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# USE OF NONWOVEN GEOTEXTILES FOR REMOVING NUTRIENTS AND SUSPENDED SOLIDS FROM A EUTROPHIC LAKE

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## ABSTRACT

Eutrophication has been identified as one of the leading risks to surface water quality especially for lake water quality in Canada. The objective of the study is to evaluate the effectiveness of nonwoven geotextiles in reducing the nutrients and suspended solids to improve lake water quality. A small scale field experiment was conducted beside a lake by using nonwoven geotextiles as filter media. Custom-made geotextiles were used in different combinations to provide maximum efficiency in removing nutrients and suspended solids (SS) to achieve an acceptable level within a shorter period of time. For an initial turbidity ranging from 4 to 9 NTU, 2 layers of 110 µm pore size filters with 3 layers of 90 µm pore size showed the best result at the 7th day of filtration, whereas 2 layers of 110 µm pore size with 3 layers of 75 µm pore size geotextiles had been found to restore the water quality at the 3rd day of filtration for an initial turbidity ranging from 9 to 14 NTU. The combination of 1 layer of 110 µm pore size with 4 layers of 90 µm pore size showed the best result at the 2nd day during filtration for an initial turbidity higher than 14 NTU. TSS removal correlated with reduction of turbidity, TP and COD concentration. Initial flow rates through the filter decreased with an increase in filter layers and decrease in filter pore size. Geotextiles as filter media have shown potential for improvement of surface water quality in terms of nutrient and TSS removal.

Key words: Eutrophication, geotextiles, TP, filtration

## 1. INTRODUCTION

Eutrophication is a natural process by which a lake or other water bodies becomes enriched in dissolved nutrients (nitrogen (N) and phosphorus (P)) that catalyze the aquatic plant growth. In enclosed water areas, eutrophication is one of the biggest problems around the world (Harper 1992, Mulligan et al. 2011). The assessment of the trophic status of a lake is measured by P concentration of the lake, its chlorophyll α concentration (an indicator of algal abundance) and transparency of water (measured by secchi disk). Eutrophication caused by elevated nutrient levels in ecosystems enhances the excessive growth of aquatic plants and thus disturbs the ecosystem, and reduces the dissolved oxygen which is needed for aquatic organisms to survive (Mccuen & Agouridis 2007, Moslemizadeh 2009). Eutrophication can be controlled by removing the nutrients from water. Contaminants entering into a lake adsorb and settle in the bottom sediments and work as potential contaminant sources into the overlaying water (Mulligan et al. 2001, Ritter et al. 2002). One of the main reasons for eutrophication is the release of P and nutrients from the sediments (Inoue et al. 2009). For controlling internal P and nutrient release into water, several methods have been implemented, like the use of chemicals – alum, calcite, lime (Chambers 1990, Cooke et al., 1993), sediment dredging (Reddy et al. 2007), in situ capping, etc. However, all of them have their own limitations such as pH, maintenance, cost, insufficient removal, constraints of particle sizes, etc. Thus remediation has to be done by taking into account the environmental conservation along with cost, maintenance and other factors (Mulligan et al. 2011).

There are currently not many economically or environmentally feasible treatment methods for recreational waters (Inoue et al. 2009). In filtration, two or more components from a liquid stream are separated based on their size differences (Cheryan 1998), so it can be one of the beneficial techniques for removal of suspended solids (SS) and contaminants adsorbed on solids from water and sediments. Fukue et al. (2006) recently developed a new and innovative environmentally friendly technology to separate the SS and contaminants from water by applying in-situ filtration. Geotextiles, permeable materials, generally used in layers or strata separation, soil improvement, reinforcement and drainage (Franks et al. 2012, Quaranta & Tolikonda 2011, Tota-Maharaj et al. 2012) may work as a potential filter medium. Very limited work has been done to remediate surface water by using geotextiles as filter media. Inoue et al. (2009) found the removal efficiencies of SS, chemical oxygen demand (COD) and total P (TP) by using nonwoven geotextiles as filter media in a small upward filtration experiment in Shimizu Utozaka pond, Japan were 88.5%, 56.5% and 64.2% respectively. Mulligan et al. (2011) performed on-site filtration tests at Lac Caron, Quebec, Canada, using nonwoven geotextiles as filter media and found that a geotextile was capable of removing SS and P by 61% and 41% on average, respectively.

The objective of this study was to treat a eutrophic lake water samples by filtration using nonwoven geotextiles and hence evaluate the effectiveness of nonwoven geotextiles as a filter media. A series of experiments was carried out beside a eutrophic lake using different combinations of geotextiles to find out the best combination providing maximum efficiency in removing nutrients and SS to achieve acceptable level within a shorter period of time. The relationship among various water quality parameters was also assessed.

## 2. MATERIALS AND METHODS

The location selected for this study was Lake Caron (74°08'50" O and 45°50'28" N), a eutrophic lake, located about 75 km north of downtown Montreal in the municipality of Saint-Anne Des Lacs, Quebec in the Laurentians.

Lake Caron is an artificial and closed water body. The surface area and volume of the lake are approximately 35,300 $m^2$ and 48,400 $m^3$ respectively. The maximum depth is 2.6 m and the average depth is 1.4 m in most parts of the lake and 0.5 m in the shallow parts. The only water sources for the lake are natural precipitation, snow melt and surface runoff from the surrounding area. During the summer, infiltration and evaporation are the two prime natural phenomena of water discharges from the lake. Though there are some private properties around the lake shore, most of the lake is surrounded by trees.

Human activities like addition of fertilizer, phosphate detergents and septic tank discharges from the nearby neighborhood have been degrading the lake water quality. There is constant erosion from rocks and land that accumulate at the bottom of the lake. Also, another contributor of internal phosphorus loading is the runoff from the forested area and plant growth, death and decomposition in the water. These changes in nutrient concentrations in the water have led to eutrophic conditions of the lake since 2008. Since then the lake is restricted to only recreational purposes like boating.

### 2.1 Filtration systems

The filtration unit used in this study was cylindrical in shape and made of plexiglas with an internal diameter of 20 cm and a height of 25 cm. This column was placed at the top of the base to hold water and support a hydraulic head of 18 cm above the filter. To support the column, another square shape base was used with a circular hole at the centre with the same internal diameter of the filtration column. Some screws were used to fix and tighten the filtration column with the square base. Water was pumped into the top of the filter column with a water pump. There was a valve at a height of 18 cm of the cylinder which is able to stop the pump automatically when the head above the filter exceeded 17 cm.

A suitable place was chosen beside the lake to install the field experiment setup. At the beginning of the experiment, the ground was leveled with some gravel and a tank with a height of 35.6 cm and width of 97.8 cm and a capacity of

543 L was placed above it. Then, the tank was filled with 300 L of lake water with the help of a pump. The whole filtration unit was placed on a flotation base made of polystyrene. There was a circular hole with 20 cm diameter at the centre with the objective to float the filtration unit in the water, as well as to pass the filtered water into the tank again. Finally, the whole filtration unit with the flotation base was placed on the water in the tank. Four submergible pumps inside the tank were used for continuous water circulation with the objective to filter all water inside the tank. The pump used to supply water through the filtration unit was operated with a flow rate of 7.47 L/min and 3.8 L/min depending upon the flow of water through the filter. To operate the pumps, power was supplied from the nearest home beside the lake. The whole unit was covered by a plastic cover in order to protect it from rain water or any other external damage. Figures 1 and 2 show the photos of the filtration unit and field experiment setup, respectively.


(a) (b)

Figure 1: (a) Filtration setup; (b) In-situ field experiment setup

Fourteen experiments were carried out beside the lake for an average of seven days' duration for each experiment from June to October, 2015. Water samples were collected to measure turbidity, TP, dissolved phosphorus (DP), total N, COD, nitrate, total suspended solids (TSS), particle size distribution every day during each experiment. Similarly, flow rates through the filter, and head development with time were also measured every day. Samples were collected for phytoplankton analysis at the beginning and end of each experiment. Turbidity was measured by a turbidity meter and TP and different forms of N were measured using test kits of HACH Co. Samples for phytoplankton analyses were sent to an analytical laboratory of the University of Montreal, Quebec, Canada.

Aquatic organisms provide the basis for aquatic food chain and play an important ecological role in aquatic ecosystems. They are crucially dependent on nutrients present in the water. But, excess amounts of nutrients in the water help promote excessive growth of aquatic organisms and thus degrade the water quality. So, the best results were chosen based on the decrease of water quality parameters (i.e., concentration of TP, turbidity, TN, COD etc.) to acceptable levels to protect aquatic life within the minimum period of time.

### 2.2 Filter media

A nonwoven filter was used as a filter medium during the filtration process. Geotextiles of distinct apparent opening sizes and materials (TE-GTX300, TE-GTN300, TE-GTN350 and TE-GTN340), custom developed and fabricated by Titan Environmental Containment Ltd –Manitoba, Canada were used in several layers (4 and 5 layers) in different combinations as filter media during the field experiments after preliminary tests. The materials used to produce geotextiles were staple fiber polypropylene for TE-GTN series and continuous fiber polyester for TE-GTX series. The apparent opening sizes and thickness of the geotextiles were 110 μm, 90 μm and 75 μm and 0.4 cm, 0.3 cm and 0.2 cm respectively. The filters were cut in circular shapes with a diameter of 22 cm before using as filter media. A total of fourteen experiments were carried out to find out the best combination providing maximum efficiency in removing nutrients and suspended solids.

## 3. RESULTS AND DISCUSSION

The tests with different combinations of geotextiles conducted beside the lake at different initial water conditions are shown in Table 1. While using a combination of 4 or 5 layers, the geotextile with higher opening size was kept on top because it would retain larger suspended particles in the filter water. Based on the initial turbidity values, the experiments were classified into four different categories. These are shown in Table 2.

Table 1: Geotextile combination with initial water condition of each experiment

| Expt. no. | Sample collection date | Geotextile combination | Initial water conditions | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Turbidity (NTU) | TSS (mg/L) | TP (mg/L) | COD (mg/L) | TN (mg/L) | Nitrate (mg/L) |
| 1 | 2/7/2015 | 4 x 110 µm | 4.01 | 8.20 | 0.08 | 25.80 | 0.99 | 0.17 |
| 2 | 9/7/2015 | 4 x 110 µm | 8.29 | 7.75 | 0.06 | 13.00 | 0.99 | 0.14 |
| 3 | 17/7/2015 | 1 x 110 µm + 3 x 90* µm | 8.19 | 9.25 | 0.05 | 27.50 | 4.20 | 0.14 |
| 4 | 23/7/2015 | 1 x 110 µm + 3 x 90* µm | 17.30 | 7.67 | 0.04 | 27.10 | 2.85 | 0.19 |
| 5 | 31/7/2015 | 1 x 110 µm + 4 x 90* µm | 19.01 | 6.83 | 0.07 | 14.60 | 1.09 | 0.19 |
| 6 | 6/8/2015 | 1 x 110 µm + 4 x 90* µm | 38.20 | 8.75 | 0.04 | 20.65 | 0.92 | 0.16 |
| 7 | 14/8/2015 | 1 x 110 µm + 4 x 90 µm | 14.25 | 6.00 | 0.06 | 27.35 | 0.63 | 0.15 |
| 8 | 21/8/2015 | 1 x 110 µm + 4 x 90 µm | 7.28 | 5.33 | 0.07 | 29.15 | 0.61 | 0.17 |
| 9 | 28/8/2015 | 2 x 110 µm + 3 x 90 µm | 16.98 | 10.33 | 0.07 | 34.70 | 1.00 | 0.12 |
| 10 | 4/9/2015 | 2 x 110 µm + 3 x 90 µm | 5.20 | 5.33 | 0.06 | 24.40 | 0.69 | 0.12 |
| 11 | 11/9/2015 | 2 x 110 µm + 3 x 75 µm | 9.15 | 9.00 | 0.06 | 8.02 | 0.53 | 0.13 |
| 12 | 15/9/2015 | 4 x 110 µm + 1 x 75 µm | 8.86 | 7.67 | 0.06 | 7.97 | 0.64 | 0.15 |
| 13 | 25/9/2015 | 4 x 110 µm + 1 x 75 µm | 10.39 | 8.00 | 0.06 | 10.50 | 0.96 | 0.17 |
| 14 | 23/10/2015 | 2 x 110 µm+2 x 90 µm+1 x 75 µm | 10.71 | 7.67 | 0.05 | 14.30 | 1.22 | 0.16 |

Table 2: Categorization of performed experiments based on initial turbidity

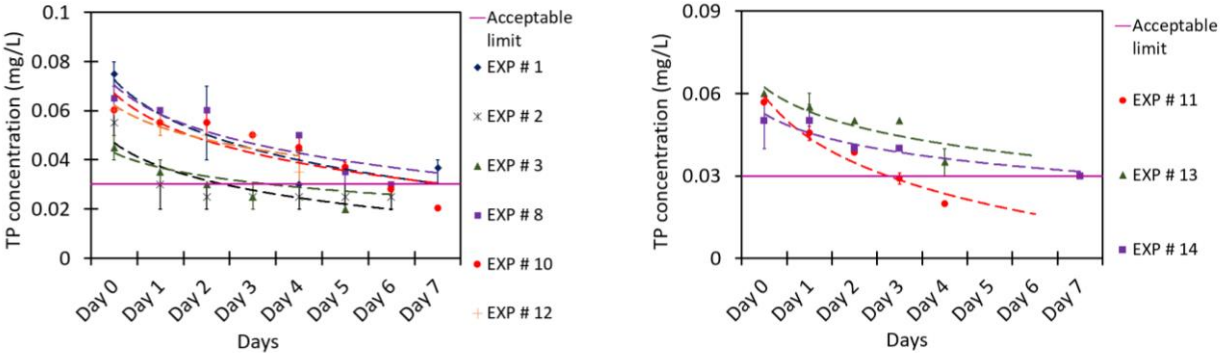
| Category | Turbidity range | Experiment no. |
|---|---|---|
| 1 | >4 to ≤ 9 | 1,2,3,8,10,12 |
| 2 | >9 to ≤ 14 | 11,13,14 |
| 3 | >14 to ≤ 19 | 4,5,7,9 |
| 4 | > 19 | 6 |

### 3.1 TP removal

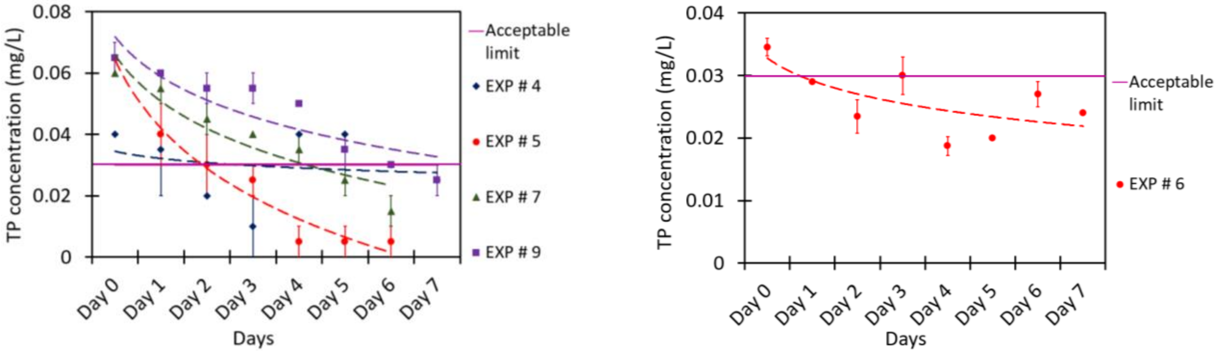
According to the MDDEP (2009), the maximum allowable range for total phosphorus concentration is 0.03 mg/L in order to reduce algal growth and eutrophication. For every experiment, both TP and DP were analysed and negligible DP was found in the water samples. Figure 2 shows the removal trend of TP for different experiments carried out in different turbidity ranges. The initial total phosphorus concentration for these experiments varied from 0.08 to 0.04 mg/L. From Figure 2 (a), experiments 2, 3 and 10, Figure 2 (b), experiment 11, Figure 2 (c), experiments 4, 5 and 7 and Figure 2 (d), experiment 6 reached the maximum allowable range. The minimum time to achieve the concentration varied from 1 to 7 days. From the results, the minimum times were 7 days for turbidity range 4 – 9 NTU (expt. 10), 3 days for turbidity range 9 – 14 NTU (expt. 11), 2 days for turbidity range 14 – 19 NTU (expt. 5) and 1 day for turbidity higher than 19 NTU (expt. 6). Based on maximum regression coefficient value, a logarithmic correlation was plotted in the case of phosphorus removal.

### 3.2 Turbidity removal

The maximum allowable turbidity value for surface water is 10 NTU suggested by Environment and Climate Change, Canada (2015). Figure 3 shows the removal trends of turbidity for different experiments with different initial turbidity ranges. The initial turbidities were below 10 NTU for all experiments in the turbidity range 4 – 9 NTU. In other cases, initial turbidity was reduced to below 10 NTU on the 1st day of filtration. Only experiment 6 where the initial turbidity was 38 NTU, took 1 more day to lower the turbidity to the acceptable limit. In this case, an exponential correlation was observed.

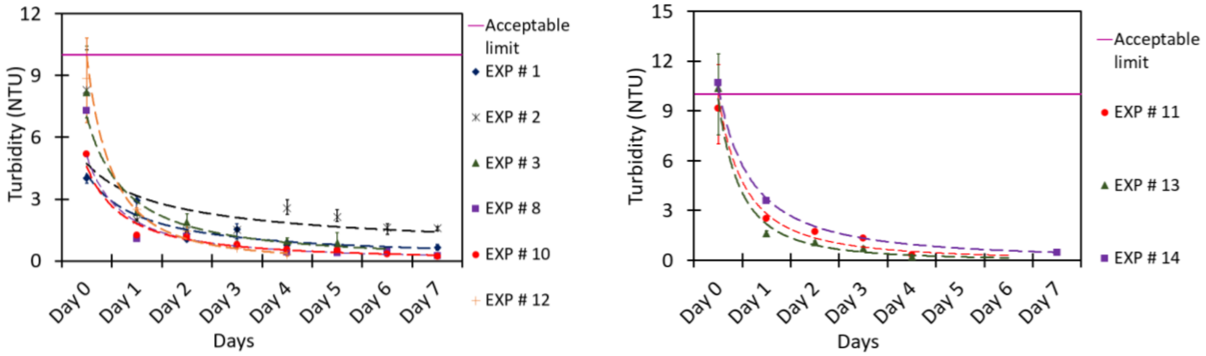


(a) Initial turbidity: >4 - ≤ 9 NTU (b) Initial turbidity: >9 - ≤ 14 NTU

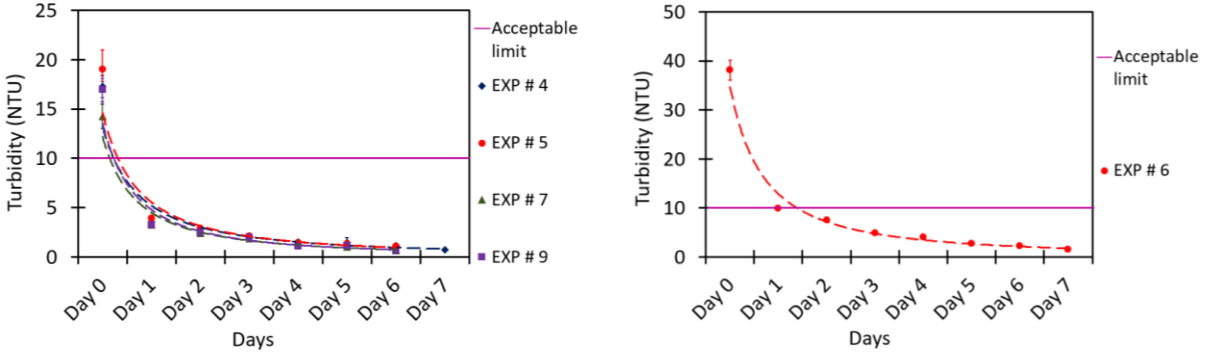


(c) Initial turbidity: >14 - ≤ 19 NTU (d) Initial turbidity: >19 NTU

Figure 2: Removal trends of TP for different experiments carried out for different turbidity ranges



(a) Initial turbidity: >4 - ≤ 9 NTU (b) Initial turbidity: >9 - ≤ 14 NTU

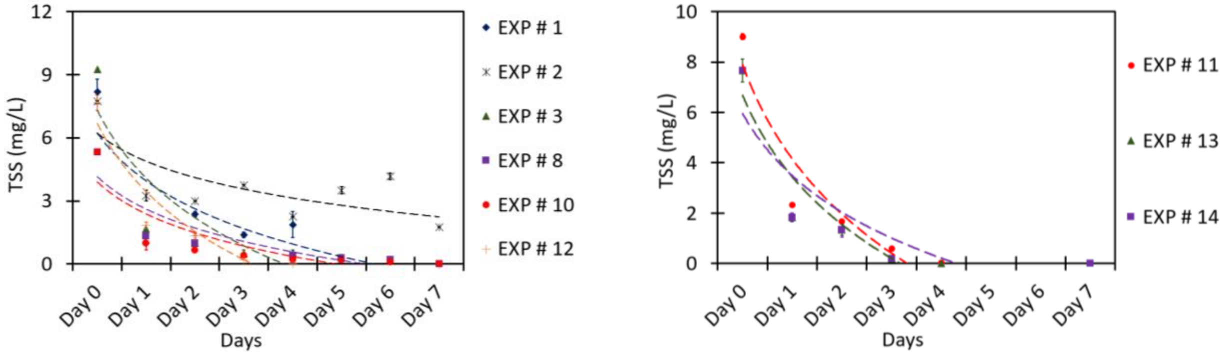


(c) Initial turbidity: >14 - ≤ 19 NTU (d) Initial turbidity: >19 NTU

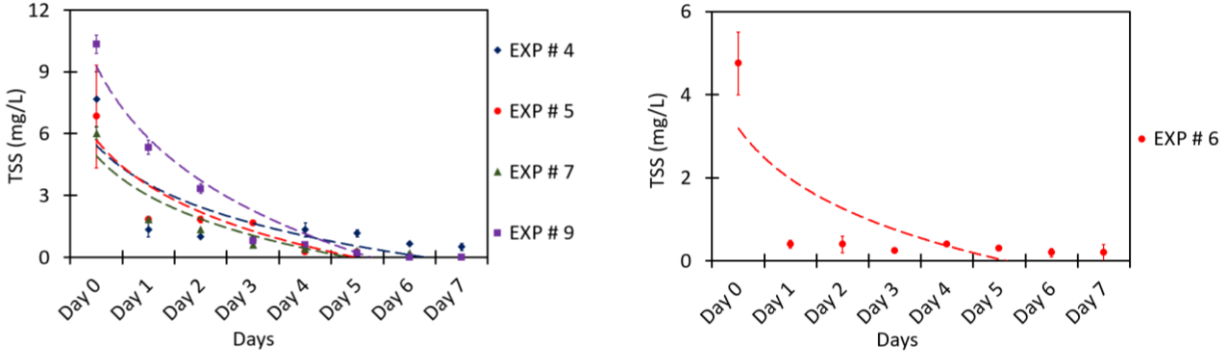
Figure 3: Removal trends of turbidity for different experiments carried out for different turbidity ranges

### 3.3 TSS removal

MDDEP (2009) suggested that in clear water, the concentration of TSS should not exceed 25 mg/L. Figure 4 shows the removal trend of TSS for different experiments with different initial turbidity ranges. In this study, the maximum TSS value among all the experiments was 10.3 mg/L. The value became almost zero at the 5th day of filtration for most of the experiments. In this case, all graphs were plotted using a logarithmic correlation based on higher regression coefficient values.



(a) Initial turbidity: >4 - ≤ 9 NTU (b) Initial turbidity: >9 - ≤ 14 NTU

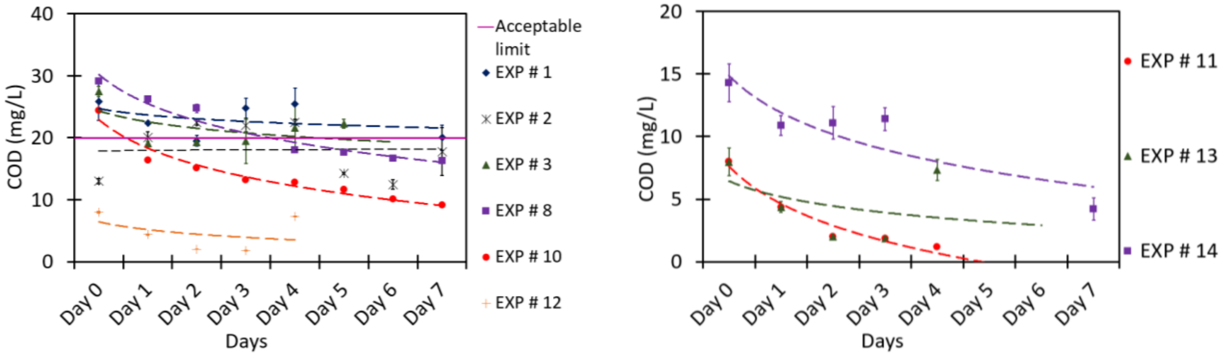


(c) Initial turbidity: >14 - ≤ 19 NTU (d) Initial turbidity: >19 NTU

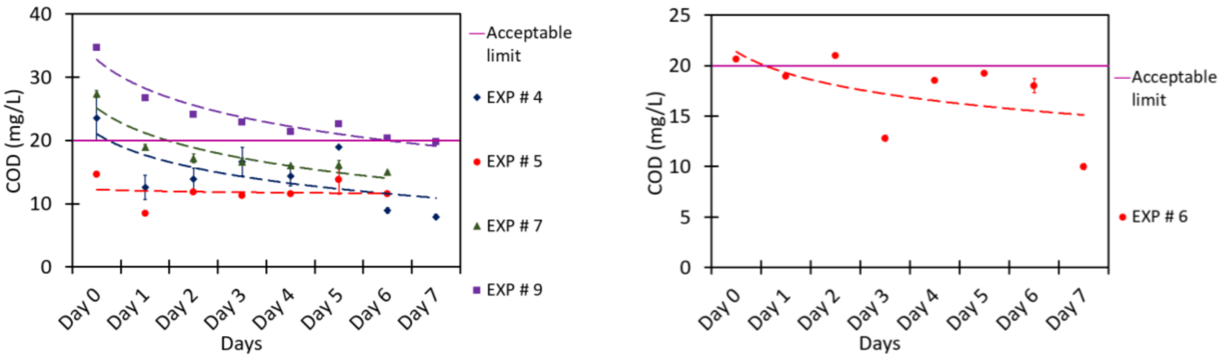
Figure 4: Removal trends of TSS for different experiments carried out for different turbidity ranges

### 3.4 COD removal

In unpolluted waters the concentrations of COD should be less than 20 mg/L (Chapman & Kimstach 1996). Figure 5 shows the removal trends of COD for different experiments with different initial turbidity ranges. The initial COD concentration for experiments 2, 5, 11, 12, 13 and 14 was below 20 mg/L and for the rest, it varied from 22 to 30 mg/L. Among the experiments at day 4, the COD concentration was reduced to 20 mg/L for both experiments 3 and 8. But, for experiments 4, 6 and 10, it was below 20 mg/L at day 1 while for experiments 7 and 9, it took 2 and 6 days to reduce the COD concentration. Similar to TSS removal, all graphs were plotted using a logarithmic correlation.



(a) Initial turbidity: >4 - ≤ 9 NTU (b) Initial turbidity: >9 - ≤ 14 NTU

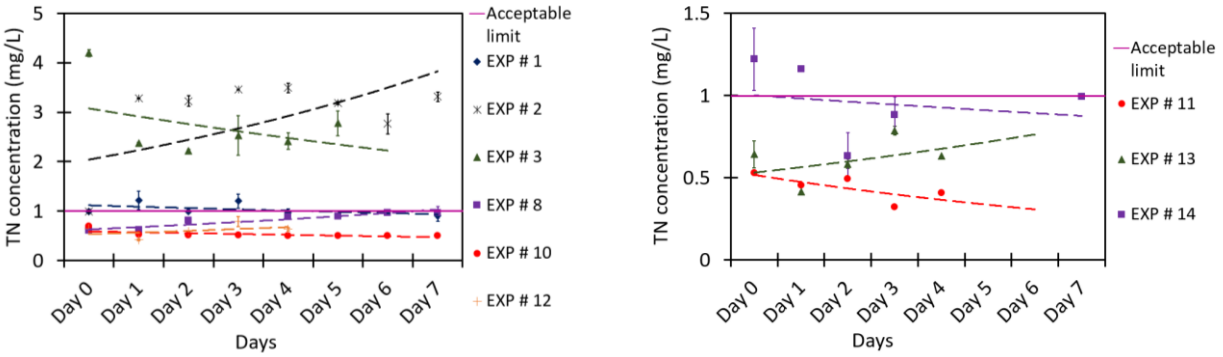


(c) Initial turbidity: >14 - ≤ 19 NTU (d) Initial turbidity: >19 NTU

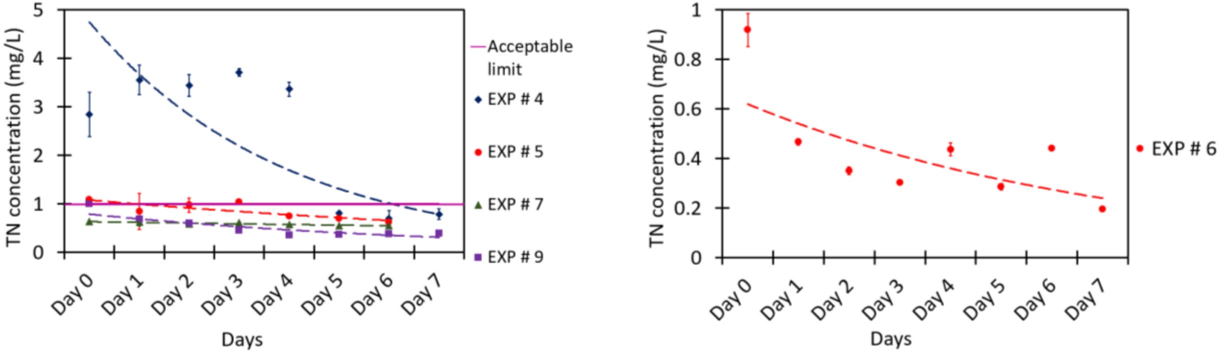
Figure 5: Removal trends of COD for different experiments carried out for different turbidity ranges

### 3.5 TN removal

Generally, total nitrogen in the lake water is the total N in the $NH_4^+$ form, the oxidized forms, $NO_2^-$ and $NO_3^-$, and N bound to suspended particles and soluble organic forms. Figure 6 shows the removal pattern of TN for experiments with different initial turbidity ranges. The initial total nitrogen concentration for experiments 3, 4, 5, 9 and 14 were above the allowable limit (1 mg/L) as suggested by Environment Canada (2014) among the 14 experiments. At the end of experiment 3, the concentration of total nitrogen didn't reduce to 1 mg/L but for the rest, it was reduced to the allowable limits during the filtration.



(a) Initial turbidity: >4 - ≤ 9 NTU (b) Initial turbidity: >9 - ≤ 14 NTU



(c) Initial turbidity: >14 - ≤ 19 NTU (d) Initial turbidity: >19 NTU

Figure 6: Removal trends of TN for different experiments carried out for different turbidity ranges

### 3.6 Best geotextile combinations for different initial conditions

Table 3 shows the geotextile combinations and the required duration of filtration to achieve the optimum results for different initial turbidity ranges at a glance. The required filtration duration was less for the higher initial turbidity values because for higher initial turbidities, more layers of smaller pore sized geotextiles were used, which accelerated the filtration and hence reduced the nutrients quickly. Previous studies showed that removal of suspended particles considerably improved the water quality for the cases where nutrients were contained in the suspended particles (Inoue et al. 2009). So, the filter combination, which is capable of removing maximum suspended particles, should show the best efficiency in removing the nutrients. The minimum pore size of geotextile filters used in the experiments conducted with initial turbidity ranging from 9 to 14 NTU was 75 µm and for the rests it was 90 µm. Hence, the experiment which had the highest percentage of particles having size more than 75 µm or 90 µm, should remove maximum nutrients and that's why, these 4 experiments provided maximum efficiency among all experiments.

Table 3: Best geotextile combinations for different ranges of initial turbidities

| Initial turbidity (NTU) | Expt. no. | Combination used | Duration of filtration (days) |
|---|---|---|---|
| > 4 - ≤ 9 | 10 | 2 x 110 µm + 3 x 90 µm | 7 |
| > 9 - ≤ 14 | 11 | 2 x 110 µm + 3 x 75 µm | 3 |
| > 14 - ≤ 19 | 5 | 1 x 110 µm + 4 x 90 µm | 2 |
| > 19 | 6 | 1 x 110 µm + 4 x 90 µm | 1 |

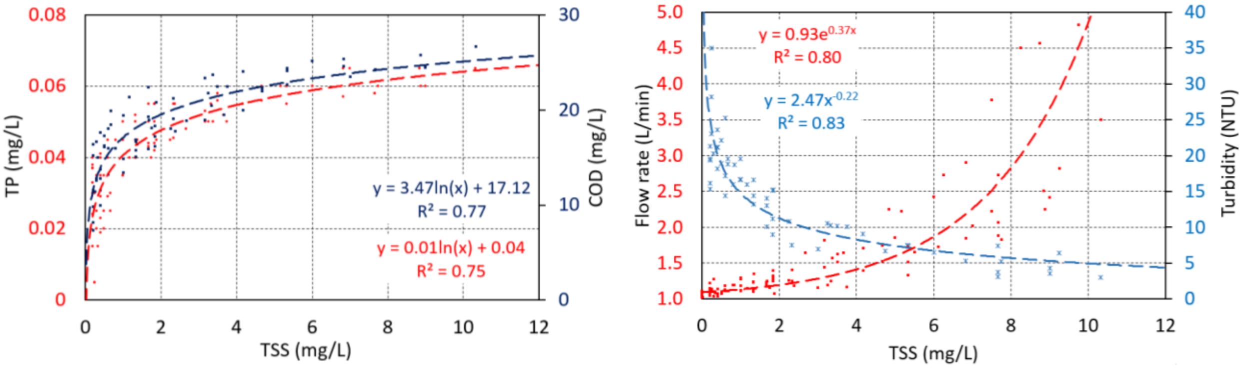
### 3.7 Correlation among different parameters

#### 3.7.1 TP and COD as a function of TSS

As mentioned in section 3.1, as there was no DP in the water samples, it was conceivable that removing suspended solids can accelerate the reduction of TP and COD from water. Figure 7 (a) shows the TP and COD concentration as a function of TSS. A good logarithmic correlation was found between these parameters with a regression coefficient of 0.75 and 0.77. The graph showed that TP and COD reduced with the removal of TSS which indicated that most of the TP and COD contents in the water were associated with SS and hence removal of SS significantly improved the water quality.

#### 3.7.2 Turbidity and flow rate as a function of TSS

The higher the amount of SS, the higher the turbidity value and the lower the flow rate through the filters. Figure 7 (b) shows the exponential correlations among turbidity, flow rate and TSS with regression coefficient higher than 0.8.



(a) TP and COD as a function of TSS (b) Flow rate and turbidity as a function of TSS

Figure 7: Correlation among different parameters

#### 3.7.3 Flow rate as a function of filters

Figure 8 shows the flow rate through the filter media as a function of filter for the experiments. Experiments 1 and 11 have been exempted as they were carried out at different pump flow rates. Generally, the flow rate decreased with an increased number of geotextiles though the flow rate also varied with the pore size of the geotextile filters. Figure 8 also shows that the flow rate after clogging (i.e., when the water holder of the filtration setup was fully filled with water) was almost the same for all experiments.

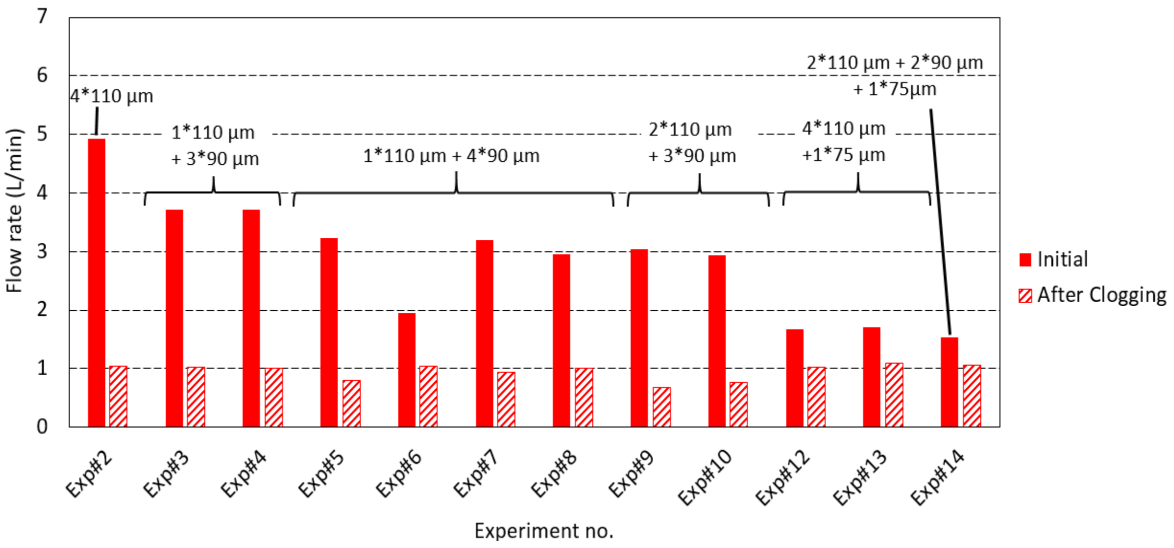


Figure 8: Flow rate as a function of filter

### 3.8 Plankton analysis results

It has been found that at the end of filtration, several phytoplankton species were removed. The quantities of some species increased and a few new species were developed throughout the filtration. Some cyanobacteria species produce a group of toxins named microcystins (Butler et al. 2009). The most common toxin-producing genera in fresh water are *Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Microcystis*, *Nodularia* and *Planktothrix* (Health & Welfare Canada 2012). Among them, cyanotoxins from *Aphanizomenon*, *Cylindrospermopsis*, and *Microcystis* genera were found in the water samples from Lake Caron. More than 90% of the cyanobacteria were removed for all four experiments. Table 4 shows the results of phytoplankton analysis for experiments 10, 11, 5 and 6 respectively.

Table 4: Results of phytoplankton analysis

| Phylum (Common name) | Name | Density (µg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Expt. # 10 | | Expt. # 11 | | Expt. # 5 | | Expt. # 6 | |
| | | Before | After | Before | After | Before | After | Before | After |
| Cyano-bacteria (blue-green algae) | *Dolichospermum flos-aquae* | 0 | 0 | | | 259.84 | 2.54 | 202.10 | 0 |
| | *Aphanothece bachmannii* | 4.71 | 0.99 | 15.08 | 0.71 | 10.56 | 1.37 | 9.90 | 5.37 |
| | *Chroococcus minimus* | 4.60 | 1.15 | 7.67 | 0.01 | 5.37 | 0 | 6.14 | 4.60 |
| | *Chroococcus prescottii* | 5.32 | 0 | 8.23 | 0 | 452.51 | 0 | 84.85 | 69.81 |
| | *Microcystis aeruginosa* | 5953.42 | 85.93 | 6063.90 | 36.83 | 466.45 | 21.48 | 1515.97 | 49.10 |
| | *Pseudanabaena limnetica* | 0 | 0 | 0 | 0 | 0.19 | 0 | 0.25 | 1.26 |
| | *Cylindrospermum stagnale* | 7.68 | 0 | 0 | 0 | 0 | 0 | 45.93 | 0 |
| | *Woronichinia naegeliana* | 0 | 0 | 14.90 | 0 | 0 | 0 | 0 | 36.09 |
| | Total | 5975.73 | 88.07 | 6109.78 | 37.55 | 1194.92 | 25.39 | 1865.14 | 166.23 |
| | **Removal (%)** | | **98.5** | | **99.3** | | **97.8** | | **91.1** |

## 4. CONCLUSIONS

In this study, nonwoven geotextiles were used as filter media in a small scale in-situ filtration experiments to reduce the contaminants in lake water. The results obtained from the experiments showed that geotextiles can work as an effective filter media to treat a eutrophic lake water in terms of removing total suspended solids, turbidity, phosphorus, other nutrients, and cyanobacteria within a shorter period of time. SS removal improved the water quality as strong correlations were found among SS with TP, COD and turbidity. This study enables not only the design of filtration systems for different cases, but also provides guidelines for full scale implementation. The test results also showed that by implementing this technique, it may be possible to make the lake safe and clean for public use for recreation activities.

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## REFERENCES

Chambers, P. A. (1990). Reduction of phosphorus and chlorophyll α concentrations following $CaCO_3$ and $Ca(OH)_2$ additions to hypereutrophic figure eight lake, Alberta. *Environmental Science and Technology, 24*: 1252-1258.

Cooke, G. D., Welch, E. B., Martin, A. B., Fulmer, D. G., Hyde, J. B., & Schrieve, G. D. (1993). Effectiveness of Al, Ca, and Fe salts for control of internal phosphorus loading in shallow and deep lakes. Paper presented at the *Proceedings of the Third International Workshop on Phosphorus in Sediments*, 323-335.

Franks, C. A., Davis, A. P., & Aydilek, A. H. (2012). Geosynthetic filters for water quality improvement of urban storm water runoff. *Journal of Environmental Engineering, 138*(10): 1018-1028.

Harper, D. (1992). *Eutrophication of Freshwaters: Principles, problems and restoration* . Suffolk: Springer-science business media, b.v.

Health & Welfare Canada, (2012). *Guidelines for Canadian Recreational Water Quality (*3rd ed). Ottawa: Authority of the Minister of National Health and Welfare.

Inoue, T., Fukue, M., Mulligan, C. N., & Uehara, K. (2009). In situ removal of contaminated suspended solids from a pond by filtration. *Ecological Engineering, 35*(8): 1249-1254.

Mccuen, R., & Agouridis, C. (2007). Water quality engineering in natural systems. *Jawra Journal of the American Water Resources Association, 43*(2): 559.

Moslemizadeh, E. (2009). *The use of geotextiles for the treatment of surface water,* M.A.Sc. thesis, Concordia University, Montreal, Canada.

Mulligan, C. N., Yong, R. N., & Gibbs, B. F. (2001). An evaluation of technologies for the heavy metal remediation of dredged sediments. *Journal of Hazardous Materials, 85*(1): 145-163.

Mulligan, C.N., Ramalingaih, T.N., Fukue, M. (2011). Removal of suspended solids and phosphorus from a eutrophic lake. *Environmental Pollution and Remediation,* Ottawa, Ontario, Canada, Aug. 17-19, 2011.

Quaranta, J. D., & Tolikonda, R. (2011). Design of non-woven geotextiles for coal refuse filtration. *Geotextiles and Geomembranes, 29*(6): 557-566.

Reddy, K., Fisher, M., Wang, Y., White, J., & James, R. T. (2007). Potential effects of sediment dredging on internal phosphorus loading in a shallow, subtropical lake. *Lake and Reservoir Management, 23*(1): 27-38.

Ritter, Solomon, K., Sibley, P., Hall, K., Keen, P., Mattu, G., Linton, B., & Len. (2002). Sources, pathways, and relative risks of contaminants in surface water and groundwater: A perspective prepared for the Walkerton inquiry. *Journal of Toxicology and Environmental Health Part A, 65*(1): 1-142.

Tota-Maharaj, K., Grabowiecki, P., Babatunde, A., & Coupe, S. J. (2012). The performance and effectiveness of geotextiles within permeable pavements for treating concentrated storm water. *International Journal of Water Technology, 2:* 207-216.