Full Scale Test of a Biofilter at the Outfall of a Construction Sediment Control Pond

Kleinburg, Ontario

Prepared by: Toronto and Region Conservation

April 2007

Final Report

FULL SCALE TEST OF A BIOFILTER AT THE OUTFALL OF A CONSTRUCTION SEDIMENT CONTROL POND

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Tim Van Seters, MES., B.Sc.
Manager, Sustainable Technologies
Toronto and Region Conservation
Authority 5 Shoreham Drive,

Downsview, Ontario
M3N 1S4

Tel: 416-661-6600, Ext. 5337
Fax: 416-661-6898

E-mail: Tim_Van_Seters@trca.on.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovate practices that help create more sustainable and liveable communities.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Construction activities have been identified as a significant source of sediment to urban streams. During the grading process of land development, vegetation is removed, natural drainage is altered, and stable topsoil is stripped away. When left uncontrolled, erosion of exposed soils by rainfall is transported via runoff. Elevated levels of suspended sediment in local watercourses can degrade water quality, increase stream flooding, influence geomorphic stability, and cause deleterious effects on aquatic life. In Ontario, sediment control measures have been required on construction sites for over a decade. However in many cases, recommended practices are either not implemented, or are improperly installed, under-engineered, or not maintained.

Biofilters are a low cost natural filtering medium used to remove sediment from stormwater. Typically, grass swales, filter strips, and wetlands have been used as biofilters to improve stormwater runoff quality and delay peak flows. Hay bales are the most common biofilter for concentrated flows, however, since they require regular maintenance (for inspections and repairs); other options are now being considered. One option that is gaining popularity is a compost biofilter. It can be vegetated and integrated into a site once the job is finished. One biofilter method uses compost to create berms (seeded or not seeded) at ESC/SWM pond outlets and have been found to be more effective in controlling suspended solids when compared to hay bales (Demars et. al, 2004).

Storey et al. (2006) found that non-seeded berms showed structural failure during flows. However, this same study suggested that seeded berms were very effective at removing suspended solids from water even though they overtopped during heavy flow. Filter socks are similar to berms but are more adaptable. For instance, they can be pre-filled to save time and arranged to suit each location. The filter sock consists of a mesh tube that is filled with coarse or fine textured compost and can be seeded depending on the consumers need. In both cases, the technologies remove sediment by decreasing flow velocities and trapping sediment in the compost media.

Filtrexx™ is an organization providing solutions to erosion and sediment control (ESC) using compost media in a mesh sock. Their trademark FilterSoxx™ (biofilter) is a mesh sock stuffed with loose organic compost or mulch which can be installed in various environments and provide both a growing and filter media. Unlike typical compost or mulch, the compost recommended by Filtrexx is typically screened depending on its application. The biofilter is designed as an alternative to typical ESC practices such as silt fences, straw bales, bank stabilization blankets, or other commonly used construction site best management practices (BMPs). Several biofilter applications are depicted in Figure 1.1.

Figure 1.1: Biofilter applications (Filtrexx[tm] 2007, USEPA, 2007)

1.1 Erosion and Sediment Control in Ontario

As the urban fringe in Canadian towns and cities expands into relatively undisturbed areas, concerns have been raised about the impact of sediment loading from construction sites on receiving water systems. In one study, monitoring of a channel reach upstream and downstream of a construction site showed an average increase in suspended solids concentration of 500%. Similar increases also occurred even though runoff volumes from the construction site comprised less than 25% of total stream flow and all of the required erosion and sediment controls had been implemented on the site (Greenland International, 2001 and TRCA, 2001).

Elevated levels of suspended sediment are a concern because of their detrimental impact on aquatic ecosystems. Effects on fish may include impairment to respiratory functions, lower tolerance to toxicants or disease, increased physiological stress, decreased reproductive success, and reduced vision, which inhibits their ability to find food (Vondracek et al., 2003). Migrating fish will avoid rivers with high suspended solids concentrations. Reduced light transmission caused by increased turbidity can also reduce primary production (plant growth) in streams, which can have important repercussions on community and channel stability dynamics (Waters 1995). Spawning and egg incubation periods are particularly sensitive times because sediment (especially clay and silt) may attach to the adhesive surface of eggs resulting in increased egg mortality (Ward, 1992).

Several techniques have been developed to control erosion and sediment transport from construction sites. Simple prevention practices rank the highest in terms of effectiveness. These typically involve minimizing the extent of disturbed area at any one time, and conserving natural cover or immediately stabilizing disturbed areas. One of the simplest ways of doing this is to phase construction, such that only a portion of the land under developed is exposed at any one time. Other structural erosion control methods, such as silt fences, rock dams, and straw bales are only moderately effective, especially for fine-grained soils and clays. An important reason for their lower level of effectiveness is their need for diligent maintenance, which is rarely done, and even more rarely enforced under existing regulations (TRCA 2006[a], TRCA, 2006[b]).

Ponds are among the most effective structural practices for reducing sediment release from construction sites. Located at the end of the treatment train, they provide the last and crucial line of defence in a multi-barrier approach that protects against excess sediment discharge to receiving waters. Unfortunately, there are no scientifically defensible standards for the design of these ponds in Ontario. As an interim measure, it has become common practice to use the ultimate (effluent-construction) stormwater management pond, designed to ‘enhanced’ level guidelines (OME, 1994, 2003), as a temporary sediment control pond (TRCA 1994, 2006). These ponds typically capture over 90% of construction site sediment, but due to extremely high influent concentrations, the quality of effluent discharged from the facilities rarely meets levels necessary to protect aquatic life in downstream receiving waters (25mg/L).

1.2 Guidelines: Erosion and Sediment Control

Provincial guidelines on ESC were published by the Ministry of Natural Resources in 1989. These guidelines recommend a 90% trap efficiency for soil particles greater than 40 µm. Temporary sediment basins should have a minimum volume of 125m^3/ha and be cleaned when this volume has been reduced by 60%. The pond need not include a permanent pool.

ESC guidelines for the Toronto and Region Conservation Authority (TRCA) jurisdiction were published in 1994 and updated in 2006. This document provides information on the purpose, installation and removal, maintenance, planning and design of ESC structures. Current guidelines recommend that the temporary sediment control pond have a permanent pool of at least 125 m^3/ha, a minimum length-to-width ratio of 4 :1 or greater, and minimum drawdown of 48 hours. The pond must be dredged when the sediment forebay design storage volume has been reduced by 50%.

1.3 Suspended Solids

Table 1.1 presents various receiving water guidelines or criteria for suspended solids and turbidity to protect aquatic organisms and their habitats. Further information on pertinent guidelines and recommendations, as well as a synopsis of research on the effects of sediment on fish and fish habitats is provided by the Department of Fisheries and Oceans (2000).

Table 1.1: Suspended solids receiving water guidelines for the protection of aquatic life

Organization	Guideline
Ontario Provincial Water Quality Objective (1999)	Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%
Canadian Water Quality Guidelines (1999)[1]	*Clear flow*: maximum increase of 25 mg/L from background levels for any short-term exposure (e.g. 24 h period). Maximum increase of 5 mg/L from background levels for any long-term exposure (e.g. inputs lasting between 24 h and 30 days). *High flow*: maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is >250 mg/L
European Inland Fisheries Advisory Commission (1965)[2]	< 25 mg/L - no harmful effects 25 – 80 mg/L - moderate to good fisheries 80 – 400 mg/L - good fisheries unlikely >400 mg/L - poor fisheries

1. Guideline is similar to the British Columbia and Manitoba (draft) guidelines
2. Adopted by US Environmental Protection Agency (1973)

The Ontario PWQO for turbidity recommends that the natural Secchi disc reading not be changed by more than 10%. The Secchi disc is a circular metal disc with alternate black and white quadrants used to measure water clarity. The disc is lowered into the water while observing the depth at which it disappears. The instrument is usually applied to lakes where natural variations in turbidity are not significant, but it can be adapted to streams by using a graduated cylinder (‘turbidity tube’) with a Secchi disc at the bottom. In practice, this method of assessing impact is difficult to apply because the relationship between suspended particulate matter and Secchi disc readings is highly non-linear (Smith and Davies-Colley, 2002). A 10% reduction in disc visibility when the water is clear represents a very small increase in particulate matter, while the reverse is true when the water is turbid.

The Canadian Water Quality Guidelines recommend maximum allowable increases according to stream ‘background’ concentrations and duration of exposure. Background is here defined as the median concentration over several years of monitoring at a reference site with similar soil texture and geology. The maximum increase for long term exposures is considerably more stringent than for short term exposures. Since background concentrations in most streams in the Greater Toronto area are below 25 mg/L, this guideline suggests that under no conditions should the stream concentration exceed 50 mg/L. This value is almost the same as the six-day exposure threshold of 55 mg/L beyond which adult freshwater non-salmonids are at risk of mortality (Newcombe and Jensen, 1996).

The federal guidance is consistent with criteria proposed earlier by a group of scientists for European freshwater fisheries in lakes and streams (EIFAC, 1965). Their criteria, which was later adopted by the USEPA (1973), was based on an extensive literature review of suspended sediment effects on fish growth, behaviour, food supply, reproductive success, mortality and disease. Their research indicated that concentrations of suspended solids below 25 mg/L would cause no harm to fish or fisheries. As concentrations rise to 80 mg/L, the quality of the fishery may be somewhat reduced, and above 80 mg/L a good fishery would be difficult to maintain (Table 1.1).

Newcombe (1986; as cited in Ward, 1992) suggests a framework for assessing impacts on aquatic biota based on the concentration of suspended solids and duration of exposure (Figure 1.2, also see Newcombe and MacDonald, 1991). The diagonal line between impact zone 2 and 3 was intentionally truncated to avoid extrapolation to very short duration – high concentration events and vice versa. This framework indicates the following:

- impacts of suspended solids concentrations on aquatic biota equal to or greater than 1000 mg/L lasting for 20 minutes or less are difficult to predict;
- suspended solids concentrations of 30 mg/L for over 8 hours but less than 700 hours (29 days) result in a moderate impact to aquatic life;
- suspended solids concentrations of 30 mg/L for over 700 hours (29 days) result in a major impact, and
- suspended solids concentrations of 100 mg/L begin to have moderate impacts on aquatic life at exposure durations above approximately 3 hours.

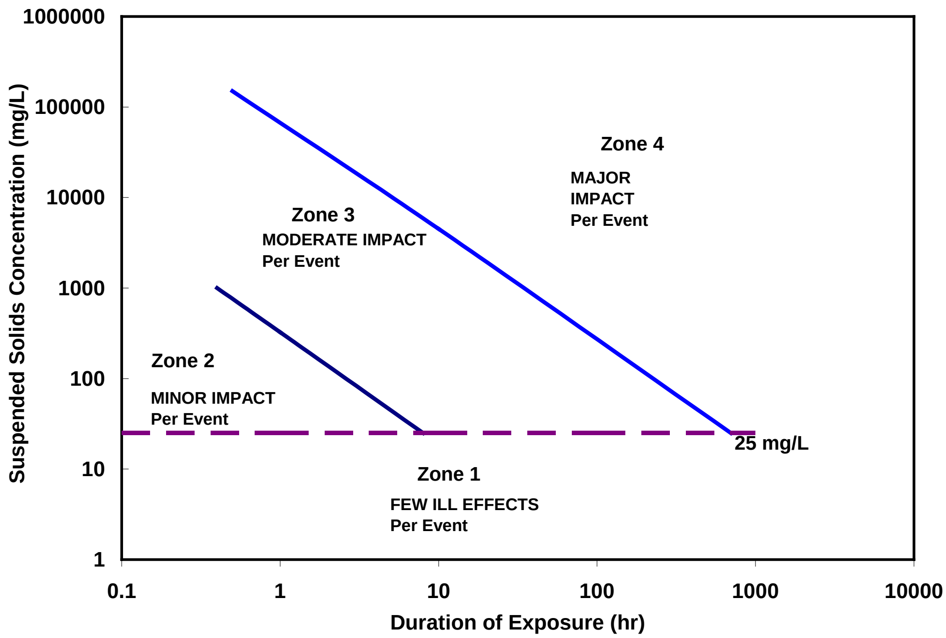

Figure 1.2: Impact of suspended solids on aquatic ecosystems as a function of concentration and duration of exposure

Models based on these relationships have been successful in predicting impacts of suspended sediment on fish, life cycles and other aquatic organisms. In this study, the concentration-duration framework is used to evaluate the potential impact of pond effluent concentrations on downstream aquatic ecosystems. Plots of discrete suspended solids per event provide an easy method of assessing harm associated with events of various sizes and intensities, as well as with different modelling scenarios. It should be recognized, however, that an accurate assessment of potential effects on aquatic life must also consider effluent loads relative to suspended solids loads in the downstream channel itself (*i.e.* mixing and dilution effects).

1.4 Study Objectives

This study is an extension of work completed by Guelph University (2007), where lab and pilot scale field testing was conducted on a biofilter in order to evaluate its capabilities as a storm water management (SWM) and ESC technology. Objectives of the Guelph University work were to:

- determine flow-through properties of the biofilter and rationalize its hydraulic design; and
- assess the effectiveness of the biofilter in removing contaminants from runoff.

Guelph University (2007) reported that the maximum flow-through rates per unit width of the 8” sock for three compost materials was approximately 1.5 L/s/m. 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% (Gharabaghi et. al, 2007).

The present study evaluates the performance of a biofilter as a sediment control technology for effluent from a temporary construction sediment control pond. The purpose of 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.

2.0 STUDY LOCATION

The study area is situated in the Humber River Watershed and drains to the East Humber River (Figure 2.1). The site is a 21.9 hectare construction site located in a low tableland area near the intersection of Highway 27 and Islington Avenue in the Humberplex Community, Kleinburg, Ontario (Figure 2.2).

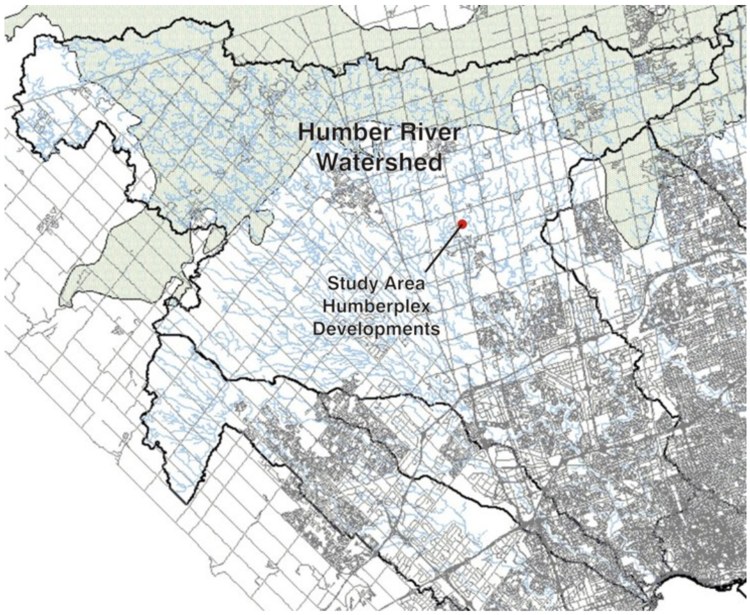

Figure 2.1: Study area, Humber River Watershed

Figure 2.2: Study location within the Humberplex Development

The Humberplex pond was chosen for the study because it fit the following criteria:

- the site was in the first phase of construction;
- grading was completed;
- pond and sewer network was online;
- effluent pond outlet was channelled with at least 1% slope; and
- sediment erosion was typical of many construction sites across the TRCA jurisdiction.

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. Two outlets were constructed (north and south side) and modelled outlet flow details are listed in Table 2.1 (URS Canada Inc, 2004). The biofilter ditch check system was installed downstream of the south outlet structure (Figure 2.3).

Table 2.1: Modelled pond outlet flow rates (URS Canada Inc, 2004)

Design Storm	Rainfall (AES 12 hr)	Outlet Flow (m^3/s)
25 mm	-	0.03
2 year	42mm	0.44
5 year	54.4mm	0.44
100 year	88.5mm	0.44

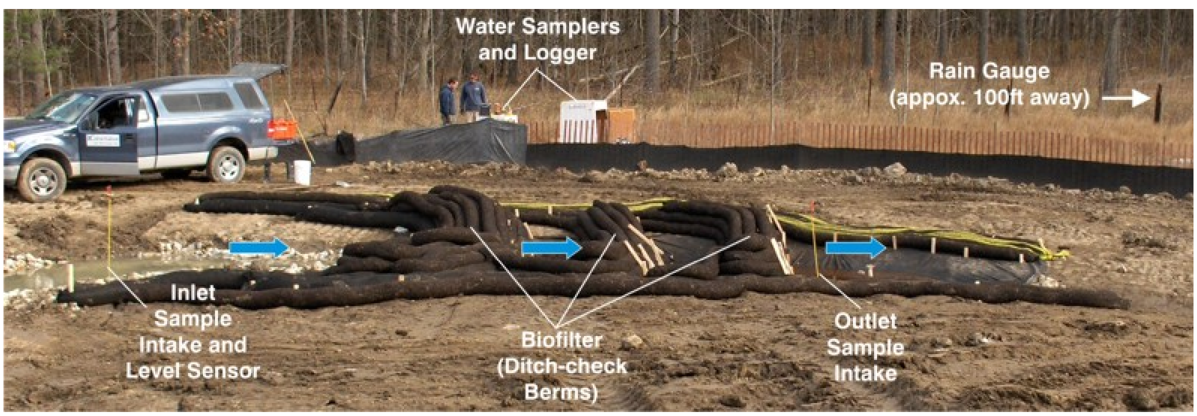

Figure 2.3: Biofilter system and monitoring equipment locations. Blue arrows depict the direction of flow

In Ontario, erosion and sediment control plans are required for all areas under construction. In practice, however, these plans are often not effectively implemented, and when they are, sediment control structures are rarely maintained on a regular basis. The Humberplex site was not an exception to this general rule (Figure 2.4). Inadequate controls within the catchment compromised the effectiveness of the end-of-pipe erosion and sediment control pond.

Figure 2.4: Extensive erosion and overland flow laden with sediment, Humberplex Developments, November 2006

3.0 METHODOLOGY

The biofilter system was monitored from November 5th to December 5th, 2006. The study was designed to be a relatively brief field test of the capacity of the biofilter to remove sediment from pond outflows under a range of different flow conditions. Results from these tests were to be used in combination with laboratory and pilot field testing of the biofilter at the University of Guelph to gain an overall understanding of the effectiveness and function of the biofilter under a range of conditions.

3.1 Water Quantity

3.1.1 Rainfall

A three season (Spring to Fall) 8 inch diameter tipping bucket rain gauge and logger was installed on site. Rainfall measurements were recorded at 5 minute intervals and downloaded bi-weekly.

3.1.2 Flow and Water Level

An ISCO 4150 flow meter and area/velocity sensor was installed in the pond outlet flow splitter and was programmed to record water level, flow, and velocity every 5 minutes (Figure 3.1). The control outfall is located upstream from the biofilter inlet.

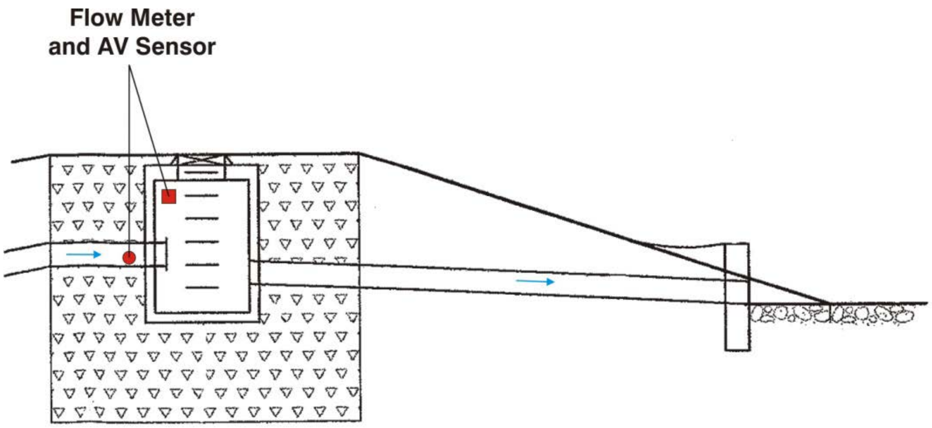

Figure 3.1: Location of outlet flow meter

The sensor was located in the upstream pipe of the flow splitter in order to avoid turbulent flows created by the differing pipe elevations and possible periodic backflow.

Level was monitored in the scouring pool between the pond outlet and biofilter in order to determine when the system overflowed and to trigger the automated water samplers.

3.2 Water Quality

Water samples were collected as grabs, time proportioned composites, and discrete aliquots. Grab samples were collected for general reference at the inlet and outlet of the pond, as well as before and after the biofilter during dry and wet weather. Samples collected before and after the biofilter are referred to as “influent” and “effluent”. These samples were analyzed both discretely and as a composite.

Influent and effluent water samples were collected using two ISCO 6700 automated water samplers and triggered via water level by the ISCO 4150 flow metre 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 litre bottle carousels which permitted both discrete and composite sampling. The samplers were programmed to take one 500ml sample per bottle every 30 minutes over a period of 24 hours. During the large events with extended drawdown, sampler carousels were switched manually and the sampler was restarted to capture the entire flow period.

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 lab services for analysis.

4.0 RESULTS AND DISCUSSION

4.1 Water Quantity

4.1.1 Rainfall

Seven rainfall events occurred during the study period ranging from 1 mm to 31 mm (Table 4.1). Water samples were collected during 5 of these events.

Table 4.1: Rainfall event summary

Date	Rainfall (mm)	Water Samples Collected (y/n)	Start	End	Duration (hrs)	Max. Rainfall (mm/5min)	Max. Rainfall Intensity (mm/hr)	Rainfall Intensity (mm/hr)
11/17/2006	3	n	2:35	9:30	6:55	0.2	2.4	0.434
12/2/2006	1.1	y	11:20	14:25	3:05	0.2	2.4	0.080
11/11/2006	7.7	y	3:15	19:30	16:15	0.7	8.4	0.474
11/7/2006 to 11/8/2006	11.7	n	10:55	3:24	16:29	0.2	2.4	0.710
11/30/2006	19.6	y	3:40	19:00	15:20	0.9	10.8	1.278
11/15/2006 to 11/16/2006	28.4	y	20:55	14:25	17:30	0.7	8.4	1.640
12/1/2006	31.5	y	0:40	16:40	16:00	0.7	8.4	1.969

4.1.2 Hydrologic Summary

Table 4.2 summarizes the rainfall, volume, drawdown time and peak flow for sampled events. Rain events are combined in this table to reflect hydrograph rise, peak, and draw-down attributes. A flow event, in this case, was defined as the period of time between the initial rise of the hydrograph to the return of flow to pre-event conditions (i.e. baseflow). All hydrographs are presented in Appendix A.

The results indicate that over 50% of rainfall is converted to stormwater runoff at the site and is discharged by the pond over a period of less than 24 hours. The recommended drawdown for temporary sediment control ponds is 48 hours. Peak outflows were higher than observed at other construction sites, especially considering that peak outflows represent only one of two outlets (TRCA, 2006).

Table 4.2: Hydrologic summary for runoff events

Event	Rainfall (mm)	Max. Rainfall (mm/5min)	Volume (m^3)	Peak of storm	Peak OutFlow (L/s)	Drawdown Time (hrs)
11/11/2006	4.7	0.7	46.18	11/11/2006 5:40	4.7	5:50
11/11/2006	3.0	0.5	129.34	11/11/2006 13:25	3.6	7:30
11/15/2006	28.4	0.7	1410.88	11/16/2006 8:00	61.4	9:45
11/30/2006	19.6	0.9	407.99	11/30/2006 15:55	22.7	6:05
12/1/2006	31.5	0.7	2025.33	12/1/2006 12:45	81.9	8:10

Notes: Flow measurements were collected at only one outlet.

4.1.3 Biofilter Flow-through Capacity

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 indicated that the flow-through capacity of the filter socks was between 2 and 4 L/s. The theoretical flow through capacity for this installation based on tests conducted at the University of Guelph was 5 L/s.

4.2 Water Quality

Flow events collected and submitted for water quality testing occurred on November 11th, 15th and 30th and December 1st, 2006. Water samples were analyzed discretely for suspended solids, and as composites for selected groups of pollutants, including metals, nutrients, and general chemistry. Due to the brief duration of the study, sample results do not reflect long term performance. Pilot scale testing at the University of Guelph showed that removal decreases over time as more and more fine sediment accumulates within the filter. Biofilter performance results for all water quality variables are presented in Appendix B. The following subsections provide a summary of selected results, with a focus on suspended solids, the primary variable of concern in runoff from construction sites.

4.2.1 Discrete Analysis: Suspended Solids

Flow and discrete TSS results for the November 11th, November 15th and November 30th runoff events are presented in Table 4.3. The November 30th event included two storms over 3 days. The first 19.6 mm event occurred on the 30th (approx. 3:30am) and the second 31.5 mm event occurred in the early morning of December 1st (approx. 12:30am). Events on November 11th and 15th were only partially captured due to power loss and/or sampler malfunction. Effluent concentrations and loads for these events are based on samples collected on the receeding limb of the hydrograph.

Results show maximum influent TSS concentrations ranging from 55 mg/L during the smallest event on November 11th to 2580 mg/L during the second of two larger back-to-back events on December 1st. Effluent concentrations, TSS loads and load based removal efficiencies varied according to event size, which in turn affected the degree to which flow overtopped the filters. At mean flow rates of 2, 8, and 18 L/s, the biofilter removed, on a load basis, 43, 36 and 6% of TSS, respectively (Nov 15th excluded). Significant overtopping was observed during all events. Pilot scale testing at the University of Guelph showed TSS removal efficiencies of between 62 and 81% for flow-through rates (<2 L/s) with no overtopping. Clearly, flow rate is a key factor explaining observed variations in biofilter performance.

Table 4.3: Suspended solids removal efficiency of biofilter

Event Date		11-Nov-06	15-Nov-06*	30-Nov-06	1-Dec-06[1]	Total
Rain (mm)		7.7	31.4	19.6	31.5	
Flow	Minimum (L/s)	1.73	1.36	1.06	0.99	
	Maximum (L/s)	3.63	38.48	22.69	81.79	
	Mean (L/s)	2.14	8.30	6.33	18.19	
TSS Influent biofilter	Maximum Concentration (mg/L)	55.20	NA	392.00	2580.00	
	Maximum Load (kg/hr)	0.50	NA	29.07	768.53	
	Mean Concentration (mg/L)	29.09	NA	148.14	660.95	
	Total Load (kg)	5.65	NA	106.10	3345.17	**3456.92**
TSS Effluent biofilter	Maximum Concentration (mg/L)	23.40	578.00	247.00	2520.00	
	Maximum Load (kg/hr)	0.25	79.76	18.43	692.86	
	Mean Concentration (mg/L)	18.07	170.72	97.79	592.59	
	Total Load (kg)	3.23	353.25	67.66	3131.81	**3202.70[2]**
Removal Efficiency (%)		42.8	NA	36.2	6.4	**7.3**

1. Total influent loads and removal efficiencies were not calculated due to sampler malfunction; only four discrete samples were collected at the inlet.
2. November 15th, 2006 event not included in total calculations.

Closer inspection of TSS pollutographs during the November 30th reveals additional insights into the performance of the biofilter (Figure 4.1). At the beginning of the first event, accumulated sediment within the filter was resuspended resulting in TSS effluent concentrations the same as, or higher than, influent concentrations. Once overtopping occurred, effluent concentrations were consistently lower than influent concentrations, even as flows overtopping the biofilter increased. There is no obvious explanation for this counter intuitive result, although the pattern of flow currents induced by the biofilter would be expected to play some role. Removal rates drop off considerably during the second storm event. Near the end of the storm, when flow rates parallel those of the earlier storm, influent and effluent concentrations remain similar (i.e. removal is negligible). Clogging of the filter with sediment is likely an important cause of the decline in performance.

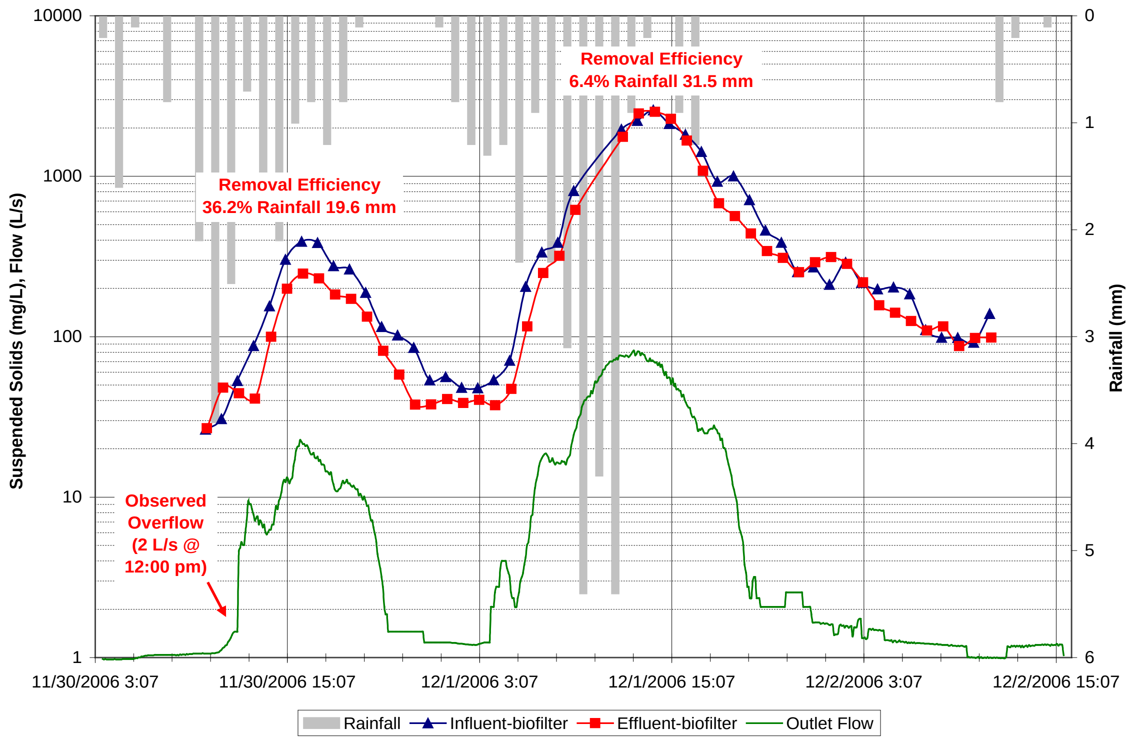

Figure 4.1: Discrete analysis: suspended solids, November 30th, 2006, total rainfall 51.1mm. Biofilter overflow at 2 to 3 L/s

Figure 4.2: Biofilter overflow caused by high flow rates and increased volumes, December 1, 2006 1:05pm

This flushing effect is also evident during the November 15th event, when TSS concentrations on the receeding limb of the hydrograph decreased from 100 mg/L to 30 mg/L even as flow rates remained relatively constant at less than 2 L/s (Figure 4.3). Although removal efficiencies were not calculated for this event because of insufficient influent quality data, the available data suggest no removal at flow rates of 30 to 50 L/s, which is consistent with evidence from the November 30th event.

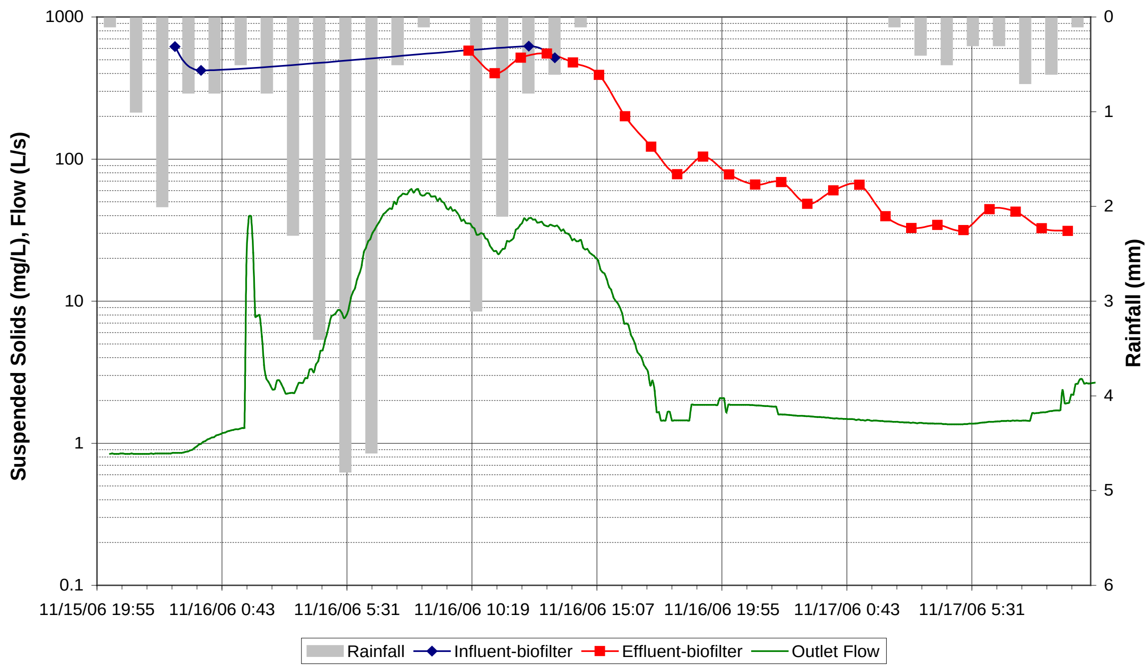

Figure 4.3: Discrete analysis: suspended solids, November 15th, 2006, total rainfall 31.4 mm

The November 11th event showed the best removal efficiencies and the lowest effluent concentrations. It was also the only event with flow rates low enough to pass mostly through the filter. In this case, effluent concentrations were consistently below the 25 mg/L target for the protection of aquatic life. Influent and effluent concentrations converge on the receeding limb of the hydrograph as influent TSS concentrations approach 'background' levels (Figure 4.4).

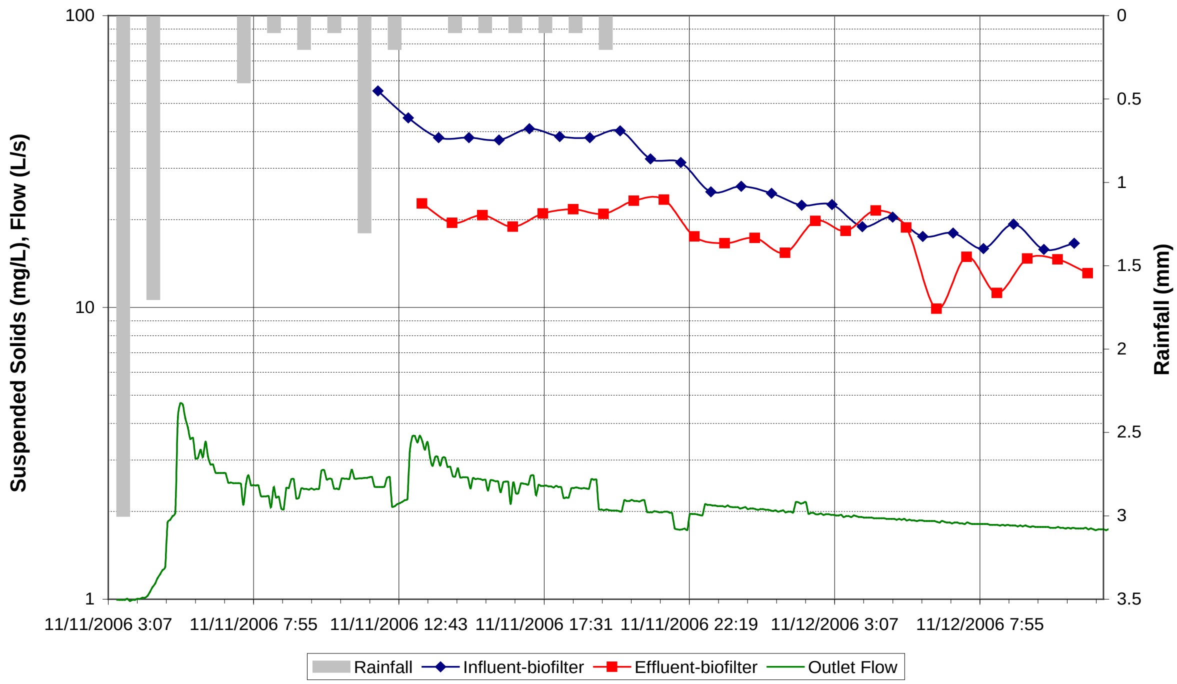

Figure 4.4: Discrete analysis: suspended solids, November 11th, 2006, total rainfall 7.7 mm

4.2.2 Particle Size Analysis

Particle size distribution (PSD) includes data for all collected events (Nov 11th, 15th, and 30th). Mean influent and effluent PSDs suggest that removal is occurring over the full range of particle sizes, not just the coarse grained fraction (Figure 4.5, also see Appendix C). Intuitively, this result does make some sense given the high levels of turbulence along the upstream edge of the filters and the fine clay sediment (d_{50} < 2 microns). Selective removal of the coarser grained sediment under these circumstances would be extremely difficult.

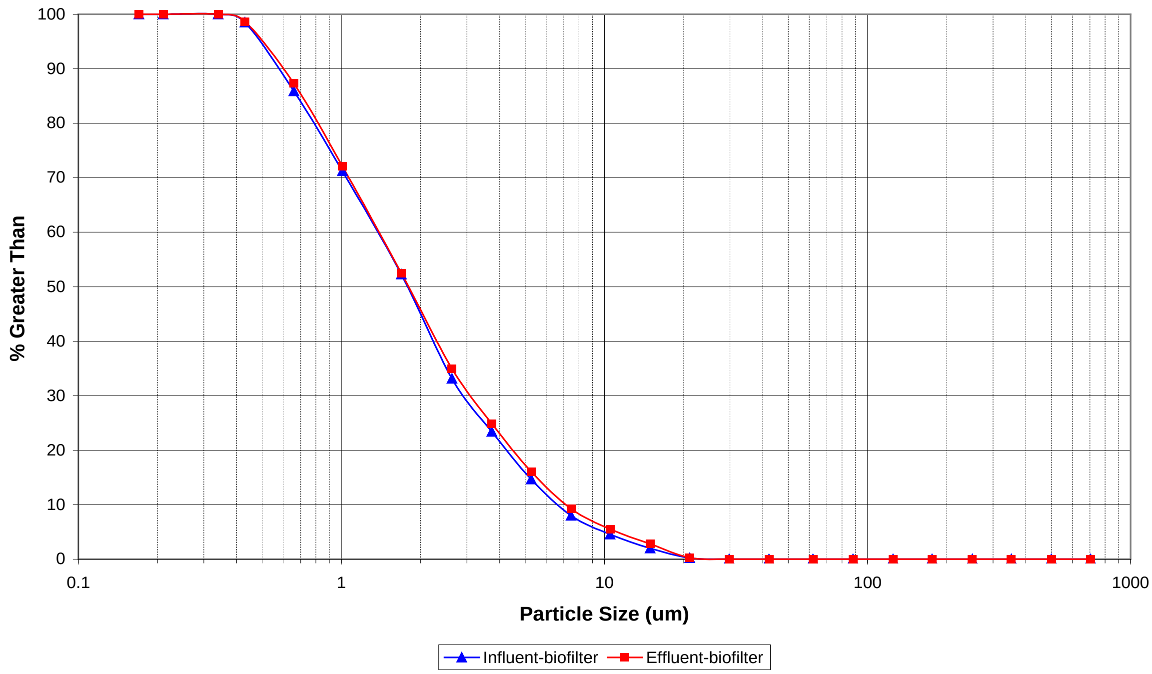

Figure 4.5: Mean particle size distribution "Influent" and "Effluent" biofilter system, Humberplex Development, November 2006

4.2.3 Other Water Quality Variables

Sample results for heavy metals indicate that the biofilter is effective in reducing the average concentration of most metals (see Appendix B), especially during small to mid-sized events. Copper was the only metal in which removal performance was poor (-12.3%). Aluminium, cadmium, copper, and iron all exceeded provincial water quality guidelines.

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.

5.0 CONCLUSIONS

This study demonstrates that biofilters have limited capacity to filter sediment from temporary erosion and sediment control pond outflows because of high flow-through rates and sediment loading. At average pond outflow rates of 2, 6 and 18 L/s, the biofilter removed 43, 36 and 6% of TSS loads. The biofilter was overtopped at flow-through rates of approximately 3 to 4 L/s. Influent and effluent particle size distributions were not statistically different, even during the smallest event (7.7 mm). As the filter ages, and void spaces fill, long term removal will likely decrease to even lower levels.

To avoid overtopping, a flow splitter would be needed at the pond outflow channel to divert high flows directly to the receiving water system. This would prolong the life of the biofilter and help to ensure that treatment only occurs for flows within the design capacity of the technology. Whether this is a cost effective solution in any given circumstance will depend on the pond outflow rate and whether or not the outlet channel configuration (*e.g.* width, slope) allows for a biofilter design that permits sufficient flow through rates.

In general, biofilters are better suited to applications with peak flow rates less than 20 L/s. These applications include sheet flow from sloping lands, channelized flow in roadside ditches or as protective filters around storm sewer catchbasins. Studies at the University of Guelph clearly show that biofilters are capable of removing appreciable quantities of sediment when overtopping is avoided. The socks are also inexpensive, completely biodegradable and provide a use for certain types of compost (i.e. the ‘overs’) that would otherwise be disposed of in a landfill. Biofilters are an important part of an overall sediment and erosion plan on construction sites, but should be applied only where flows do not exceed the design flow-through capacity of the biofilter.

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APPENDIX A

Pond Outlet Hydrographs for Selected Events

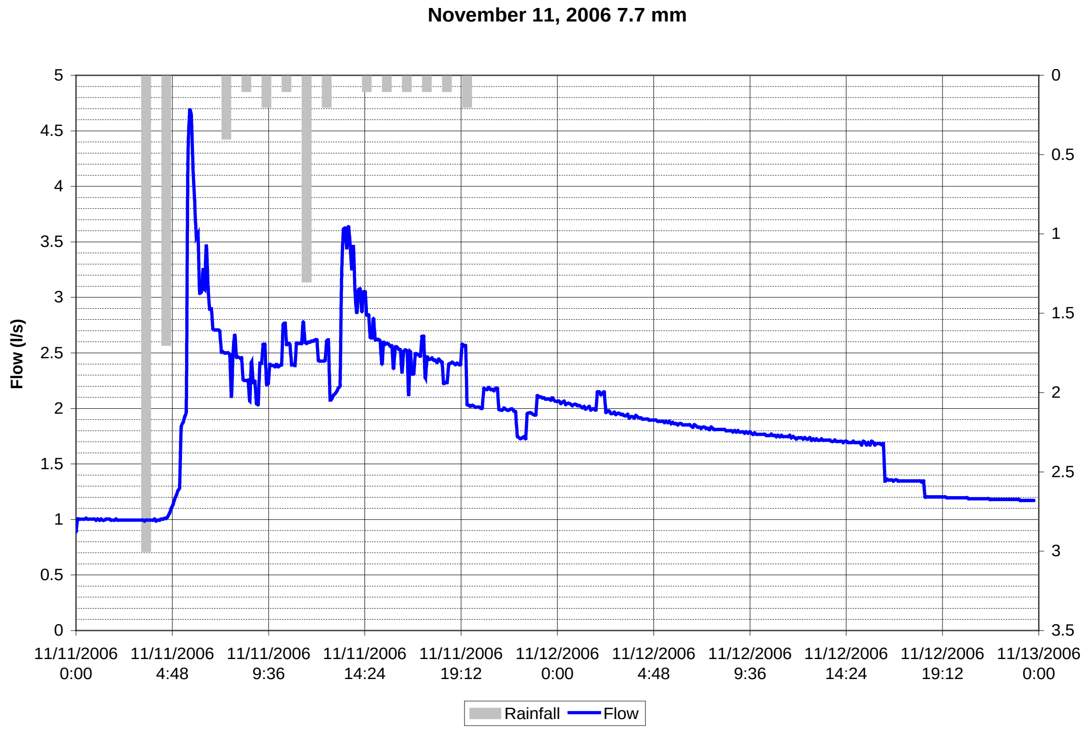

Figure A1: Hydrograph for November 11th, 2006 event

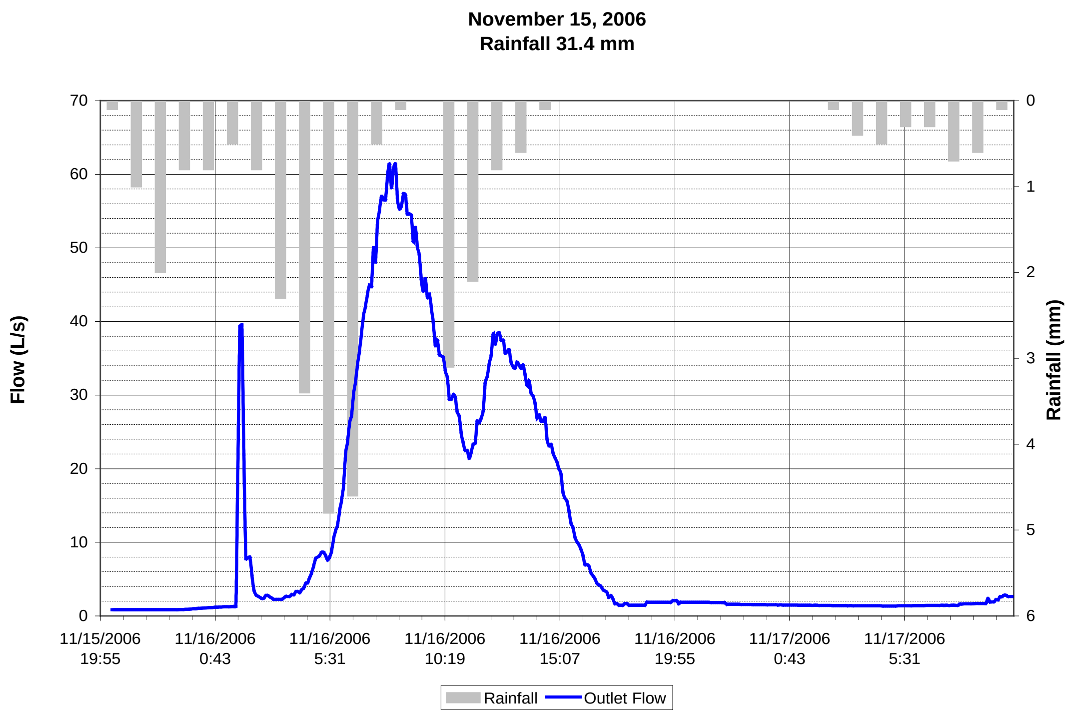

Figure A2: Hydrograph for November 15th, 2006 event

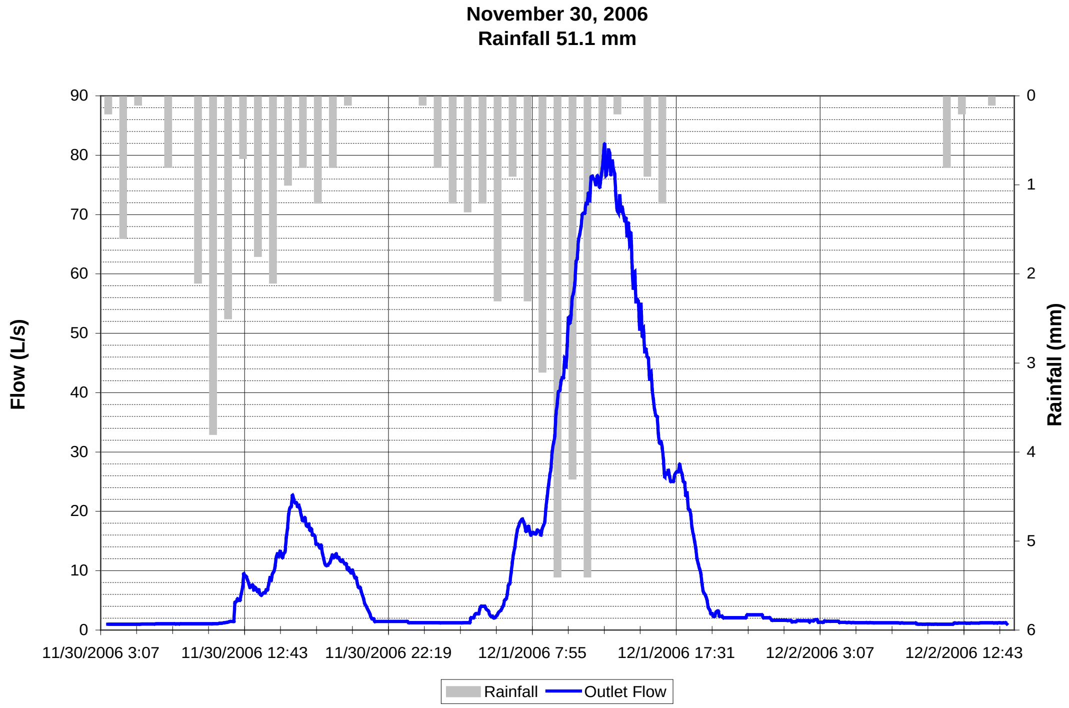

Figure A3: Hydrograph for November 30th, 2006 event

APPENDIX B

Biofilter Water Quality Performance Results

Table B1: Biofilter water quality performance results

					Influent-biofilter					Effluent-biofilter				Performance
	Parameter	Units	Guideline	# of Samples	Min	Max	Mean	Median	# of Samples	Min	Max	Mean	Median	Influent vs. Effluent
General Chemistry	Chloride	mg/L		3	11.800	17.700	15.567	17.200	4	12.600	18.900	16.000	16.250	**-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**
	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**
	Solids; suspended	mg/L		3	**26.500**	**859.000**	**356.500**	**184.000**	4	**28.700**	**740.000**	**268.175**	**152.000**	**24.8**
	Solids; suspended, ash	mg/L		3	**21.900**	**754.000**	**312.300**	**161.000**	4	**22.700**	**648.000**	**233.675**	**132.000**	**25.2**
	Solids; suspended, LOI	mg/L		3	4.600	**105.000**	**44.400**	**23.600**	4	6.000	**92.300**	**34.450**	**19.750**	**22.4**
	Conductivity	uS/cm		3	219.000	358.000	303.000	332.000	4	227.000	371.000	306.250	313.500	**-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	**-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	**-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	**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	**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	**-0.7**
	Turbidity	FTU	5	3	**59.000**	**1880.000**	**748.000**	**305.000**	4	**226.000**	**2000.000**	**1077.250**	**1041.500**	**-44.0**
Nutrients	Nitrogen; ammonia+ammonium	mg/L		3	0.001	0.031	0.017	0.019	4	0.001	0.157	0.078	0.078	**-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	**-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	**0.9**
	Phosphorus; phosphate	mg/L		3	0.016	0.103	0.063	0.069	4	0.026	0.104	0.060	0.055	**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	**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	**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**	**15.9**
	Barium	ug/L		3	25.600	112.757	61.689	46.711	4	22.800	101.119	50.961	39.962	**17.4**
	Beryllium	ug/L	11	3	0.100	0.524	0.241	0.100	4	0.100	0.472	0.193	0.100	**20.0**
	Calcium	mg/L		3	47.300	110.553	71.602	56.954	4	46.300	93.074	61.881	54.074	**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**	**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	**0.0**
	Chromium	ug/L	8.9	3	2.140	4.969	3.432	3.188	4	2.610	5.135	3.365	2.857	**2.0**
	Copper	ug/L	5	3	**7.620**	**18.865**	**13.360**	**13.596**	4	**12.262**	**21.858**	**15.005**	**12.950**	**-12.3**
	Iron	ug/L	300	3	**519.000**	**3106.973**	**1762.690**	**1662.098**	4	**407.000**	**2867.483**	**1526.639**	**1416.037**	**13.4**
	Magnesium	mg/L		3	7.773	8.700	8.338	8.540	4	6.740	8.740	7.839	7.938	**6.0**
	Manganese	ug/L		3	32.200	487.406	214.794	124.777	4	26.100	423.836	170.069	115.170	**20.8**
	Molybdenum	ug/L	10	3	0.800	0.800	0.800	0.800	4	0.800	0.800	0.800	0.800	**0.0**
	Nickel	ug/L	25	3	0.650	7.820	3.480	1.969	4	1.460	6.080	3.115	2.460	**10.5**
	Lead	ug/L	5	3	5.000	5.000	5.000	5.000	4	5.000	5.000	5.000	5.000	**0.0**
	Strontium	ug/L		3	235.114	259.000	246.469	245.292	4	200.000	252.000	227.172	228.343	**7.8**
	Titanium	ug/L		3	2.143	5.381	4.051	4.630	4	1.810	5.735	3.471	3.170	**14.3**
	Vanadium	ug/L	7	3	2.510	6.589	4.253	3.659	4	0.750	5.172	2.761	2.561	**35.1**
	Zinc	ug/L	20	3	4.200	**31.320**	16.415	13.725	4	5.950	**30.146**	15.549	13.050	**5.3**

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

APPENDIX C

Mean Particle Size Distribution

Table C1: Mean particle size distribution

		Mean %								Total %							
		Influent-biofilter			Effluent-biofilter			Influent-biofilter	Effluent-biofilter	Influent-biofilter			Effluent-biofilter			Influent-biofilter	Effluent-biofilter
Class	Grain Size Distribution	Bottle 1 to 8	Bottle 9 to 16	Bottle 17 to 24	Bottle 1 to 8	Bottle 9 to 16	Bottle 17 to 24	composite	composite	Bottle 1 to 8	Bottle 9 to 16	Bottle 17 to 24	Bottle 1 to 8	Bottle 9 to 16	Bottle 17 to 24	Average	Average
Sand	% <1000 um, >704 um	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
	% <704 um, >500 um	0	0	0	0	0	0	0	0								
	% <500 um, >352 um	0	0	0	0	0	0	0	0								
	% <352 um, >250 um	0	0	0	0	0	0	0	0								
	% <250 um, >176 um	0	0	0	0	0	0	0	0								
	% <176 um, >125 um	0	0	0	0	0	0	0	0								
	% <125 um, >88 um	0	0	0	0	0	0	0	0								
	% <88 um, >62 um	0	0	0	0	0	0	0	0								
Silt	% <62 um, >42.2 um	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	33.3	19.4	17.5	34.7	14.2	25.7	**23.4**	**24.9**
	% <42.2 um, >29.8 um	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000								
	% <29.8 um, >21.1 um	0.500	0.000	0.200	0.425	0.000	0.350	0.233	0.258								
	% <21.1 um, >14.9 um	3.233	0.100	2.000	4.400	0.425	2.800	1.778	2.542								
	% <14.9 um, >10.5 um	4.333	1.233	2.067	4.075	0.875	3.200	2.544	2.717								
	% <10.5 um, >7.46 um	5.500	2.067	2.800	5.225	2.000	4.000	3.456	3.742								
	% <7.46 um, >5.27 um	8.767	6.633	4.567	9.100	4.625	6.750	6.656	6.825								
	% <5.27 um, >3.73 um	10.933	9.400	5.833	11.500	6.275	8.600	8.722	8.792								
Clay	% <3.73 um, >2.63 um	12.267	10.133	6.800	12.425	7.475	10.400	9.733	10.100	66.7	80.6	82.5	65.3	85.8	74.3	**76.6**	**75.1**
	% <2.63 um, >1.69 um	16.533	19.700	21.200	15.950	20.325	16.300	19.144	17.525								
	% <1.69 um, >1.01 um	18.333	20.700	17.900	17.675	20.150	21.000	18.978	19.608								
	% <1.01 um, >0.66 um	12.267	16.500	15.233	12.025	17.425	16.150	14.667	15.200								
	% <0.66 um, >0.43 um	6.667	12.200	18.967	6.525	18.150	9.450	12.611	11.375								
	% <0.43 um, >0.34 um	0.667	1.333	2.433	0.675	2.275	1.000	1.478	1.317								
	% <0.34 um, >0.21 um	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000								
	% <0.21 um, >0.10 um	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000								
								100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**