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GEOTEXTILE FILTRATION FOR IMPROVING SURFACE WATER QUALITY OF EUTROPHIC LAKES

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Abstract: Eutrophication and impaired surface water quality are challenging problems due to the restriction in using many lakes and ponds for drinking and public recreational purposes. Lake Caron, located in the municipality of Sainte-Anne-des Lacs in Quebec, is one such lake hit by algal blooms every year. This *on-site* study investigates the use of a floatable geotextile filtration unit for removing suspended particles, nutrients and algae to improve the lake water quality. Different combinations of three non-woven geotextiles (GTX-300, GTN-300, and GTN-350A), differing in apparent opening sizes, were tested with lake water and monitored real time for surface water quality parameters with the help of a YSI EXO2 probe. Water quality was assessed by considering parameters such as suspended solids (SS), turbidity, total phosphorus (TP) and nitrogen (TN), and chlorophyll and blue green algae-phycocyanin (BGA-PC) concentrations in the lake water. Effective removal of SS by filtration resulted lowering TP concentration in the lake water, close to the Quebec provincial norms set for the protection of aquatic life. Overall, the filtration tests resulted in 85-98% turbidity, 89-99 % SS, 60-82% TP, 25-50% (TN), 71-78 % chlorophyll and 93-97% BGA-PC removal.

***Key Words**:* Geotextiles, Filtration, Suspended solids, Phosphorus, and Eutrophication

1 INTRODUCTION

Eutrophication is an outcome of enrichment of nutrients, especially phosphorus and nitrogen, in aquatic systems and is characterized by dense algal blooms in freshwater, especially by cyanobacterial blooms (blue–green algae) (Correll 1998, Reeders et al. 1998). It poses serious threats to water quality, aquatic biodiversity, public health, and social life. The major consequences of eutrophication in surface water include high turbidity, reduced aquatic biodiversity, low dissolved oxygen and toxin release from certain types of cyanobacteria (blue green algae) (Shinder 2006, Chislock et al. 2013). Phosphorus (P) is considered as a growth limiting nutrient for primary production and its excess concentration can result in harmful algal blooms in lakes (Lewis and Wurtsbaugh 2008).

Lake Caron (Quebec, Canada) is a shallow artificial lake impacted by algal blooms every summer, and has been on the list of the MDDEP (Ministère du Développement Durable de l'Environnement et des

Parcs (MDDEP), of eutrophic lakes in Quebec since 2008. The lake has been exposed multiple times to massive algal blooms in the past. In order to protect the inhabitants around the lake from cyanobacterial toxins, MDDEP restricted the use of lake for swimming. Many times, the total phosphorus concentration in the lake water was above the lower limit (30 µg/L) set for eutrophic lakes by the MDDEP. The considering factors for eutrophication in Lake Caron include surface runoff from the forest area around the lake, fertilizer use and septic tank discharges in the past, and sediment phosphorus release (Karim et al. 2013; Sarma et al. 2016).

Many remediation techniques have been practiced so far for the restoration of eutrophic lakes, which include source control, application of chemicals (use of alum, calcite, chemicals, adsorbents, algaecide)(Cooke et al. 1993; Xie et al. 2014), sediment dredging (Reddy et al. 2007) and capping with clean sediments. However, high transportation costs and lack of disposal sites associated with sediment dredging, and toxicity problems associated with chemical additions (Cooke et al. 1993) etc., restrict the use of these technologies for remediating small and shallow eutrophic lakes. Therefore, economical and environmentally acceptable restoration alternatives must be identified and tested for mitigating eutrophication in lakes.

Nutrients that enter into surface water adsorb on to fine suspended particles including particulate organic matter, and sediment fines, and eventually settle on to the bottom sediments (Mulligan et al. 2009; Inoue et al. 2009). In eutrophic lakes, microbial degradation of algal biomass and other organic materials create anaerobic conditions in the bottom sediments which results in the release of sediment phosphorus in to the overlaying water (Chislock et al. 2013). Therefore, removing algal biomass together with fine sediment particles, and suspended particulate organic matter could reduce the total phosphorus in the water column (Mulligan et al. 2009, Inoue et al. 2009, Sarma et al. 2016).

Filtration is a solid –liquid separation technology, which separates solid particles from a liquid stream based on the differences in particle size. Geotextiles are strong, robust, and chemically and microbial resistant materials that are used for many environmental applications such as drainage, solid separation, filtration and soil reinforcement (Franke et al. 2012; Tota-Maharaj et al. 2012). Recent research studies addressed potential feasibility of using on-woven geotextiles as filter media for removing suspended solids, nutrients, heavy metals and organic matter from surface and storm water (Mulligan et al. 2009, Sarma et al. 2016, Frank et al. 2012, Inoue et al. 2009).

The present study is an extension of on-site filtration experiments that were conducted last year, and was to evaluate the reliability of geotextile filters for improving Lake Caron water quality under new lake circumstances with different combinations of selected non-woven geotextiles, prior to future in-situ filtration tests. The objective was to determine also the effect of sediment resuspension on water quality by conducting filtration tests with sediment to simulate actual lake conditions.

2 MATERIALS AND METHODS

2.1 Study Area

Lake Caron, an artificial, shallow, eutrophic lake, located in the municipality of Sainte-Anne –des-Lacs was selected for this study. The approximate lake surface area is 35,300 m^2 with average water volume of 46,400 m^3. The maximum and average depths are 2.6 and 1.4 m, respectively. Main sources of water in Lake Caron include precipitation, surface run off and snow. Sloped land with wild trees covers one side of the lake and surface runoff from this side significantly increases the load of nutrients and vegetative organic materials into the lake. In the past, trees on the shore were chopped down into the lake to expand the lake and thus this resulted in high organic matter in some parts of the lake. Lake Caron sediments in some places are rich in nutrients and organic matter. Sediment phosphorus concentration in some parts of the lake varied between 908-1310 mg/kg. Figure 1a shows algal blooms that occurred in Lake Caron in 2016.

2.2 Onsite floating filtration setup

Filtration experiments were performed in a plastic tank (35.6 cm height and 543 L volume) placed on the ground levelled with gravels, near to the lakeshore. During the summer, algal blooms in the lake often accumulated at station 4 by the action of wind and currents. Therefore, this station was selected for the onsite and future in-lake experiments. In this study, two different kinds of filtration tests were performed: (i) filtration with lake water alone, and (ii) filtration with lake water and sediment. The filtration unit consists of a cylindrical filtration column, made of plexi glass, of 20 cm internal diameter and 25 cm in height, and a square shaped base, as a filter holder, with a circular hole at the centre with the exact diameter of the filtration column (20 cm). The filtration column was placed on the base to hold water and support a hydraulic head of 18 cm above the filter. Screws were used to fix and tighten the filtration column with the square base. A water level controller, which can turn on and off the pump automatically, was used at a height of 18 cm of the filtration column to avoid water overflow. For the filtration tests, the tank was first filled with about 300 L of lake water using a submersible pump. After this, the filtration unit, with selected geotextile filters, was placed on a piece of polystyrene foam to float the entire unit on the tank water. A circular hole with a 20 cm diameter was made in the centre of the foam to pass the filtered water into the tank.

For the filtration tests with sediment, the surface sediment was sampled at station 4 using a grab sampler and then stored in a closed container at 4^{o}C for about 2 weeks. A calculated quantity of lake surface sediment was added into the tank filled with lake water to lay sediment over the bottom of the tank. Since, the addition of sediments resulted high initial turbidity, 2-3 days of settling time was given prior to starting the filtration tests in such cases. Four submersible pumps were used in the tank continuously circulate the water in the tank with the objective of filtering all water in the tank. However, three pumps with a very low mixing speed were used in the cases of the filtration tests with lake sediment to avoid sediment resuspension. A tarpaulin was used to cover the whole filtration set-up to protect it from rain and other external influences. A YSI EXO2 multiparameter (Hoskin) probe was placed in the tank to measure the physical and biological parameters of the lake water.

Figure. 1: (a) Algal bloom in Lake Caron (2016); (b) On-site floating geotextile filtration unit

2.3 Filter Media

Non-woven geotextile filters (TE-GTX 300, TE-GTN 300, and TE-GTN 350) custom developed and received from Titan Environmental and Containment Ltd. MB, were used in this study. Different combinations of these filters, with varying numbers of filters (4-5), were tested in the field test. Table 1 shows some of the properties of selected geotextiles used in this study. The filter selection, combination, and number of layers were based on the previous field tests. The TE- GTX 300 filter is made of continuous filament polyester (PET) with an apparent opening size of (AOS: 110 µm) and has a characteristic white color that enables visual inspection of the filter for clogging and to take the decision of when to change the filters. The filters TE-GTN 300 (AOS: 90µm) and TE-GTN 350-A (AOS: 75 µm) are of black color and made of 100% virgin staple fiber polypropylene. The filters were cut in a circular shape with a 22 cm diameter and washed with deionized water overnight before placing them on the filter support. The filter with high AOS was placed on the top followed by other filters with decreasing AOS. During each filtration test, clogged filters were replaced by new filters and continued the test until the turbidity was reduced to a desired level. Lake water quality was monitored frequently by analyzing chemical, biological and physical parameters.

Table 1: Characteristics of the non-woven geotextiles used in this study

Filters	Apparent Opening Size (AOS) µm	Flux ($L/m^2/min$)	Mass/unit area (g/m^2)	Material	Permittivity (sec^{-1})
TE-GTX 300	110	3,900	300	PET	1.62
TE-GTN 300	90	3,300	300	PP	0.75
TE-GTN 350 A	75	2,700	350	PP	0.56

PET: Polyester; PP: Polypropylene

2.4 Analysis

Water samples were collected from the tank before, after and during the experiments for measuring turbidity, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), chemical oxygen demand (COD), nitrate (NO_3^-) and phytoplankton. The dissolved forms of phosphorus, nitrogen and COD were also measured. For this, collected water samples were filtered through a 0.45µm syringe filter and the filtrate was used for the analysis. Hatch test kits were used for the analysis of phosphorus, COD, NO_3^- and TN in the water samples. The turbidity of lake water was measured using an Oakton turbidity meter. Physical and biological water quality parameters such as pH, temperature, turbidity, dissolved oxygen (DO), oxidation-reduction potential (ORP), chlorophyll *a* and blue green algae-phycocyanin (BGA-PC) were measured in-situ with the help of YSI EXO2 water quality sonde (Hoskin). The flow rate and head development were measured over time during the experiment.

3 RESULTS AND DISCUSSION

3.1 Water Quality

Table 2 shows the quality of Lake Caron water samples collected from station 4 over the period of July-Sept. 2016. The general water quality parameters used to define the tropical state of a lake are TP, COD, chlorophyll a concentrations and transparency (secchi disk). TP concentration in the lake water (32-50 µg/L) was within the criteria set for eutrophic lakes (30-100 µg/L) by MDDEP and its concentration in the surface water must be less than 30 µg/L in order to control algal growth and protect aquatic organisms (MDDEP). The total dissolved phosphorus (TDP) concentration was between 7-9 µg/L. The pH (6.3-7.4) and DO (7.0-7.9 mg/L) were within the proposed limit to protect the aquatic organisms. The COD must be less than 20 mg/L for unpolluted surface water (Chapman and Kimstach 1996) and it was higher for the lake water. The chlorophyll a concentration in the lake water was close to the lower limit (8-25 µg/L) set for the eutrophic lakes by the MDDEP.

Table 2: Quality of Lake Caron water during July-Sep, 2016

Parameters	Values
TP (µg/L)	32-50
COD (mg/L)	30.8-46
TN (mg/L)	0.82-1.4
Chlorophyll (µg/L)	8-3.4

BGA-PC (µg/L)	0.12-0.7
pH	7.2-6.8
Turbidity (NTU)	10.4-32.4
ORP (mV)	199-351
Temp (°C)	22-29
OD (mg/L)	7-7.9

3.2 Filtration Tests

3.2.1 Filtration of lake water alone

A total of 5 filtration experiments with lake water alone were executed with different filter combinations. However, only the experiments with the best results obtained are discussed here. In this test, a combination of three TE-GTX 300 (110 µm) and a TE-GTN 350 A (75 µm) was used for filtering lake water with an initial turbidity of 14.9 (NTU), TP of 34 µg/L, TCOD (total COD) of 36 mg/L and TN of 0.9 mg/L. The top and bottom filters, and some times the whole filter combination, were replaced by new filters due to clogging during the experiment. The experiment was run for 5 days continuously and showed significant removal for turbidity (97%), TSS (96%), TP (64%), COD (33%), chlorophyll a (84%), BGA-PC (91%). The TP concentration in the filtered water was about 12 µg/L, which is close to the recommended level for TP in surface water needed for aquatic organisms (MDDEP 2012). About 90% of the turbidity was removed within a day and that was reflected in the removal of TP as well (Figure 2a). TP removal was found to be directly related to the turbidity removal, as the TP in the lake water was mainly associated with suspended particles including fine sediments, particulate organic matter and algal biomass. Thus, removing turbidity or suspended particles by filtration can significantly reduce the TP level in the surface water (Sarma et al. 2016).

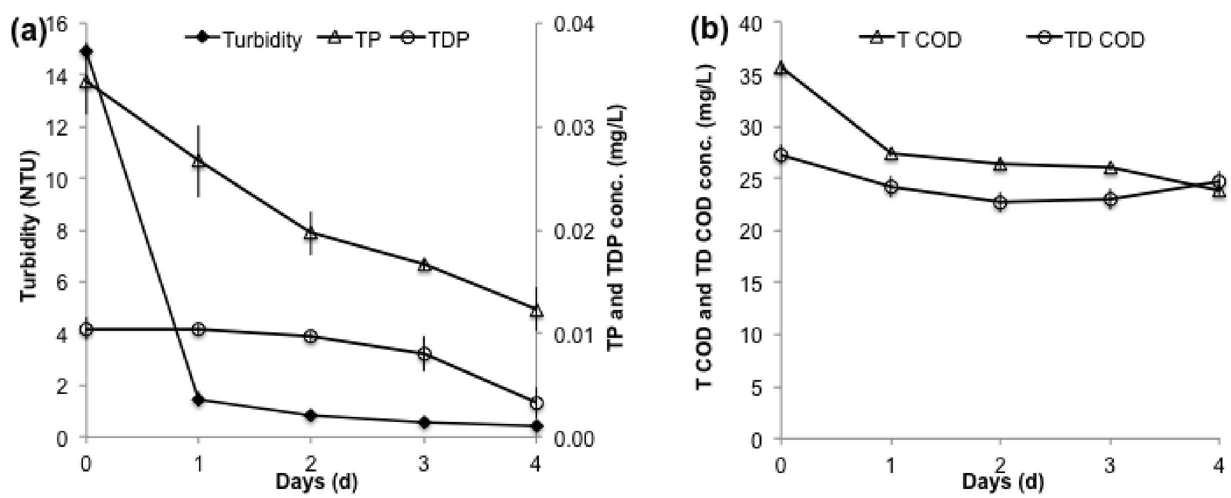

Figure 2: Removal of (a) Turbidity, TP, &TDP and (b) TCOD & TDCOD during filtration using 3xTE-GTX (110 µm) + 1x TE-GTN (75 µm) filter combination.

Figure 2b shows the TCOD concentration in the filtered water over the experimental period. As can be seen in Figure 2b, a reduction in TCOD was observed initially (within 24 h) because of the significant removal of algal biomass and suspended particles that contribute to the turbidity. Thereafter, TCOD concentration remained the same or changed slightly as the COD was mainly due to dissolved organic forms and thus resulted less COD removal (33%) by filtration. Similar to COD, TN concentration decreased (by 25%) on the first day, and then remained almost the same throughout the experiment as TN was mainly in the dissolved form, which is difficult to remove by filtration (Figure 3a). No removal was observed for NO_3^- as most of the NO_3^- was in the dissolved form in the lake water. Besides, an increase in total and dissolved nitrate concentrations (NO_3^- and DNO_3^-, respectively) was observed over time. This could be due to the oxidation of other reduced nitrogen species (NO_2^- and NH_4^+) in the water. During filtration, the ORP increased from 299 to 415 mV due to the dynamic condition in the tank water, created by mixing and the filtration process. The increased ORP and high DO might have helped the oxidation of reduced chemical species in the water. Due to some analytical variability, dissolved nitrate (DNO_3^-) concentrations were found, to be sometimes, slightly higher than the total NO_3^-. Figure 3b shows the removal trend for chlorophyll a and BGA-PC over time. Both chlorophyll a and BGA-PC concentrations were found to decrease, gradually. Another experiment with the same combination of filters with lake water having a high initial turbidity of 32 NTU showed significant removal for TP (59%), turbidity (98%), TCOD (41%), chlorophyll a (77%) and BGA-PC (93%). However, due to the high initial turbidity, more filters were used due to fast clogging.

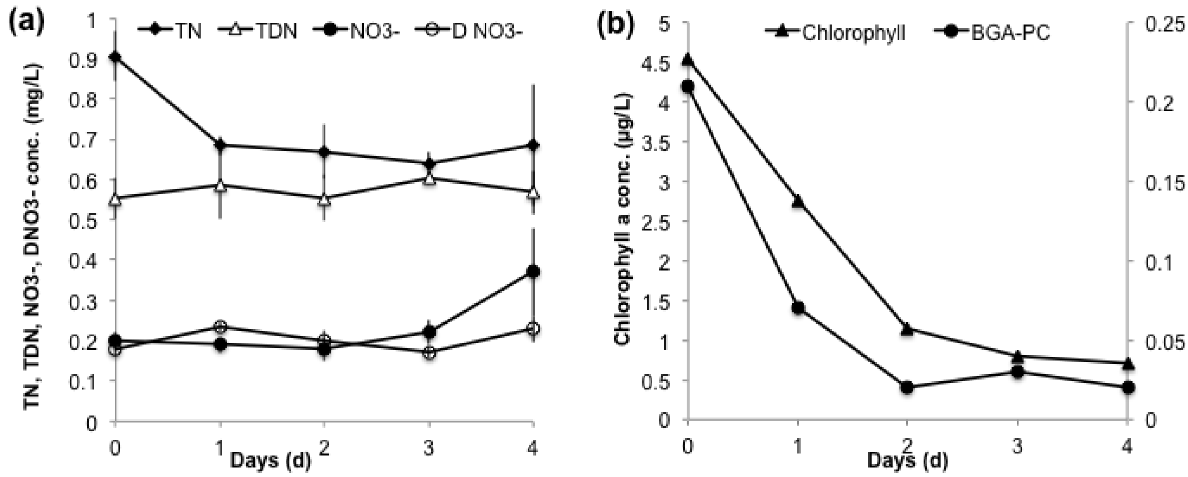

Figure 3: Removal of (a) TN, TDN, NO_3^-, & DNO_3^- and (b) chlorophyll a and BGA-PC during filtration using 3xTE-GTX (110 µm) + 1x TE-GTN (75 µm) filter combination.

3.2.2 Filtration of lake water with sediments

Two filtration experiments were conducted with sediments. For the first test, approximately 3.8 kg dry sediment were added into the tank containing 300 L of lake water, which resulted in a solid content of about 1.25%. The filtration unit was idled for 3 days to settle re-suspended particles, after which filtration was started and continued for 19 days.

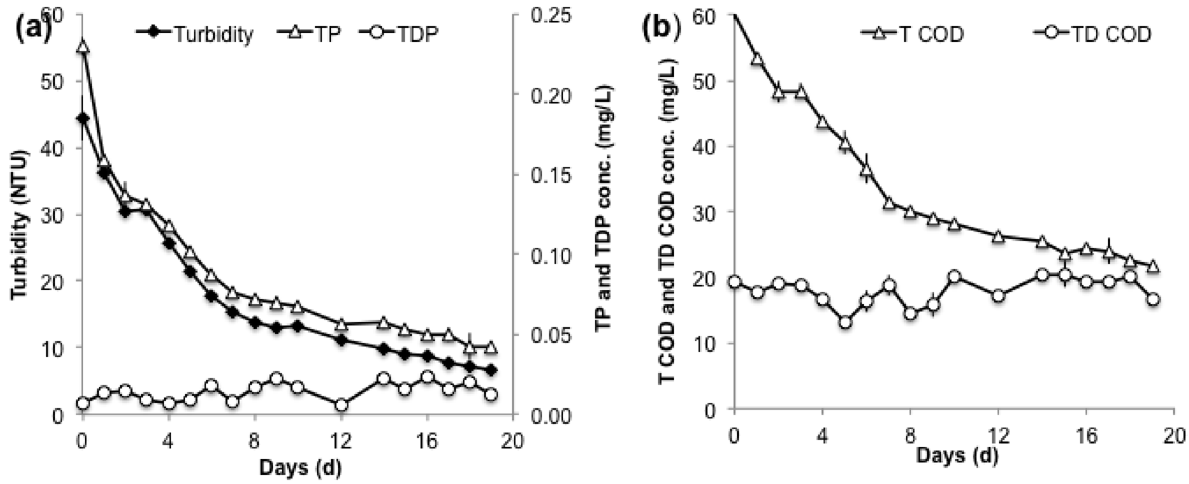

Figure 4: Removal of (a) Turbidity, TP, &TDP and (b) TCOD & TDCOD during filtration using 3xTE-GTX (110 µm) + 1x TE-GTN (75 µm) filter combination.

The initial turbidity, chlorophyll a and BGA-PC concentrations resulting from sediment addition were 202 NTU, 19.9 µg/L, 1.26 µg/L, respectively. Three days of settling allowed significant reduction in turbidity (49.8 NTU), chlorophyll a (3.75) and BGA-PC (0.21µg/L). The initial concentration of TP, TCOD, TN and turbidity in the lake water alone were 0.032, 38.5, 0.76 mg/L and 12.4 NTU, respectively. Addition of sediment resulted in low DO (4.13 mg/L) and pH (5.5). The filter combination used for the filtration test included three TE-GTX 300 (110 µm) and one TE-GTN 350 A (75µm). Because of the high turbidity, the filters clogged rapidly and were replaced by a new set of filters with the same combination. Six sets of filters were used for the entire test. The test results observed for turbidity, TP and COD are given in Figure 4a. The initial concentrations of TP (0.25 mg/L) and COD (60 mg/L) were relatively high due to the fine suspended sediment particles and particulate organic matter in the overlaying water, resulting from the sediment resuspension. As Figure 4a shows, the turbidity was reduced gradually and about 52% and 85% removals were achieved in 5 and 19 days, respectively. The TP removal trend was found to be similar to turbidity which indicates that more than 70-75% of the P was in the particulate form associated with fine sediment particles, algae, and particulate organic matter. The removal mechanism for turbidity and TP includes both filtration and gravity settling. However dynamic conditions in the tank hindered settling of suspended particles, and therefore removal could be mainly due to filtration. The TDP concentration in the lake water varied between 7-23 µg/L, and its increase sometimes during the experiment could be due to either sediment phosphorus release or microbial degradation of settled organic matter (dead algae and sedimentary organic matter) in the sediment.

Figure 4b shows the removal of total and dissolved COD during the filtration test. Filtration was found to effectively remove particulate forms of organic matter, and there was a good correlation between TCOD and turbidity removal. The concentration of dissolved COD was almost the same throughout the experiment and indicates that filters alone cannot remove dissolved forms of COD, and phosphorus. Using filters incorporated with organic rich sediments could enhance the removal of dissolved forms of COD and P through adsorption on the sediment.

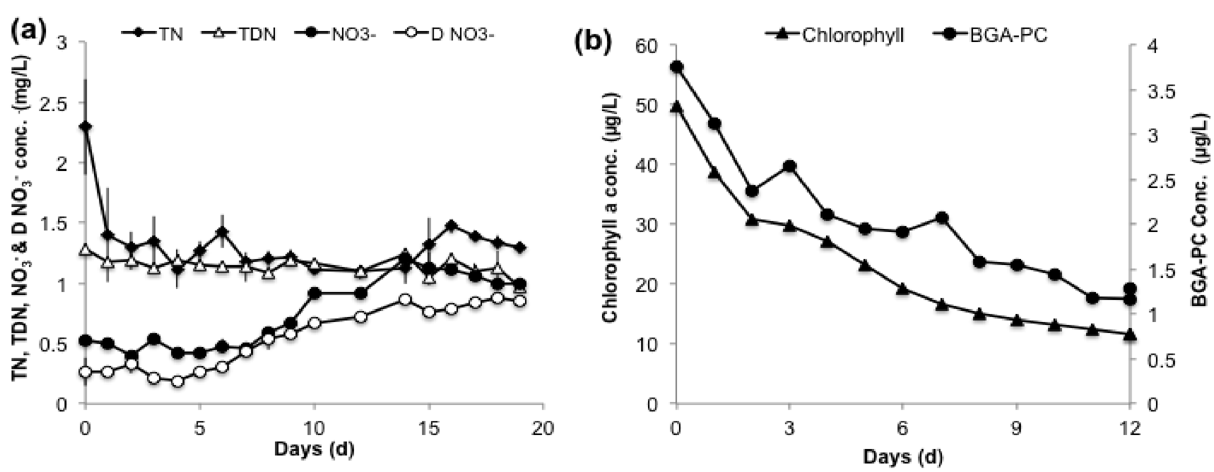

Figure 5: Removal of (a) TN, TDN, NO_3^-, & DNO_3^-, and (b) Chlorophyll a & BGA-PC during filtration using 3xTE-GTX (110 µm) + 1x TE-GTN (75 µm) filter combination.

Figure 5b shows the removal trends for TN, TNO_3^-, chlorophyll a and BGA-PC during the filtration test. As discussed before, the majority of TN was in the dissolved forms as $NO3^-$, NO_2^- and other nitrogen forms. Like TN, NO_3^- was mainly in the dissolved forms and therefore, no significant removal was observed for both TN and NO_3^-. A gradual increase in NO_3^- concentration was observed (Figure 5A) and this could be due to the oxidation of reduced forms of nitrogen (NO_2^- and NH_4^+) in the lake water. Chlorophyll a and BGA-PC removal trends during filtration are given in Figure 5b. Due to some technical problems with the YSI probe, the chlorophyll and BGA-PC concentrations were not monitored between days 12 to19. About 66% chlorophyll *a* and 78% BGA-PC removal was achieved by the first 12 days. Overall, turbidity, TP, and TCOD removal were 85%, 82% and 65%, respectively.

Another filtration test with sediment (solids content of 1.15%) was performed under the same conditions as mentioned before with different filter combinations as follows: two TE-GTX 300 (110 µm) and three TE-GTN 350 A (75 µm) (day 0), two TE-GTX 300 and three TE-GTN 300 (90 µm) (day 1), three TE-GTX 300 and 1 TE-GTN 300 (day 3) and one TE-GTX 300 and three TE-GTN 300 (day 9). A significant reduction in turbidity was observed when the number of filters with small opening sizes (75 and 90 µm) was increased. Using more filters with a smaller pore size could capture more solids and minimize carry over of undersized particles through the filters. However, these kinds of filter combinations are susceptible to fast clogging. Filters with a large opening size (110 µm) were less liable to clogging. However they were not very effective towards fine particle capture. Figure 6a-b shows the removal trends for turbidity, TP, and COD during the filtration. Actual concentrations of TP, COD, TN and turbidity in the lake water were 0.04, 32, 0.7 (mg/L) and 2.6 (NTU), respectively. Addition of sediment resulted in very high turbidity, and chlorophyll a concentration in the water. Two days of settling significantly reduced turbidity, chlorophyll a, and BGA-PC concentrations in the lake water to 46.5 NTU, 7.44 (µg/L) and 0.52 (µg/L), respectively.

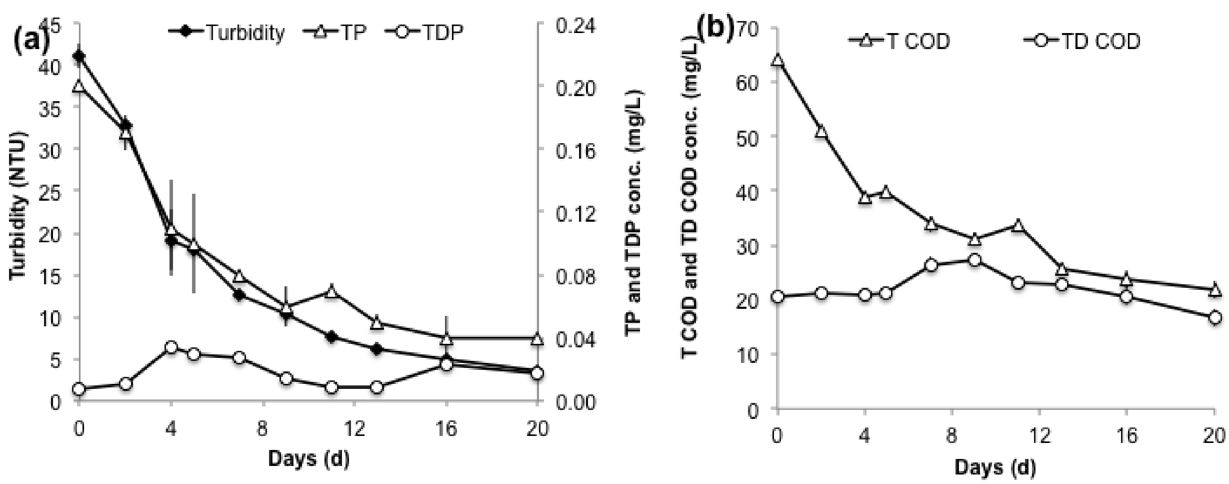

Figure 6: Removal of (a) turbidity, TP, TDP & (b) TCOD and TDCOD during filtration

The maximum removal obtained for turbidity, TP and COD were 91, 80 and 66%, respectively. TP and COD removal trends were similar to turbidity as they were mainly in the form of particulates, which contribute to turbidity in water. Significant reduction in TCOD was observed along with turbidity until all particulate organic matter was removed by filtration.

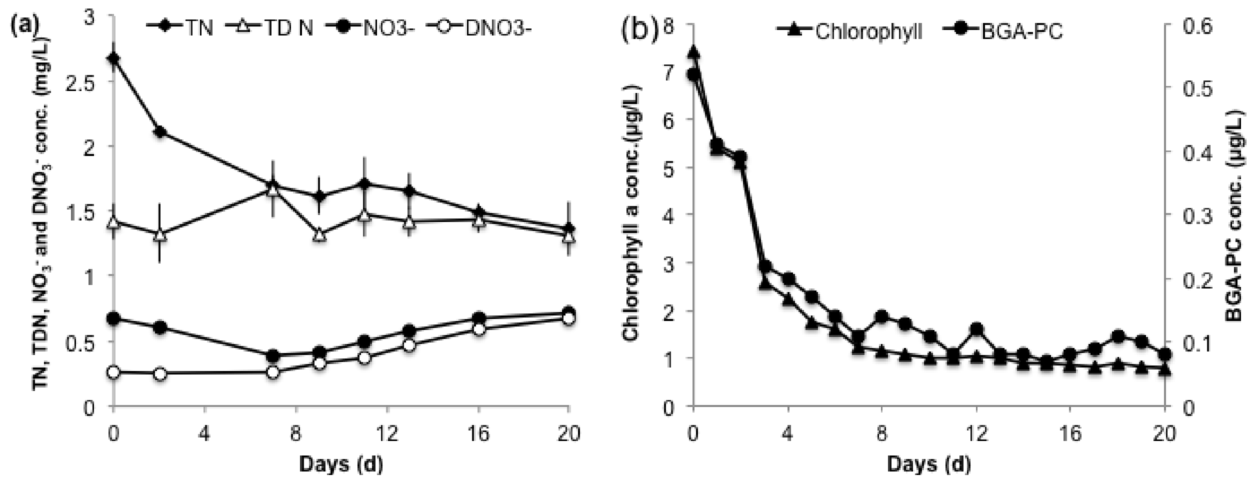

Figure 7: Removal of (a) TN, TDN, NO_3^-, & DNO_3^-, and (b) chlorophyll a & BGA-PC during filtration.

Figure 7 shows removal of TN, NO_3^-, chlorophyll a and BGA-PC during the filtration test. The ORP increased from 306 to 525 mV over time. Overall percent removal obtained for turbidity, TP, TCOD, chlorophyll a, BGA-PC were 93, 80, 66, 89, 93 %, respectively.

In general, filtration using selected non-woven geotextile filters improved lake water quality in terms of turbidity, suspended solids, TP and chlorophyll a concentration in the filtered water. However, the filters are not effective for removing nitrogen (as TN, and NO_3^-) as it mainly exists in its dissolved forms in the lake water.

4 CONCLUSIONS

The test results from this study have shown that non-woven geotextile filters can be used for improving surface water quality. The geotextile filters allowed reduction of the TP and chlorophyll a concentration in Lake Caron water to the limit set for oligotrophic lakes by MDDEP. Since phosphorus in overlaying water is mainly in the particulate form, removing suspended particles by filtration could lower TP concentration and improve the aesthetics of the water. The geotextile filters resulted in the removal of 85-98% turbidity, 59-82% TP, 67-89% chlorophyll a, 78-93% BGA-PC and 33-66% COD depending on the initial water quality. Filter combinations with more (2-3) smaller size filters are more effective for suspended solids removal. This method is environmental attractive since it does not add any foreign materials in the lake water, and is simple and feasible to operate onsite. Since the filtration process generates clogged filters, reuse of the used filters must be addressed in the future work. In situ filtration tests will be performed in the next phase of this project.

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