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USE OF NON-WOVEN GEOTEXTILES FOR IMPROVING WATER QUALITY OF A EUTROPHIC LAKE: AN IN-SITU STUDY

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Abstract: Lakes are an integral part of the freshwater resources in Quebec and their protection is very important as any impairment in the lake water quality can affect the public's health and aquatic life. Lake Caron, a shallow eutrophic lake located in the Sainte-Anne-des-Lacs municipality in Quebec, has been under swimming advisory for many years due to algal blooms every summer. In this present study, a floating filtration unit with a sand prefilter and non-woven geotextile filter media, was tested to improve the lake water quality in a small area of the lake enclosed by a turbidity curtain. The water quality was monitored during the test by deploying two YSI-EXO2 probes in and out of the curtain and analysing water samples for total phosphorus, COD, turbidity, and total suspended solids. The geotextile filters together with the sand filter were effective for removing algae and suspended particles. Overall the filtration resulted in 78% total suspended solids, 39% total phosphorus and 53 % chlorophyll *a* removal in the contained lake water. Use of the pre-sand filtration allowed removal of large size particles and thus reduced rapid clogging of geotextiles.

Key Words: Blue green algae, Non-woven geotextiles, Filtration, Suspended Solids, Total Phosphorus

1 INTRODUCTION

There are more than a half million lakes in the province of Quebec in Canada and they are extensively connected to the socio-economy of the province in multiple ways by providing water for drinking, energy, agriculture, industry and tourism (MDDELCC 2002). Therefore, any deterioration in the lake water quality can have significant impacts on public health and biodiversity, especially where the lake water serves for drinking and recreation purposes. Eutrophication has been reported in many lakes across the province as a result of excess nutrient, especially of phosphorus (P), load into aquatic systems through point and non-point sources (Cloutier and Michelle 2007). High turbidity, low dissolved oxygen (DO), presence of cyanotoxins, low water transparency to light and reduced aquatic biodiversity are some of the consequences associated with the eutrophication (Shinder 2006; Chislock et al. 2013). Lakes are vulnerable ecosystems and need to be protected against eutrophication by limiting P concentration in the surface water through controlling external and internal P loadings (Sondergaard et al. 2003).

Internal phosphorus loading is one of the potential sources of P in the overlaying water in many shallow eutrophic lakes (Sondergaard et al. 2003). Lake Caron (Quebec, Canada) is a shallow, artificial lake (ABVLAC Org.). According to the reports of MDDEP (Ministère du Développement Durable de l'Environnement et des Parcs (MDDEP), the lake has been in a eutrophic state since 2008. In the past few years, algal blooms were reported in the lake during summer. The lake is currently under a swimming advisory to protect its inhabitants from the risk of algal cyanaotoxins due to the algal blooms. Often, the level of total phosphorus (TP), and chlorophyll *a* (Chl. *a*) concentration in the lake water are within the norm values set for eutrophic lakes in Quebec. The possible sources of P in the lake water include surface runoff from the forest area around the lake, past practices of fertilizer use and septic discharge, and internal sediment phosphorus release (Veetil et al. 2018; Karim et al. 2013). Since the lake sediments are characterized with high P and organic matter content and there is a limited direct P input into the lake, the eutrophication of the lake could be potentially due to the sediment phosphorus release (Veetil et al. 2017).

Phosphorus exists in both dissolved and particulate forms in the surface water. Among these, dissolved P is readily available to algae and other aquatic organisms, whereas the particulate P either remains in the water column or settles down and incorporates into the bottom sediments. After each bloom, the dead algae settle down on the sediment where they undergo microbial mineralization and this results in the release of P into the overlaying water (Sondergaard et al. 2003). In shallow lakes, like Lake Caron, seasonal recycling and release of sediment P into the overlaying water could be potential reasons for eutrophication (Sondergaard et al. 2003). Thus, removing particulate forms of P, organic matter and algal biomass could reduce the concentrations of TP and organic matter in the water column and sediment that may later reduce the occurrence of eutrophication (Mulligan et al. 2009, Inoue et al. 2009, Sarma et al. 2016).

Filtration is a physical separation technique that differentiates particles based on the particle size and uses different filter media in order to achieve specific goals like removing suspended solids (SS), nutrients and organic matter (OM). Geotextiles are permeable synthetic materials and are used for many environmental applications such as drainage, solid separation, filtration, and soil reinforcement (Mulligan et al. 2009, Inoue et al. 2009, Franke et al. 2012, Tota-Maharaj et al. 2012). Many researchers recently cited the use of geotextiles as a filter media for removing the SS and other pollutants including nutrients and heavy metals from storm water and surface water (Alam et al. 2018; Frank et al. 2012; Mulligan et al. 2009; Inoue et al. 2009). Mulligan et al. (2009) reported 93-98% turbidity, 98-99% SS, and 65-75% COD (chemical oxygen demand) removal in a laboratory filtration test of river water using different non-woven geotextiles. Also, Inoue et al. (2009) reported significant removal of TP, COD and SS from a pond water using an in-situ upward geotextile filtration.

Over the past few years, the research team from Concordia University has been monitoring Lake Caron water quality and performing on-site filtration experiments to improve the surface water quality using non-woven geotextiles as a filter media. Significant removal for Chl. *a*, TP, and SS was observed in the recent on-site filtration experiments conducted at the lake. This present study objectives are to monitor the lake water quality and evaluate the in-situ use of geotextile filtration at large scale to improve the water quality in a small area of the lake contained by a turbidity curtain.

2 MATERIALS AND METHODS

2.1 Study Area

Water sampling and in-situ filtration tests were conducted in Lake Caron, located at Sainte-Anne-des-Lacs municipality in Quebec. The lake is very shallow with maximum and average depths are 2.6 and 1.4 m, respectively (ABVLAC Org. 2018). The lake watershed is occupied with wild trees and a few local residents. The approximate surface area and water volume of the lake are 35,3000 m^2 and 46,400 m^3, respectively.

The in-situ filtration set up was made by isolating and containing a small area of the lake using a floating turbidity silt curtain obtained from Titan Environmental Containment Inc. The enclosure made for the in-situ test was in an elliptical area and the volume of the contained water was approximately 2.86 m^3. The turbidity curtain is 14.6 m long and 1.2 m wide and is made of a woven fabric. It is designed to retain suspended particles including the algae and fine sediment particles, based on the filter permeability, with in the enclosure while allowing the water to pass through it. The fabric is designed to float on the top by floating tubes and sink at the bottom by a long heavy iron chain. Figure 1 shows the map of Lake Caron with sampling stations and the enclosure made for the in-situ study.

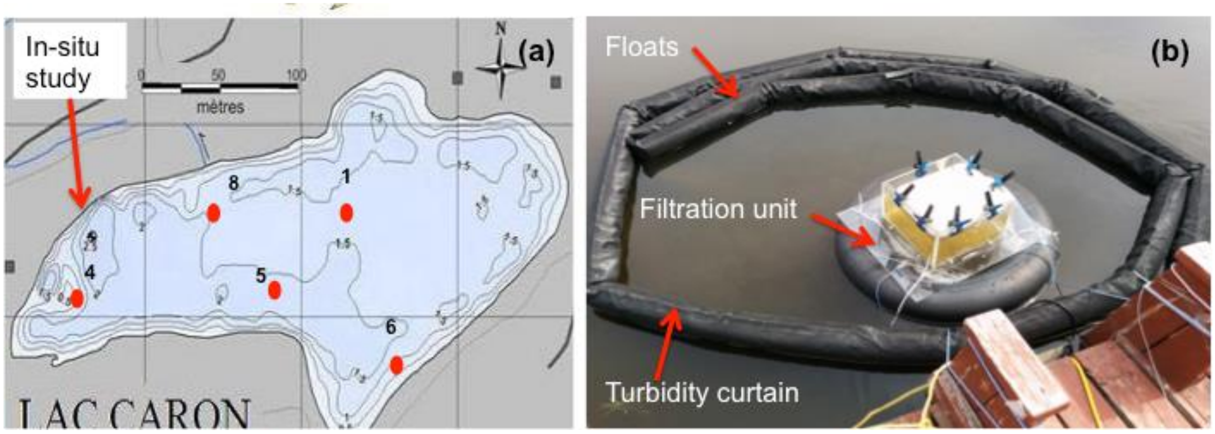

Figure 1: (a) Lake Caron with sampling stations; (b) In-situ filtration set up

2.2 Floating filtration apparatus

The filtration unit is basically an open rectangular vessel, made of plexi glass, with a galvanized copper grid at the bottom to support the filters (Figure 2). The filters were fixed on the grid with the help of four side panels with clamps as shown in Figure 2. A float switch was used to control water level and thus to avoid overflow of water during filter clogging. The dimensions of the filtration unit were 30.5 x 30.5 x 20 cm (W x L x H). An inflated tube was used to float the filtration unit on the water. A small submersible pump with adjustable flow rate was used to pump the contained lake water with a flow rate of 2.86 L/min. A distributer was placed at the top of the unit to sprinkle the water evenly on the filter. The geotextile filtration was performed with and without using a pre-sand filtration. The sand was washed multiple times with tap and distilled water and analyzed for P (using Agilent 7700 series Inductively Coupled Plasma Mass Spectrometry (ICP-MS)) to make sure that no P leaching occurs from the sand during the filtration. For the tests with pre-sand filtration, the lake water infiltrated through a sand bag, containing cleaned sand, placed on the distributor. The infiltrate was then filtered through selected geotextiles having different opening sizes.

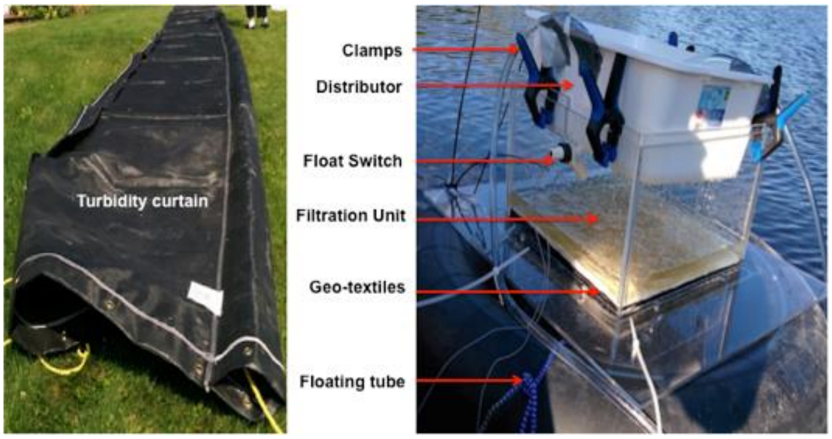

Figure 2: Floating filtration unit

2.3 Filter media

Non-woven geotextiles (TE-GTX-330 (110 µm), TE-GTT-100-100 (100 µm), TE-GTN-230 (212 µm) and TE-GTN-116 (300 µm)) custom developed and provided by Titan Environmental Containment Ltd, MB, were used in this study as filter media to capture the SS and algae in the water column. Some of the given filters were selected based on the previous on-site trails performed during 2015-2017. The filters were cut to exact size and arranged in a descending order of their apparent opening size (AOS) for the tests. A combination of filters of different opening sizes was used for filtering the water. Different filter combinations were tried during the in-situ test. Upon clogging, used filters were replaced by new ones.

2.4 Water sampling and analysis

Water sampling was performed at different selected stations (St.1, St.4, St.6, and St.8) across the lake during the summer of 2018. Water samples were collected in cleaned 1L amber color bottles and stored at 4°C for physico-chemical analysis. During the filtration test, water samples were collected from both in and out of the curtain to see the changes in the water quality due to the filtration. The water samples were analyzed for different parameters such as particle size distribution, total suspended solids (TSS), TP, total nitrogen (TN), nitrate (NO_3^-), COD and turbidity. The dissolved forms of phosphorus (TDP), nitrogen (TDN), COD (TDCOD) and nitrate (TD NO_3^-) were also measured and for this water samples were filtered through a 0.45 µm syringe filter before the analysis. Test kits from Hach chemicals were used for analysing TP (TNT 843, Method 10209, ascorbic acid method), TN (TNT 826, Method 10208, persulfate digestion), NO_3^- (TNT 835, Method 10206, dimethyl phenol method) and COD (TNT 820, Method 10221, reactor digestion method) by following Hach protocols (Hach 2018). For the total P, N, COD, and NO_3^- analysis, water samples were acid digested in a Hach DRB 200 acid digestion unit and then measured using a spectrophotometer (Hach DR 2800). Particle size analysis (PSA) was performed with a laser diffraction particle analyzer (LA-960 Horiba laser particle size analyzer). YSI-EXO2 multi water quality probes were deployed both in and out of the curtain to monitor the real time water quality during the test. A set of sensors in the probe allowed measuring parameters such as pH, temperature, turbidity, dissolved oxygen (DO), oxidation-reduction potential (ORP), chlorophyll a (Chl. *a*) and blue green algae-phycocyanin (BGA-PC) concentrations.

3 RESULTS AND DISCUSSION

3.1 Water Quality

Table 1 shows Lake Caron water quality that was monitored between June and October of 2018. In Quebec, the lake tropical classification is based on TP, chlorophyll a and transparency (secchi disk) of lake water. TP concentration in the lake water must be less than 30 µg/l to control algal growth and to protect aquatic organisms. However, the average concentration in Lake Caron samples was 30.3 µg/L, within the criteria set for eutrophic lakes (30-100 µg/L) by MDDEP. The concentration was low (17 µg/L) in early June and increased gradually up to 37 µg/L over time with the increase in temperature. The COD was 29.6 mg/L for the lake water. Total suspended solid concentrations were slightly higher (5.9 mg/L) than those found last year (3.7 mg/L). The pH and DO of the lake water were 6.4 and 8 which are within the proposed limit to protect the aquatic organisms. The lake water pH and DO were 6.7 and 8.7, respectively. The Chl. a concentration was 12.6 µg/L. The PSA results showed that 50% (d_{50}) and 90% (d90) of the suspended solids were below 80 and 197 µm sizes, respectively.

Table 1: Lake Caron water quality in 2017 and 2018

Parameters	**2017**	**2018[a]**
TP (µg/L)	32±5.9	30.3±1.7
COD (mg/L)	26.7±3.5	29.6±0.4
NO_3^- (mg/L)	0.2±0.06	0.21±0.02
TN (mg/L)	0.84±0.1	0.94±0.04
TSS (mg/L)	3.7±0.91	5.9±0.7

a Average of 8 samplings

3.2 In-situ filtration

The in-situ test ran for 91 days during which different geotextile filters and filter combinations were tested. Filtration was started with a combination of three TE-GTT-100 (100 µm) and two TE-GTX-330 (110 µm) geotextiles, but this combination was not effective due to rapid clogging after a few hours of filtration. In most cases, the top two layers became completely clogged by forming a green algal layer on the filters (Figure 3). Due to fast clogging, filtration was then performed using a single filter (TE-GTT-100), instead of using multiple geotextiles at the same time. However, the clogging problem continued and forced the use of geotextiles with larger opening sizes (>110 µm) such as TE-GTN-230 (212 µm) and TE-GTN-116 (300 µm) filters. The rapid clogging of the filters could be due to the high TSS and large SS in the lake water. As the filtration using TE-GTN-230 alone was not effective, use of a pre-sand filter was tried together with the TE-GTN-230 geotextile. Though, the pre-sand filter helped to capture some large size algae and SS, the clogging problem continued and forced frequent changes of the filter. Later, the TEGTN-230 (220 µm) was replaced by the TE-GTN-116 (300 µm). This combination was found to be more effective and allowed the filtration to run continuously for more than 2 days without changing any filter. Figure.3 shows the changes in TP and TDP concentration in and out of the curtain during the filtration. As seen in Figure 3, the initial TP concentrations inside and outside the curtain were 41.5 and 32.5 µg/L, respectively. The high TP concentration in the contained water was due to its high TSS (9.4 mg/L) content. During the course of filtration, the TP concentration in the contained water decreased significantly in the first few days and then reduced gradually to below the norm set for eutrophic lakes (30 µg/L).

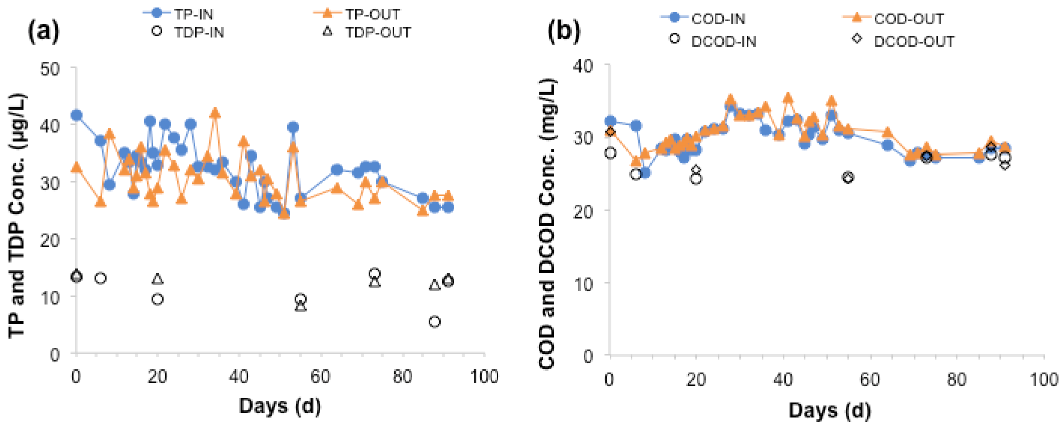

Figure 3: Change in conc. of (a) TP & TDP and (b) COD & DCOD during filtration

Considering the initial and final concentrations of TP, the filtration resulted in about 38.5 % TP removal in the contained water, while it was 15% for the lake water outside the curtain (without filtration). The dissolved form of P (TDP) accounted for a significant percent of the TP and its concentration, before and after filtration, remained almost same for the water in and out of the curtain. The filtration test was not very effective for COD removal as most of the COD (>88%) was in its dissolved form. However, the removal of algal biomass and suspended organic matter resulted in a slight reduction of the COD concentration. Similarly, there was no removal observed for TN and NO_3^- as they were mainly in their dissolved forms.

Figure 4a shows the change in TSS during the test. The initial TSS inside and outside the curtain was 9.4 and 7. 5 mg/L, respectively. During the test, the TSS in the contained water reduced gradually over time and reached to below the TSS value obtained for the lake water outside the curtain. An increase in TSS was observed both in and out of the curtain between 25 to 30 days, due to the increased algal growth resulted by the warm weather conditions at this time period The filtration resulted in about 78% TSS removal in the contained water, owing to both the filtration and settling processes. On the other hand, the net TSS removal outside the curtain was 42%, solely because of the settling of algae. Figure 4b shows the changes in Chl. *a* concentration inside and outside the curtain during the filtration test. Due to some technical problems, simultaneous monitoring of the water quality inside and outside the curtain using the YSI-EXO2 probe was not able to performed during the test, as expected. During the test, the inside water quality was monitored for more than 40 days, whereas the outside water quality was monitored for just a few days (from days 75 to 88). As seen in Figure 4b, from day 49 to 72, the Chl *a* concentration in the contained water significantly decreased to its lowest value of 4.4 µg/L and then increased, both in and out, for some time and then decreased.

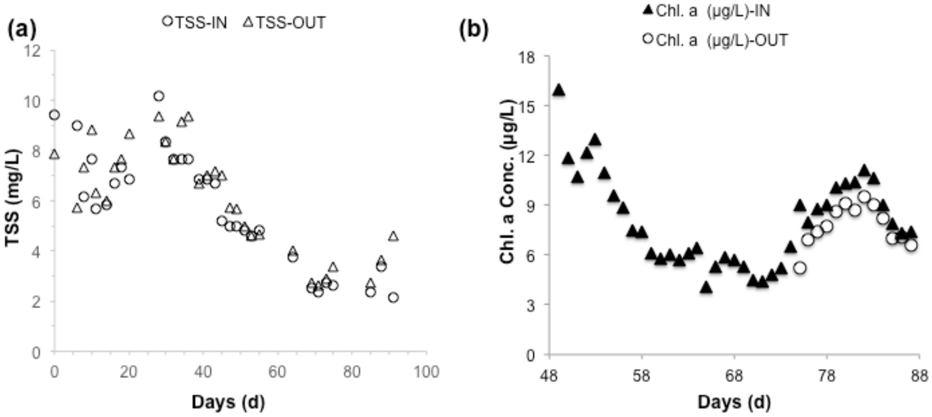

Figure. 4: Concentrations of (a) TSS (mg/L) and (b) Chl. *a* (µg/L) inside and outside of the curtain during filtration

Considering the initial and final probe data, the net Chl. *a* removal for the contained water was about 53 The lower movement of water within the enclosure favoured the algae growth in the contained water and promoted adhesion on the side of the curtain and forming large algal lumps. This self-adhering nature of the algae must be considered in the next phase as it limits the algae available in suspension mode for filtering and affects the probe data. Giving sufficient water movement in the enclosure may reduce the adhesion of algae on the curtain. As the enclosure was very sturdy and small in size, the role of wind-induced currents on the movement of particles in the contained water was very low.

The particle size distribution of SS in the water samples taken from inside and outside the curtain during the filtration is given in Figure 5. Initially, the particle size distribution was found to be similar for the samples taken from both in and out. Before the test, about 50 % (d50) of the particles were under 77 µm, whereas 90 % of the particles were <200 µm.

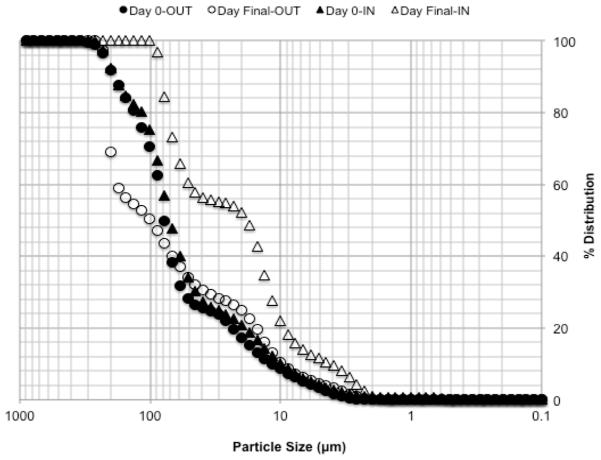

Figure 5. Particle size distribution of SS in the lake water before and after filtration

As seen in Figure 5, the filtration allowed the removal of large and fine SS in the contained water and resulted in about 50 % of the particles below 8 μm on the final day. On the other hand, due to the increased algal growth, about 50% (d_{50}) of the particles were below100 μm in the final sample taken from outside the curtain. Overall, the geotextile filters were able to remove algae and the filtration resulted in 38.5 % TP, 78% TSS, and 53% Chl. *a* removal. Because of the very stagnant nature of water inside the curtain, the effect of filtration on the lake water quality must be evaluated under the same enclosed conditions, instead of comparing the contained lake water quality against the lake water outside the curtain. In the next phase of the project, the water quality with and without filtration will be evaluated under the same enclosed conditions. The filtration tests will be performed using solar energy for running submersible pumps and float switch in the next phase.

4 CONCLUSIONS

The in-situ test results have shown the potential of non-woven geotextiles for use as a filter media to improve the surface water quality by removing algae and SS that adversely affect the water quality. Use of geotextile filter together with a pre-sand filter yielded significant removal of TP (38.5%), TSS (78%), and Chl. *a* (53%) from the contained lake water and reduced the concentration of TP and Ch. *a* in the lake water to below the norm set for eutrophic lakes by MDDEP. The yearly changes in the lake water quality in terms of algal size and shape are challenging for proper selection of geotextiles for the filtration. In this study, filters having higher pore sizes were found to be more effective for removing algae with less clogging issues. The simple design and flexibility make this floating filtration unit potentially beneficial for both in-situ and on-site applications. The unit is ideal for localized applications in which a specific area of the lake with a massive algal bloom and SS can be treated without disturbing the aquatic life.

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