%	33%
PB R11	May 24th	B	11	8"	Hybrid	15	1	1039	767	692	480	26%	33%	54%
PB R13	May 26th	B	13	8"	Hybrid	15	1	1353	842	592	504	38%	56%	63%
PB R14	May 26th	B	14	8"	Hybrid	15	1	935	789	625	546	16%	33%	42%
PB R15	May 29th	B	15	8"	Hybrid	15	1	1090	749	551	449	31%	49%	59%
PB R17	May 29th	B	17	8"	Hybrid	15	1	1024	885	688	527	14%	33%	49%
PA-A1-R1-S	June 7th	B	1	18"	Alltreat	5	1	827	N/A	N/A	376	N/A	N/A	55%
PA-A1-R2-S	June 7th	B	2	18"	Alltreat	5	1	849	N/A	N/A	425	N/A	N/A	50%
PA-A1-R3-S	June 7th	B	3	18"	Alltreat	5	1	549	N/A	N/A	250	N/A	N/A	54%
PA-A1-R4-S	June 7th	B	4	18"	Alltreat	5	1	675	N/A	N/A	384	N/A	N/A	43%
PA-A1-R5-S	June 8th	B	5	18"	Alltreat	5	1	937	N/A	N/A	446	N/A	N/A	52%
PA-A1-R6-S	June 8th	B	6	18"	Alltreat	5	1	992	N/A	N/A	595	N/A	N/A	40%
PA-A1-R8-S	June 8th	B	8	18"	Alltreat	5	1	1056	N/A	N/A	656	N/A	N/A	38%
PA-A1-R9-S	June 9th	B	9	18"	Alltreat	5	1	1011	N/A	N/A	545	N/A	N/A	46%
PA-A1-R10-S	June 9th	B	10	18"	Alltreat	5	1	1113	N/A	N/A	619	N/A	N/A	44%
PA-A1-R11-S	June 9th	B	11	18"	Alltreat	5	1	1201	N/A	N/A	659	N/A	N/A	45%
PA-A1-R12-S	June 9th	B	12	18"	Alltreat	5	1	568	N/A	N/A	329	N/A	N/A	42%
PA-A1-R13-S	June 9th	B	13	18"	Alltreat	5	1	888	N/A	N/A	502	N/A	N/A	44%
PA-A1-R14-S	June 9th	B	14	18"	Alltreat	5	1	878	N/A	N/A	508	N/A	N/A	42%
PA-A1-R15-S	June 13th	B	15	18"	Alltreat	5	1	812	N/A	N/A	391	N/A	N/A	52%
PA-A1-R16-S	June 13th	B	16	18"	Alltreat	5	1	724	N/A	N/A	474	N/A	N/A	35%
PA-A1-R17-S	June 13th	B	17	18"	Alltreat	5	1	838	N/A	N/A	499	N/A	N/A	40%
PA-A1-R18-S	June 13th	B	18	18"	Alltreat	5	1	785	N/A	N/A	534	N/A	N/A	32%
PA-A1-R19-S	June 13th	B	19	18"	Alltreat	5	1	788	N/A	N/A	512	N/A	N/A	35%
PA-A1-R20-S	June 13th	B	20	18"	Alltreat	5	1	866	N/A	N/A	527	N/A	N/A	39%
PA-A1-R21-S	June 15th	B	21	18"	Alltreat	5	1	822	N/A	N/A	501	N/A	N/A	39%
PA-A1-R23-S	June 15th	B	23	18"	Alltreat	5	1	878	N/A	N/A	464	N/A	N/A	47%
PA-A1-R25-S	June 15th	B	25	18"	Alltreat	5	1	892	N/A	N/A	520	N/A	N/A	42%
PA-A1-R26-S	June 15th	B	26	18"	Alltreat	5	1	887	N/A	N/A	520	N/A	N/A	41%
PA-A1-R27-S	June 16th	B	27	18"	Alltreat	5	1	668	N/A	N/A	409	N/A	N/A	39%
PA-A1-R28-S	June 16th	B	28	18"	Alltreat	5	1	736	N/A	N/A	506	N/A	N/A	31%
PA-A1-R29-S	June 16th	B	29	18"	Alltreat	5	1	938	N/A	N/A	581	N/A	N/A	38%

Appendix E: Polymer Tests

Table 11: Polymer Jar Tests - Initial Polymer Concentration 25 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	26	26	26.4	52.8	27	11.9	0.014	0.09314	0
0.5	25	25	25.4	50.8	26	12	0.014	0.06614	0
1	24	24	24.4	48.8	25	12.2	0.014	0.04715	0
2	23.8	24	24.4	48.8	25	12.2	0.014	0.03334	0
4	22	22	22.4	44.8	23	12.5	0.014	0.02386	0
8	21	21	21.4	42.8	22	12.7	0.014	0.01701	0
15	19	19	19.4	38.8	20	13	0.014	0.01257	0
30	16.8	17	17.4	34.8	18	13.3	0.014	0.00899	0
60	14.8	15	15.4	30.8	16	13.7	0.014	0.00645	0
120	12	12	12.4	24.8	13	14.2	0.014	0.00464	0
240	11	11	11.4	22.8	12	14.3	0.014	0.0033	0
480	9	9	9.4	18.8	10	14.7	0.014	0.00236	0
1440	6	6	6.4	12.8	7	15.2	0.014	0.00139	0

Concentration (mg/L)	25
Conductivity (um)	100
pH	8.28
Temperature	21.5

Table 12: Polymer Jar Tests - Initial Polymer Concentration 25 mg/L (Hydrometer no. 2)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	23.5	24	24.4	48.8	25	12.2	0.014	0.09431	0
0.5	23	23	23.4	46.8	24	12.4	0.014	0.06723	0
1	22.8	23	23.4	46.8	24	12.4	0.014	0.04754	0
2	21.5	22	22.4	44.8	23	12.5	0.014	0.03375	0
4	19.5	20	20.4	40.8	21	12.9	0.014	0.02424	0
8	18.5	19	19.4	38.8	20	13	0.014	0.01721	0
15	16	16	16.4	32.8	17	13.5	0.014	0.01281	0
30	15.5	16	16.4	32.8	17	13.5	0.014	0.00906	0
60	13.8	14	14.4	28.8	15	13.8	0.014	0.00647	0
120	11	11	11.4	22.8	12	14.3	0.014	0.00466	0
240	9	9	9.4	18.8	10	14.7	0.014	0.00334	0
480	7	7	7.4	14.8	8	15	0.014	0.00239	0
1440	5	5	5.4	10.8	6	15.3	0.014	0.00139	0

Concentration (mg/L)	25
Conductivity (um)	80
pH	8.29
Temperature	21.5

Table 13: Polymer Jar Tests - Initial Polymer Concentration 50 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	31	31	31.4	62.8	32	11.1	0.014	0.09	0
0.5	30	30	30.4	60.8	31	11.2	0.014	0.064	0
1	26	26	26.4	52.8	27	11.9	0.014	0.047	0
2	23	23	23.4	46.8	24	12.4	0.014	0.034	0
4	20	20	20.4	40.8	21	12.9	0.014	0.024	0
8	18	18	18.4	36.8	19	13.2	0.014	0.017	0
15	17	17	17.4	34.8	18	13.3	0.014	0.013	0
30	16	16	16.4	32.8	17	13.5	0.014	0.009	0
60	14	14	14.4	28.8	15	13.8	0.014	0.006	0
120	12	12	12.4	24.8	13	14.2	0.014	0.005	0
240	9	9	9.4	18.8	10	14.7	0.014	0.003	0
480	3	3	3.4	6.8	4	15.6	0.014	0.002	0

Concentration (mg/L)	50
Conductivity (um)	0.1
pH	8.5
Temperature	21

Table 14: Polymer Jar Tests - Initial Polymer Concentration 50 mg/L (Hydrometer no. 2)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	36	36	35.4	70.8	37	10.2	0.014	0.086	1
0.5	31	31	30.4	60.8	32	11.1	0.014	0.064	1
1	16	16	15.4	30.8	17	13.5	0.014	0.05	1
2	8	8	7.4	14.8	9	14.8	0.014	0.037	1
4	7	7	6.4	12.8	8	15	0.014	0.026	1
8	7	7	6.4	12.8	8	15	0.014	0.018	1
15	6	6	5.4	10.8	7	15.2	0.014	0.014	1
30	6	6	5.4	10.8	7	15.2	0.014	0.01	1
60	5	5	4.4	8.8	6	15.3	0.014	0.007	1
120	5	5	4.4	8.8	6	15.3	0.014	0.005	1
240	4	4	3.4	6.8	5	15.5	0.014	0.003	1
480	2	2	1.4	2.8	3	15.8	0.014	0.002	1

Concentration (mg/L)	50
Conductivity (um)	0.1
pH	21
Temperature (oC)	21

Table 15: Polymer Jar Tests - Initial Polymer Concentration 100 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^{+}	A	D	Zero
0.25	31	31	29.4	58.8	32	11.1	0.01	0.08995	2
0.5	22	22	20.4	40.8	23	12.5	0.01	0.0675	2
1	16	16	14.4	28.8	17	13.5	0.01	0.0496	2
2	12	12	10.4	20.8	13	14.2	0.01	0.03597	2
4	11	11	9.4	18.8	12	14.3	0.01	0.02553	2
8	10	10	8.4	16.8	11	14.5	0.01	0.01817	2
15	9	9	7.4	14.8	10	14.7	0.01	0.01336	2
30	9	9	7.4	14.8	10	14.7	0.01	0.00945	2
60	8	8	6.4	12.8	9	14.8	0.01	0.0067	2
120	7	7	5.4	10.8	8	15	0.01	0.00477	2
240	7	7	5.4	10.8	8	15	0.01	0.00338	2
480	5	5	3.4	6.8	6	15.3	0.01	0.00241	2
1440	4	4	2.4	4.8	5	15.5	0.01	0.0014	2

Concentration (mg/L)	100
Conductivity (um)	0.1
pH	8.41
Temperature	21

Table 16: Polymer Jar Tests - Initial Polymer Concentration 100 mg/L (Hydrometer no. 2)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^{+}	A	D	Zero
0.25	30	30	32.4	64.8	31	11.2	0.01	0.09036	-2
0.5	30	30	32.4	64.8	31	11.2	0.01	0.06389	-2
1	29	29	31.4	62.8	30	11.4	0.01	0.04558	-2
2	27	27	29.4	58.8	28	11.7	0.01	0.03265	-2
4	26	26	28.4	56.8	27	11.9	0.01	0.02329	-2
8	24	24	26.4	52.8	25	12.2	0.01	0.01667	-2
15	23	23	25.4	50.8	24	12.4	0.01	0.01227	-2
30	20	20	22.4	44.8	21	12.9	0.01	0.00885	-2
60	16	16	18.4	36.8	17	13.5	0.01	0.0064	-2
120	14	14	16.4	32.8	15	13.8	0.01	0.00458	-2
240	11	11	13.4	26.8	12	14.3	0.01	0.0033	-2
480	10	10	12.4	24.8	11	14.5	0.01	0.00235	-2
1440	5	5	7.4	14.8	6	15.3	0.01	0.00139	-2

Concentration (mg/L)	100
Conductivity (um)	0.1
pH	8.35
Temperature (oC)	21

Table 17: Polymer Jar Tests - Initial Polymer Concentration 200 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	32	32	34.4	68.8	33	10.9	0.01	0.089	-2
0.5	18	18	20.4	40.8	19	13.2	0.01	0.069	-2
1	15	15	17.4	34.8	16	13.7	0.01	0.05	-2
2	1	1	3.4	6.8	2	16	0.01	0.038	-2
4	0	0	2.4	4.8	1	16.1	0.01	0.027	-2
8	-1.5	-2	0.4	0.8	-1	16.4	0.01	0.019	-2

Concentration (mg/L)	200
Conductivity (um)	0.1
pH	8.17
Temperature	21

Table 18: Polymer Jar Tests - Initial Polymer Concentration 300 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	40	40	41	82.8	41	9.6	0	0.084	-1
0.5	37	37	38	76.8	38	10	0	0.061	-1
1	30	30	31	62.8	31	11	0	0.045	-1
2	2	2	3.4	6.8	3	16	0	0.038	-1
4	0	0	1.4	2.8	1	16	0	0.027	-1
8	0	0	1.4	2.8	1	16	0	0.019	-1

Concentration (mg/L)	300
Conductivity (um)	0.2
pH	8.08
Temperature	21

Table 19: Polymer Jar Tests - Initial Polymer Concentration 500 mg/L (Hydrometer no. 1)

Time (min)	Hydrometer Reading, R	Rounded Hydrometer Reading	R_{cp}	Percent Finer	R_{CL}	L^+	A	D	Zero
0.25	30	30	32.4	64.8	31	11.1	0.0135	0.08995	-2
0.5	28	28	30.4	60.8	29	11.5	0.0135	0.06474	-2
1	25	25	27.4	54.8	26	12	0.0135	0.04677	-2
2	0	0	2.4	4.8	1	16.1	0.0135	0.0383	-2
4	-1	-1	1.4	2.8	0	16.3	0.0135	0.02725	-2
8	-1	-1	1.4	2.8	0	16.3	0.0135	0.01927	-2

Concentration (mg/L)	500
Conductivity (um)	0.2
pH	7.77
Temperature	21.5

Table 20: Liquid Polymer Tests

Sample	Date of Sampling	Water Temp (°C)	Polymer Concentration or Surface Area	Inlet Sediment Concentration (mg/L)	Outlet Sediment Concentration (mg/L)	Percent Removal Calculated	Total Average Percent Removal Calculated
Liquid Tests							
Run 1	9-Aug-06						93.21%
Blank	9-Aug-06	13	0 mg/L	651.61	292.13	55.17%	
Set 1	9-Aug-06	13	5 mg/L	651.61	34.93	94.64%	
Set 2	9-Aug-06	13	5 mg/L	651.61	48.99	92.48%	
Run 2	9-Aug-06						
Blank	9-Aug-06	14	0 mg/L	651.61	346.11	46.88%	
Set 1	9-Aug-06	14	5 mg/L	651.61	51.97	92.02%	
Set 2	9-Aug-06	14	5 mg/L	651.61	41.21	93.68%	
Run 4	10-Aug-06						78.97%
Blank	10-Aug-06	14	0 mg/L	706.63	361.00	48.91%	
Set 1	10-Aug-06	14	50 mg/L	696.83	124.91	82.08%	
Set 2	10-Aug-06	14	50 mg/L	685.15	163.00	76.21%	
Run 5	10-Aug-06						
Blank	10-Aug-06	13	0 mg/L	582.00	271.34	53.38%	
Set 1	10-Aug-06	13	50 mg/L	651.61	124.44	80.90%	
Set 2	10-Aug-06	13	50 mg/L	660.50	153.85	76.71%	
Run 6	11-Aug-06						80.09%
Blank	11-Aug-06	14	0 mg/L	680.41	444.53	34.67%	
Set 1	11-Aug-06	14	25 mg/L	666.78	135.59	79.67%	
Set 2	11-Aug-06	14	25 mg/L	736.04	152.38	79.30%	
Run 7	11-Aug-06						
Blank	11-Aug-06	13	0 mg/L	666.13	506.91	23.90%	
Set 1	11-Aug-06	13	25 mg/L	651.61	101.32	84.45%	
Set 2	11-Aug-06	13	25 mg/L	709.32	163.40	76.96%	
Run 8	16-Aug-06						86.12%
Blank	16-Aug-06	12	0 mg/L	657.40	305.85	53.48%	
Set 1	16-Aug-06	12	15 mg/L	650.13	92.85	85.72%	
Set 2	16-Aug-06	12	15 mg/L	688.97	95.37	86.16%	
Run 9	16-Aug-06						
Blank	16-Aug-06	12	0 mg/L	680.61	395.58	41.88%	
Set 1	16-Aug-06	12	15 mg/L	644.35	91.07	85.87%	
Set 2	16-Aug-06	12	15 mg/L	642.89	85.26	86.74%	
Run 10	16-Aug-06						76.52%
Blank	16-Aug-06	12	0 mg/L	598.84	209.54	65.01%	
Set 1	16-Aug-06	12	1 mg/L	551.72	105.67	80.85%	
Set 2	16-Aug-06	12	1 mg/L	568.78	118.83	79.11%	
Run 11	16-Aug-06						
Blank	16-Aug-06	12	0 mg/L	684.07	392.89	42.57%	
Set 1	16-Aug-06	12	1 mg/L	658.39	165.72	74.83%	
Set 2	16-Aug-06	12	1 mg/L	679.70	195.01	71.31%	

Table 21: Solid Polymer Tests

Sample	Date of Sampling	Water Temp (°C)	Polymer Concentration or Surface Area	Inlet Sediment Concentration (mg/L)	Outlet Sediment Concentration (mg/L)	Percent Removal Calculated	Total Average Percent Removal Calculated
Solid Tests							
Run 12	17-Aug-06						73.21%
Blank	17-Aug-06	13	0 cm^2	690.71	325.29	52.90%	
Set 1	17-Aug-06	13	360 cm^2	712.72	170.55	76.07%	
Set 2	17-Aug-06	13	360 cm^2	792.26	154.86	80.45%	
Run 13	17-Aug-06						
Blank	17-Aug-06	13	0 cm^2	712.16	381.76	46.39%	
Set 1	17-Aug-06	13	360 cm^2	784.67	204.79	73.90%	
Set 2	17-Aug-06	13	360 cm^2	699.49	262.77	62.43%	
Run 14	18-Aug-06						64.44%
Blank	18-Aug-06	12	0 cm^2	667.68	303.71	54.51%	
Set 1	18-Aug-06	12	720 cm^2	679.01	173.15	74.50%	
Set 2	18-Aug-06	12	720 cm^2	758.45	203.13	73.22%	
Run 15	18-Aug-06						
Blank	18-Aug-06	13	0 cm^2	665.84	303.71	54.39%	
Set 1	18-Aug-06	13	720 cm^2	759.08	292.56	61.46%	
Set 2	18-Aug-06	13	720 cm^2	813.16	418.01	48.59%	

Appendix F: Particle size Distribution Analysis

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
Inlet	50.5	36.5	10.6	2.4	418	301	88	20				
Outlet	56.5	36.8	5.0	1.7	212	138	19	7	49%	54%	79%	67%

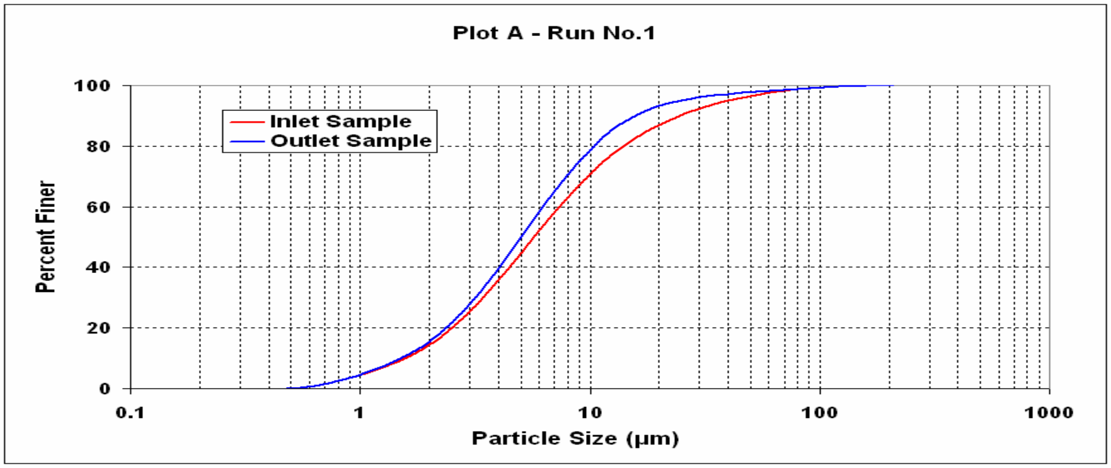

Figure 45: Particle size distribution for longevity tests, Run number 1

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	44.9	39.6	12.4	3.1	381	336	106	26				
Z	51.9	39.5	6.2	2.4	220	168	26	10	42%	50%	75%	60%

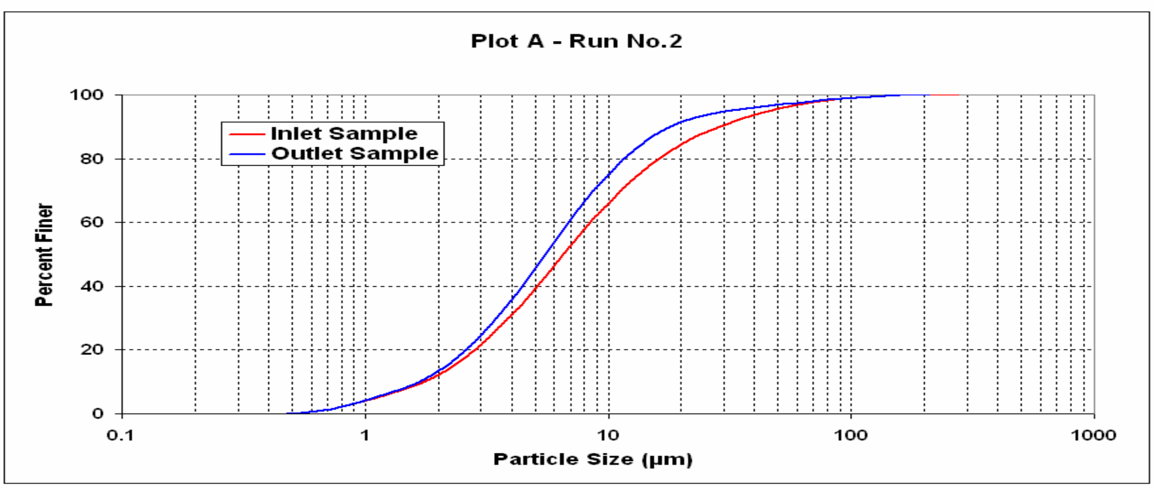

Figure 46: Particle size distribution for longevity tests, Run number 2

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	43.8	38.6	12.5	5.0	296	261	85	34				
Z	58.6	35.3	4.4	1.8	225	136	17	7	24%	48%	80%	80%

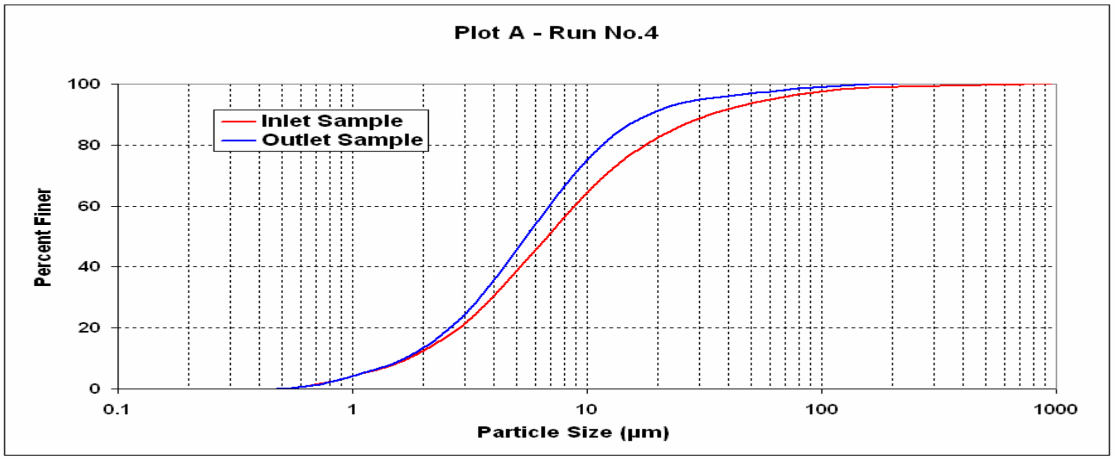

Figure 47: Particle size distribution for longevity tests, Run number 4

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	37.6	37.4	16.5	8.4	352	351	155	79				
Z	55.5	38.2	4.8	1.5	248	170	21	7	30%	51%	86%	92%

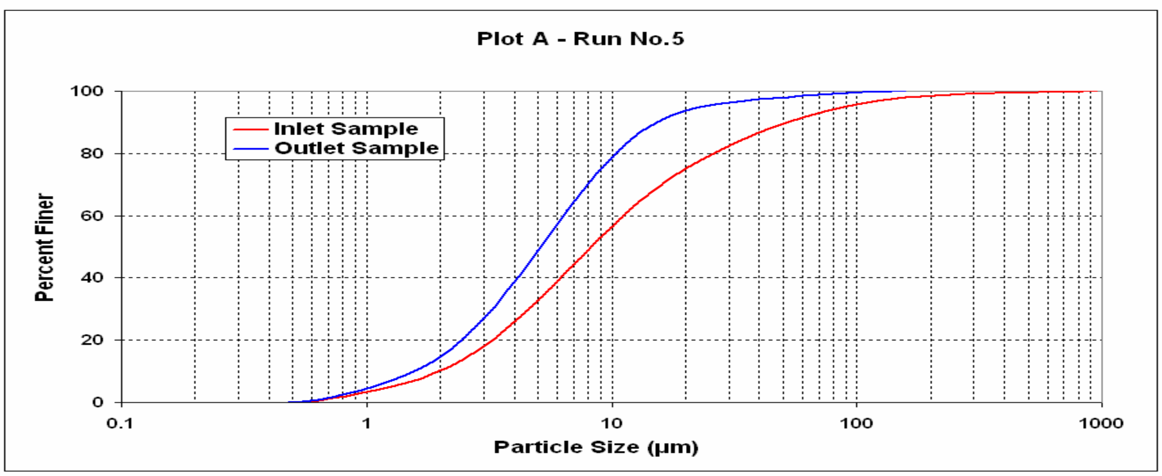

Figure 48: Particle size distribution for longevity tests, Run number 5

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	45.1	36.7	14.0	4.2	447	364	139	42				
Z	32.3	38.1	17.3	12.2	192	227	103	73	57%	38%	26%	-73%

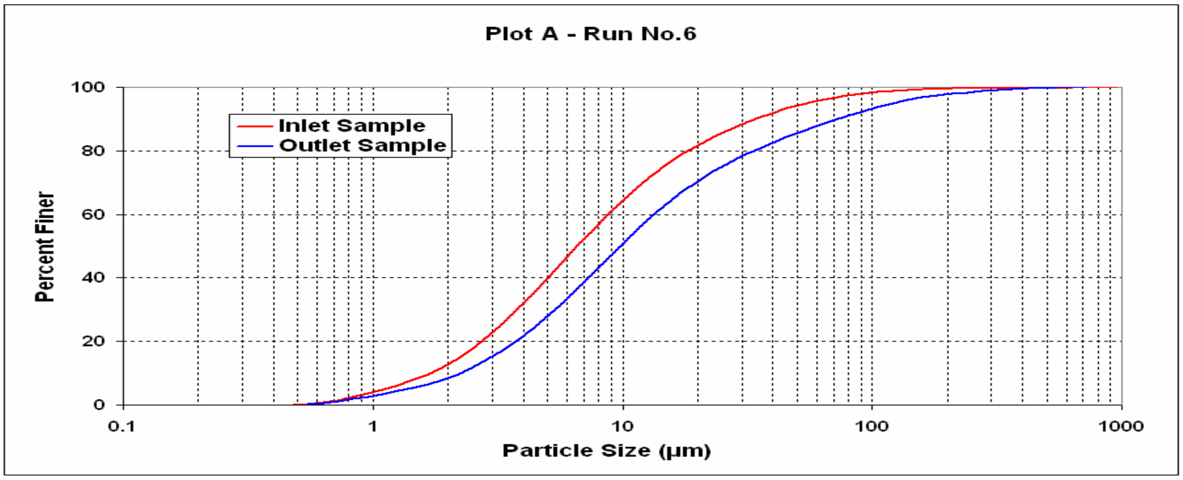

Figure 49: Particle size distribution for longevity tests, Run number 6

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	45.4	37.7	12.3	4.5	480	398	130	48				
Z	56.5	36.7	5.4	1.5	371	241	35	10	23%	40%	73%	80%

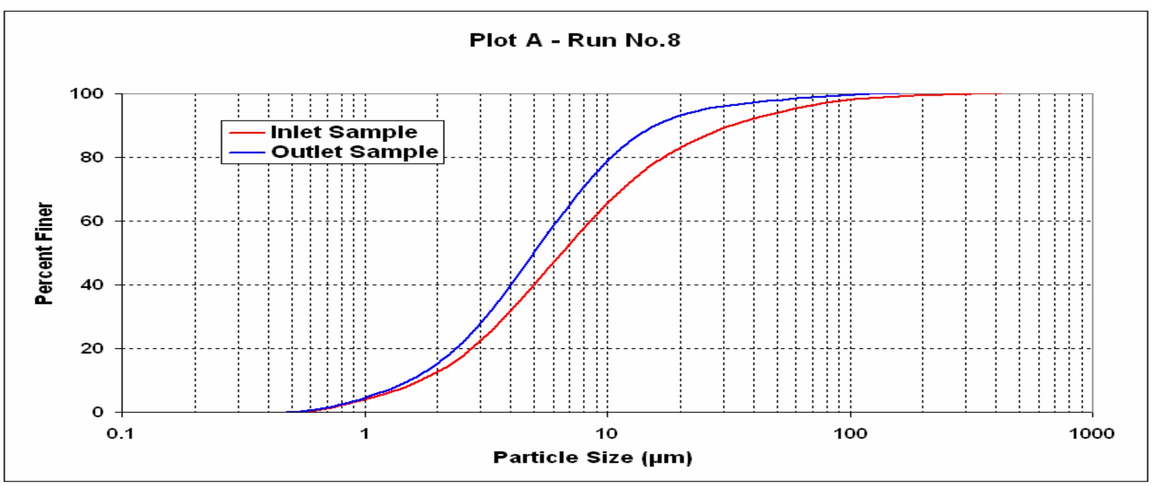

Figure 50: Particle size distribution for longevity tests, Run number 8

Sedimet Class Sizes:

Class 1: 0.01 μm < d < 5.754 μm
Class 2: 5.754 μm < d < 19.953 μm
Class 3: 19.953 μm < d < 60.256 μm
Class 4: 60.256 μm < d < 1096 μm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	45.1	35.7	13.8	5.4	456	361	140	55				
Z	52.0	35.3	5.0	7.6	284	192	27	42	38%	47%	80%	24%

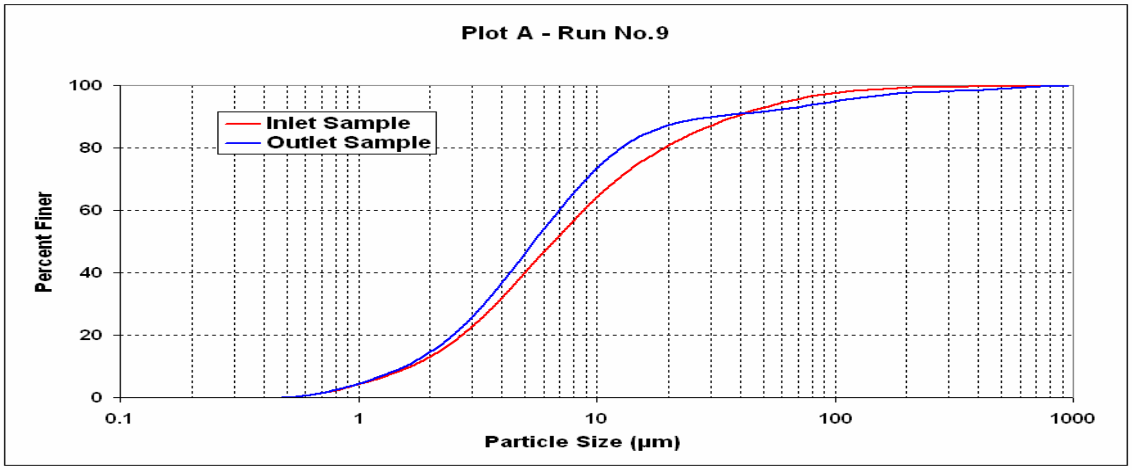

Figure 51: Particle size distribution for longevity tests, Run number 9

Sedimet Class Sizes:

Class 1: 0.01 μm < d < 5.754 μm
Class 2: 5.754 μm < d < 19.953 μm
Class 3: 19.953 μm < d < 60.256 μm
Class 4: 60.256 μm < d < 1096 μm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	46.0	35.1	13.1	5.8	512	391	146	64				
Z	58.6	34.3	4.7	2.4	363	213	29	15	29%	46%	80%	77%

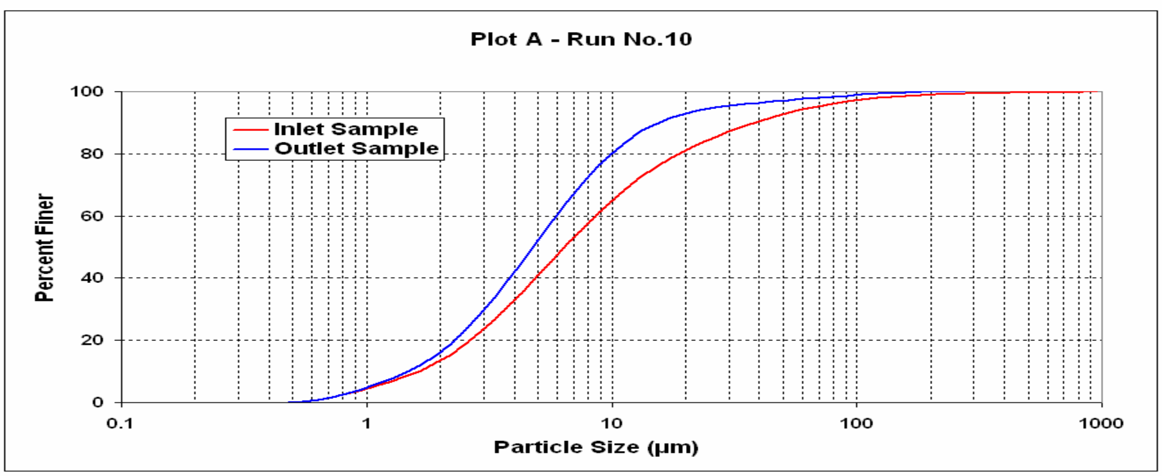

Figure 52: Particle size distribution for longevity tests, Run number 10

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	50.2	34.2	11.7	3.9	603	411	141	46				
Z	59.7	34.0	4.6	1.6	393	224	30	11	35%	45%	78%	77%

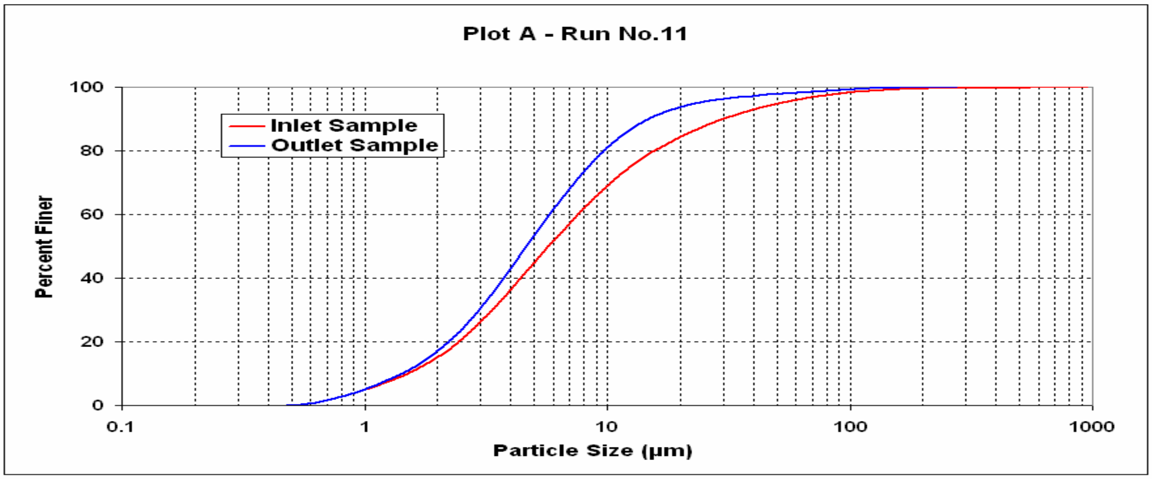

Figure 53: Particle size distribution for longevity tests, Run number 11

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	52.7	38.0	8.0	1.4	463	333	70	12				
Z	55.1	37.0	5.6	2.2	280	188	29	11	39%	44%	59%	5%

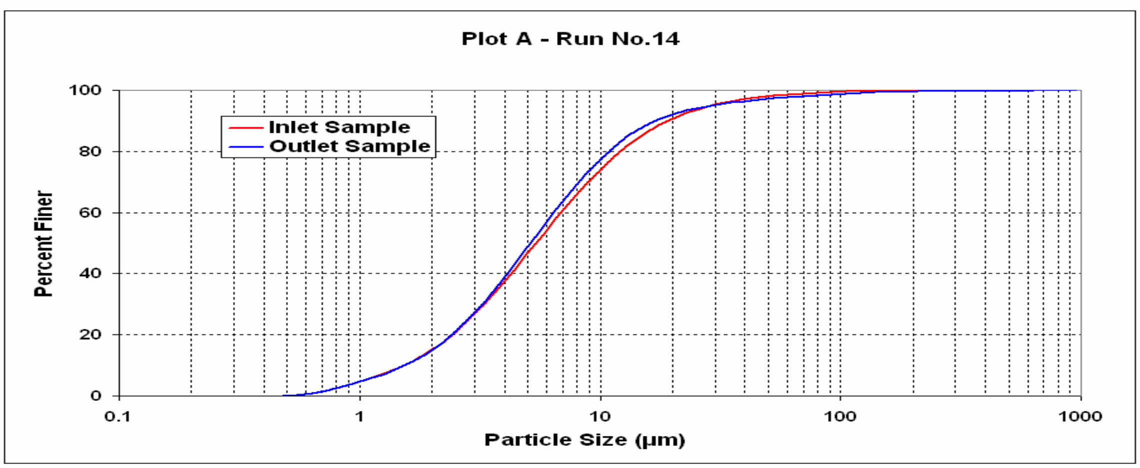

Figure 54: Particle size distribution for longevity tests, Run number 14

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	47.4	35.8	12.0	4.7	423	320	107	42				
Z	50.6	36.2	7.9	5.2	263	188	41	27	38%	41%	62%	35%

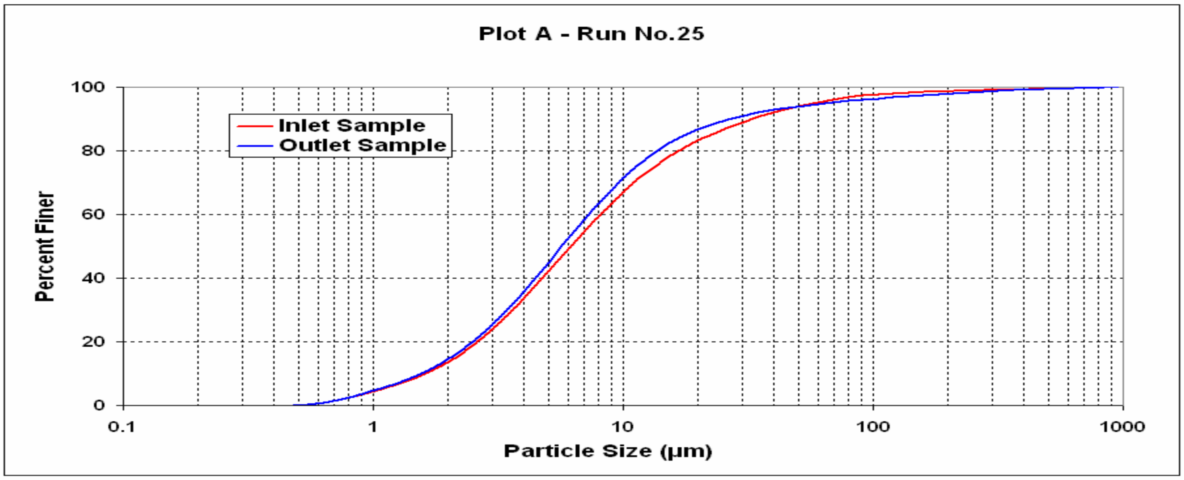

Figure 55: Particle size distribution for longevity tests, Run number 25

Sedimet Class Sizes:

Class 1: 0.01 µm < d < 5.754 µm
Class 2: 5.754 µm < d < 19.953 µm
Class 3: 19.953 µm < d < 60.256 µm
Class 4: 60.256 µm < d < 1096 µm

class	1	2	3	4	1	2	3	4	1	2	3	4
	%				mg/l				removal efficiency			
I	36.2	39.5	16.6	7.7	266	291	122	56				
Z	45.6	35.1	8.4	10.9	231	177	43	55	13%	39%	65%	3%

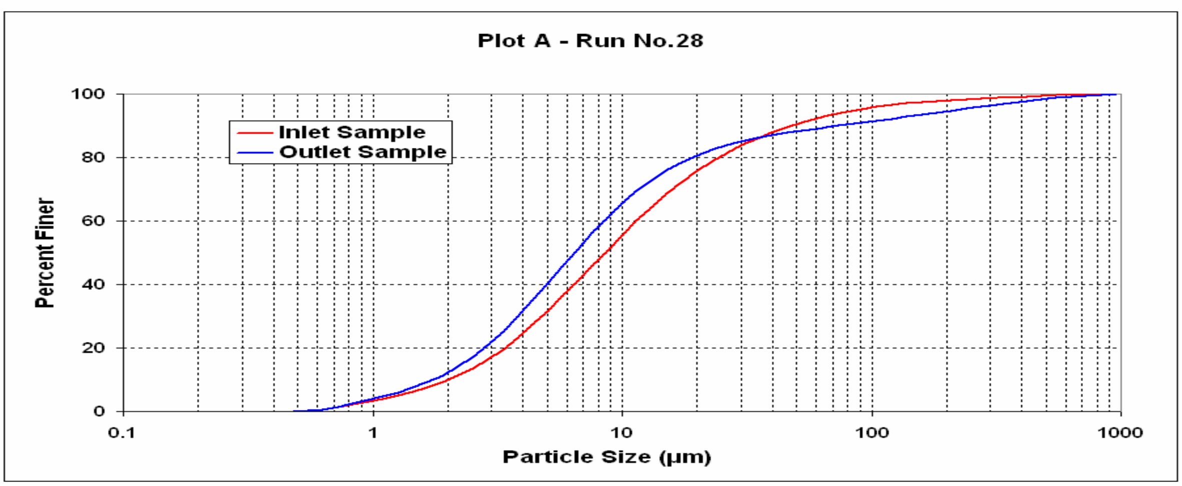

Figure 56: Particle size distribution for longevity tests, Run number 25