Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

IN-SITU REMOVAL OF ALGAE AND SUSPENDED SOLIDS FROM A EUTROPHIC LAKE USING NON-WOVEN GEOTEXTILES

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Abstract: Lake Caron, a shallow eutrophic lake located in Sainte-Anne-des-Lacs municipality in Quebec, has been the site of algal blooms every summer since 2008. In this trial study, an in-situ floating filtration unit provided with non-woven geotextiles as filter media was tested to treat the water in a small area of the lake enclosed by a floating turbidity curtain. Energy from a solar panel was used to operate the unit. Non-woven geotextiles with different opening sizes were used to capture algae and suspended particles of various sizes. Water quality was monitored inside and outside of the turbidity curtain by examining total suspended solids, turbidity, total phosphorus, COD, total nitrogen and nitrate. Chlorophyll *a* and blue green algae (phycocyanin) concentrations were monitored through out the filtration by deploying a YSI-EXO2 probe. The filters were effective towards algae and suspended particle removals.

Keywords: Eutrophication, Suspended Solids, In-situ filtration, Non-woven geotextiles, Algae

1 INTRODUCTION

As a source of fresh water, lakes are connected to public's health and activities in places where they serve for drinking and recreational purposes (MDDEP 2002). Eutrophication has been reported in many lakes in Canada, including the Great Lakes, because of excess nutrient inputs, especially phosphorus (P), in the lakes through both point and non point sources (De Pinto et al. 1986; Environment Canada 2013). Multiple problems associated with eutrophication include increased primary production, reduced transparency, decreased aquatic biodiversity, low dissolved oxygen (DO) and release of algal toxins (Carpenter et al. 1999; Shinder 2006; Chislock et al. 2013).

The Ministry of Sustainable Development, Environment and Action Against Climate Change of Quebec has taken preventive measurements to address eutrophication in its lakes by monitoring the lake water for total phosphorus (TP), chlorophyll a (Chl *a*), transparency by secchi disk, and dissolved organic carbon through the Quebec Volunteer Lake Monitoring Program (VLMP). Lake Caron is a shallow, artificial, eutrophic lake located in Sainte-Anne-des-Lacs, Quebec. Since 2008, the lake has been in a eutrophic state and listed in the MDDEP's (Ministère du Développement Durable, de l'Environnement et des Parcs (MDDEP) list of eutrophic lakes in Quebec. The lake is currently under a swimming advisory to protect the lake inhabitants from the risks of algal cyanotoxins. The possible sources of P in the lake water include surface run off from the forest area around the lake, excessive fertilizer use and septic tank discharges and internal sediment phosphorus release (Karim et al. 2013, Veetil et al. 2017).

Nutrients entered the lakes through surface run off in to the water column for a long time where they adsorb on to suspended sediment fines (clay particles) and particulate organic matter. The solids settle on the bottom sediment where P can slowly release into the overlaying water (Sondergaard et al. 2003; Mulligan et al. 2009; Inoue et al. 2009). 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 P-bearing SS, 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 particle separation technique that uses different materials as filter media in order to achieve specific goals like removing the SS, nutrients and organic matter. Geotextiles are permeable synthetic materials, well known for their use in geotechnical, environmental and hydraulic applications (Mulligan et al. 2009; Inoue et al. 2009). Very recently, geotextiles as filter media have been evaluated 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 from river water in a laboratory filtration test with the geotextiles. Similarly, significant removal was reported for TP, COD and SS from a pond water using an in-situ upward geotextile filtration system (Inoue et al. 2009).

Over the past few years, the research team from Concordia University has been monitoring Lake Caron water quality and conducting filtration tests using non-woven geotextiles to improve the water quality. The results from previous on-site studies conducted at the lake were promising for the SS, TP, COD and Chl *a* removals (Veetil et al. 2017, Sarma et al. 2016). In this study, the filtration of the lake water was performed in-situ, using renewable solar energy as source of electricity for the operation. The main objective of this study was to assess the effectiveness of geotextile filtration under real lake conditions for improving the lake water quality by isolating a small portion of the lake by a turbidity curtain.

2 MATERIALS AND METHODS

2.1 Study Area and Experimental Site

The in-situ filtration experiment was conducted in Lake Caron at Ste. Anne-des-Lacs, Quebec. The approximate surface area and water volume of the lake are 35,300 m^2 and 46,400 m^3, respectively. The maximum and average depths are 2.6 and 1.4 m, respectively. For the in-situ filtration test, a small area of the lake was selected and contained in a rectangular shape by deploying a floating turbidity curtain (14.6 m x 1.2 m)(L x W) obtained from Titan Environmental Containment Inc. The turbidity curtain was made to contain and control suspended particles including the algae and fine sediment particles within the enclosure. The volume of water that contained was about 2.88 m^3, which is about 9 times higher than the volume used for the previous on-site test. Figure 1 shows the map of Lake Caron with sampling stations and the enclosure made for the in-situ study.

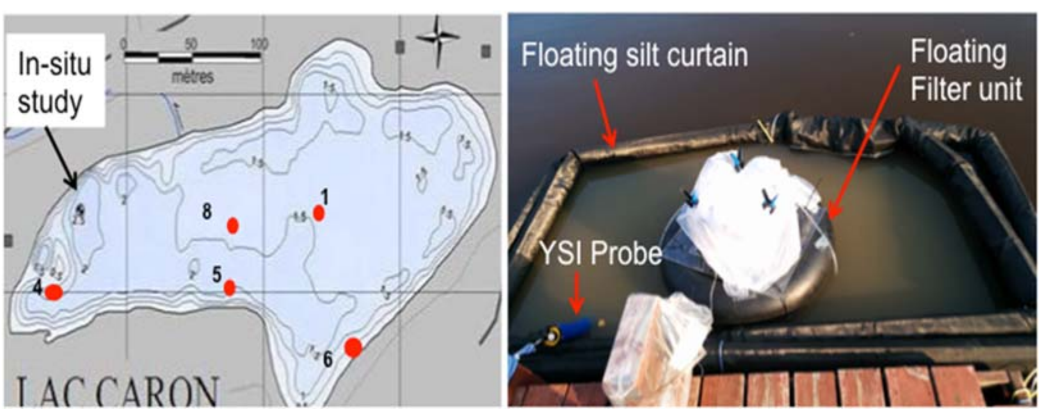

Figure 1: (a) Lake Caron with sampling stations; (b) In-situ filtration set up

2.2 Floating Filtration Unit and Filter Media

The filtration unit is an open squared rectangular vessel, made of plexi glass, with a galvanized copper grid at the base to support the filters (Figure 2). The dimension of the filter unit was 30.5 x 30.5 x 20 cm (W x L x H). A float switch was used to control water level and thus to avoid overflow of water, especially during filter clogging. The whole unit was floated on an inflated synthetic rubber tube (Figure 2). Two submersible water pumps (DC 12V, 4.8 W) having flow rates of 240 L/h were used for pumping the water. The electrical supply to the pumps and float switch was made using a solar panel (AXITEC) (260 W, 30.92 V, 8.43 Ah) and a battery (Crown)(12V, 130 Ah). The dimensions of the solar panel and battery were 164 x 99.2 x 3.5 cm and 33 x 17.1 x 23.8 cm (W x L x H), respectively. The solar panel system was sufficient for supplying electricity to a 10 W system for 24 h for 3 days with low or no light conditions.

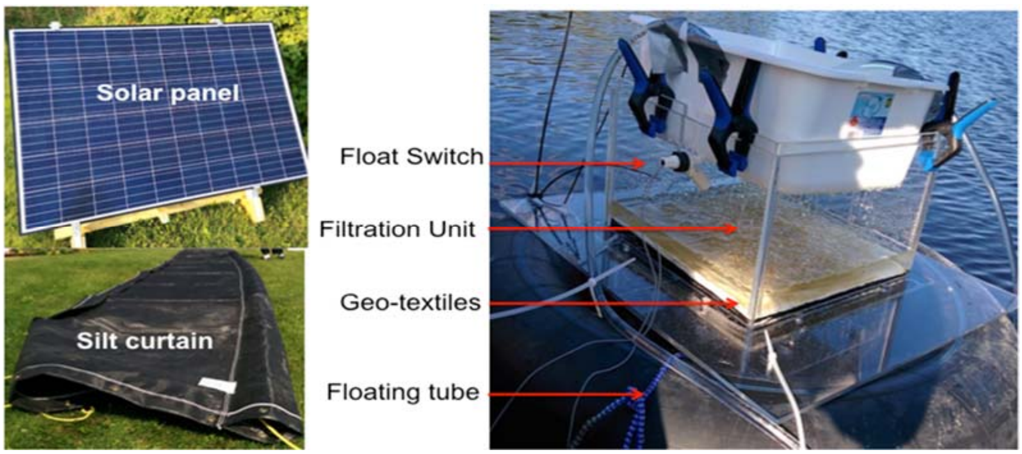

Figure 2. Floating filtration unit

Non-woven geotextiles filters (TE-GTX 300, TE-GTN 300, TE-GTN 350A, TE-GTN 350 B) custom developed and received from Titan Environmental Containment Ltd., MB, were used as filter media to capture the suspended particles, algae and nutrients from the lake water. The filter selection and combination was based on the previous on-site studies during 2015-2016. Table 1 shows the physical characteristics of the geotextiles (based on the data sheets obtained from Titan Environmental Containment Ltd.) used for the study. The filters were cut to area of 30.5 x 30.5 cm (W x L) and arranged in a descending order of their apparent opening size (AOS) for the tests. Different filter combinations were tried during the in-situ test. Upon clogging, used filters were replaced by new ones.

Table 1: Characteristics of the non-woven geotextiles

Filters	Apparent Opening Size (AOS) (µm)	Flow rate ($L/m^2/min$)	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
TE GTN 350B	65	2700	350	PP	0.56

PET: Polyester; PP: Polypropylene
Permittivity*=Volumetric flow rate/unit area of cross-section/unit head

The TE- GTX 300 filter is white in color and made of a continuous filament fibre polyester (PET) with 110 µm AOS. The filters TE-GTN 300 (AOS: 90 µm) and TE-GTN 350-A (AOS: 75 µm) are of black color and made of 100% virgin staple fibre polypropylene.

2.3 Water Sampling and Analysis

Water sampling was conducted at selected stations in Lake Caron from June to September in 2017. During the course of filtration test, water samples from both in and outside of the turbidity curtain were taken and analysed to determine changes in the water quality owing to the filtration. Water samples were collected in 1L brown bottles and stored at 4ºC prior to physico-chemical analysis.

The lake water samples were analysed for 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 (D COD), and nitrate (TD NO_3^-) were also measured. For this, water samples were filtered through 0.43 µm pore size filters immediately after sampling and stored under 4ºC. 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). Besides, in-situ water quality was monitored throughout the experiment by deploying a YSI EXO2 (E-528-EXO2 YSI, rented from Hoskin Scientific, Canada) water quality probe in the contained water. The YSI probe allowed real-time monitoring of water pH, temperature, turbidity, dissolved oxygen (DO), oxidation-reduction potential (ORP), Chl *a* and blue green algae-phycocyanin (BGA-PC) concentrations. Particle size analysis (PSA) was performed with a laser scattering particle size analyzer (LA-950 V2, Horiba laser particle size analyzer).

3 RESULTS AND DISCUSSION

3.1 Lake Water Quality

The lake water analysis results (Table 2) confirmed the lake's eutrophic state and poor water quality. Except for a couple of instances, TP and Chl *a* concentrations were within in the norm set for eutrophic lakes (TP: 30-100 µg/L and Chl a: 8-25 µg/L) by the MDDELCC, especially during warm weather conditions.

Table 2. Lake Caron Water Quality (Jun.-Sept. 2017)

Parameters	Values
TP (µg/L)	32±5.9
TN (mg/L)	0.84±0.14
COD (mg/L)	26.7±3.5
NO_3^- (mg/L)	0.22±0.06
TSS (mg/L)	3.7±0.91
Temp (°C)	22.7±2.2
Conductivity (µS/cm)	24±1.6
TDS (mg/L)	16.4±16.4
DO (mg/L)	8±0.87
pH	6.8±0.18
ORP (mV)	334±60
Turbidity (NTU)	2±0.7
Chlorophyll (µg/L)	9.2±2.8
BGA-PC (µg/L)	0.5±0.05

The lake water pH was in a slightly acidic to neutral state, within the proposed limit for the Quebec surface water criteria (pH 6.5-9) for protecting aquatic life (CCME, 2009). The DO level was within the lowest acceptable limit proposed to support aquatic life in cold (pH 6.5-9.5) and warm (pH 6-6.5) surface water (CEQG, 1999). The size of the SS in the lake water ranged between 2 and 152 μm. The PSA results showed that 90% of the particle's size (d_{90}) was under the range of 72 to116 μm and 50 % of the particles have (d_{50}) diameters under the 21 to 30 μm range.

3.2 In-situ filtration experiment

The deployment of the turbidity curtain caused high turbidity in the contained water (116 NTU), which was later reduced to 23.1 NTU, after two days of settling. The filtration test was started with a filter combination of two TE-GTX 300 (110 μm), one TE-GTN 300 (90 μm) and one TE-GTN 350 A (75 μm). The experiment was run for 32 days during which filters clogged were replaced by new filters and a total of 34 filters of different filter combinations were used. The lake water quality was found to be much better for the turbidity and algal biomass in 2017 than in 2016. However, the geotextiles, especially the top TE-GTX 300 filter with high permittivity, were found to clog rapidly even at very low turbidity. Figure 3 shows the non-woven geotextiles before and after the filtration. During the test, the algae formed a layer on the filter surface intertwined with the filamentous fibers in the TE-GTX 300 (Figure 3) and this reduced the filter's permittivity significantly to a completely clogged state. While the algae mainly were retained on the top filter, very fine SS were captured on the filters below with small opening sizes.

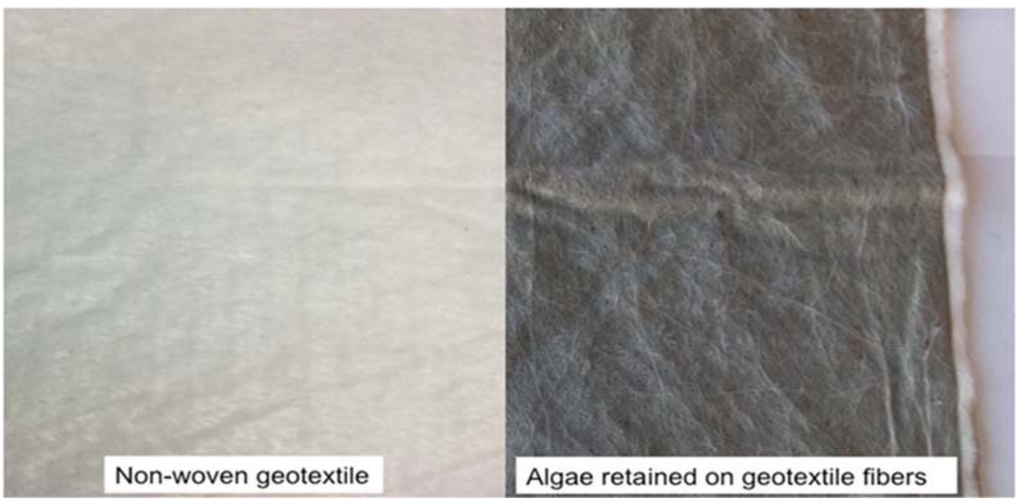

Figure 3. Non-woven geotextile before and after filtration

Figure 4 shows the change in total and dissolved forms of P and COD during the filtration test. As seen in the Figure 4a, the TP concentration in the contained water was initially high due to the high SS and its concentrations inside and outside the turbidity curtain were 75.5 and 28.5 μg/L, respectively. A significant reduction in TP (56%) was observed for the filtered water in the first 7 days, obviously due to the removal of P bearing suspended sediment particles and the algae by both the filtration and settling process. At the end of the test, TP concentration in the treated water was reduced to below the norm set for eutrophic lakes (30 μg/L) in Quebec. The net TP removal was 72%. The concentration of dissolved P (TDP) was similar in both filtered and non-filtered water through out the experiment, indicates that this in-situ test did not cause release of P into the overlaying water. The filtration test was not very effective for COD removal as most of the COD (76-92%) was in the dissolved form (Figure 4b). However, the removal of algal biomass and suspended organic matter resulted in a slight reduction in the COD concentrations in the filtered water.

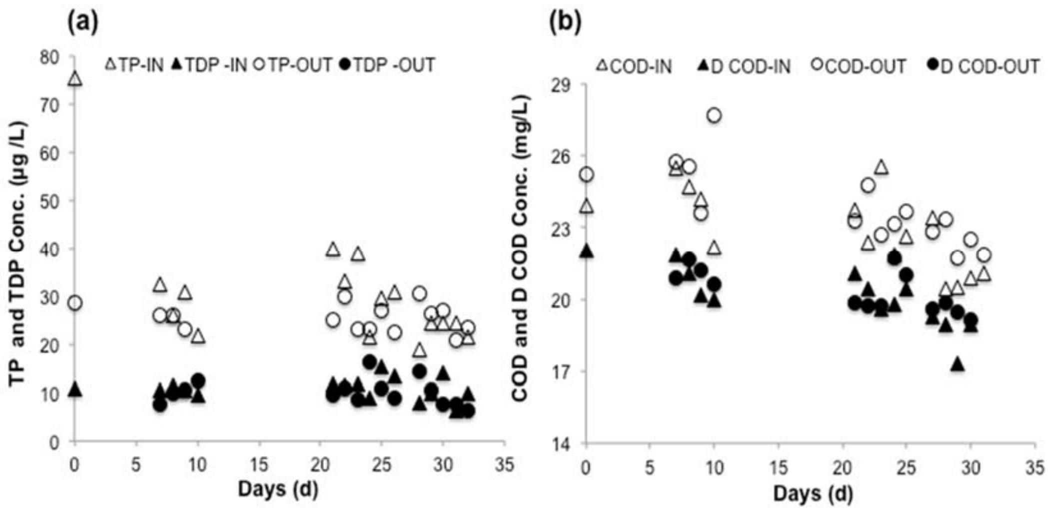

Figure 4. Change in conc. of (a) TP & TDP and (b) COD & D COD during filtration

The change in water turbidity and suspended particles during the filtration test is given in Figure 5. The initial turbidity inside and outside the curtain was 23.1 and 1.48 NTU, respectively. The turbidity removal was significant in the first few days (day 0 to 5) of filtration owing to both the filtration and settling process and thereafter, it was mainly due to the filtration process.

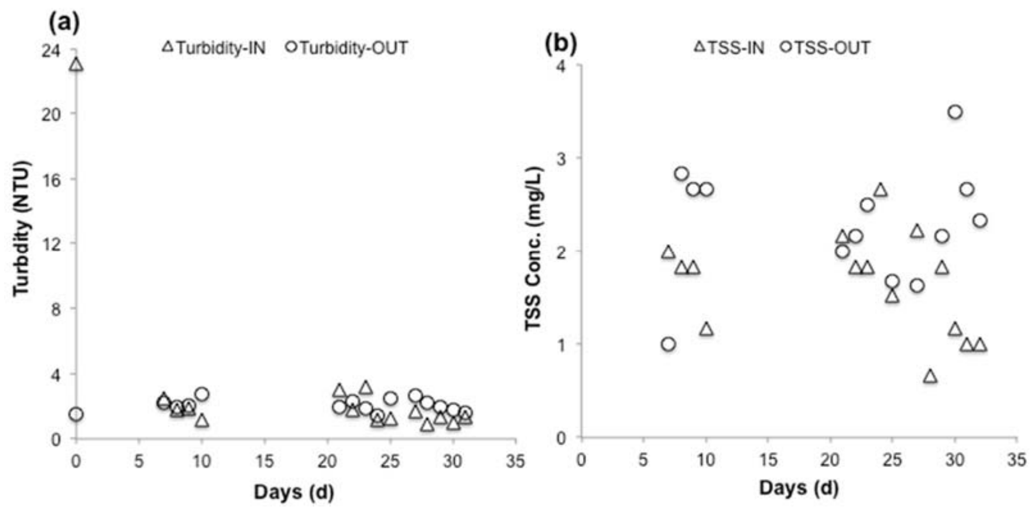

Figure 5. Change in (a) Turbidity and (b) TSS inside and outside the silt curtain during filtration

Considering the initial and final turbidity in the contained water, about 94% turbidity removal was achieved during the test. The final turbidity in the filtered water was 1.3 NTU, which is about 2 times less than those outside the curtain (2.7 NTU). The turbidity of contained water was also monitored hourly during the test by using the YSI probe (Figure 6) and compared the values with those obtained by a hand held turbidity meter (Oakton turbidity meter, T-100). As seen in the Figure 6, the turbidity in the contained water was reduced, from 21.7 to 2.74 NTU, close to the normal lake water turbidity within two days of filtration and settling. The SS data shown in Figure 5b is from day 7 to 32, when about 50% TSS removal was observed. At the end, the TSS concentrations outside and inside the curtain were 2.3 and 1 mg/L, respectively.

Figure 6 shows the changes in temperature, turbidity and Chl *a* concentration in the contained lake water over the filtration test, monitored by the YSI probe. Water temperature is known to have significant role in algal growth and bloom development as the increase in temperature enhances the phytoplankton productivity (Wells et al. 2015). Though the mild weather and low water temperature adversely affected the algal growth throughout the summer in 2017, an increase in the algal growth was experienced later at the end of September due to the warmer weather conditions. As seen in Figure 6, a slight increase in Chl *a* concentration was observed with the increase in water temperature (Day 0-11). While the filtration continues, the chlorophyll *a* concentration in the filtered water was reduced gradually, yielding about 48 % removal. The lake water in the enclosure was in a stagnant condition and this favored the algae in the water to stick on the curtain's inner wall. This reduced the removal of algae to some extent by (i) limiting the algae available in the suspension mode for pumping and filtering and (ii) frequent pump failure due to entrained air bubbles. Therefore, this problem will be addressed in the next phase of this project by changing the pumps in the system.

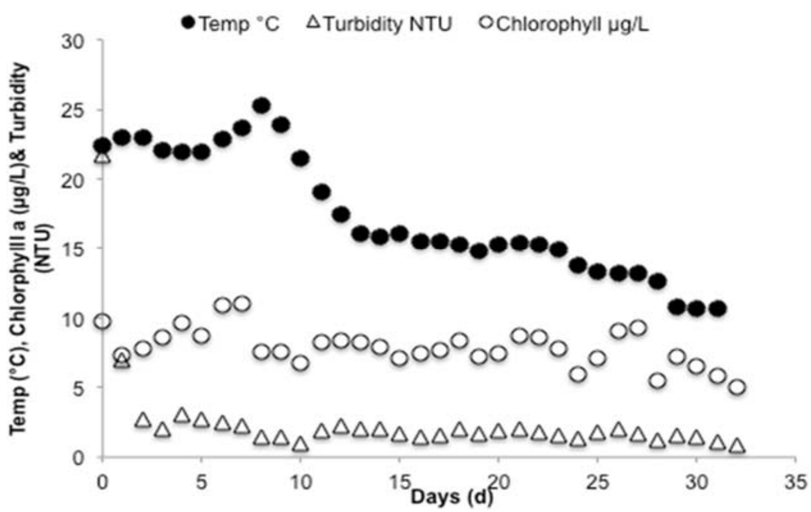

Figure 6. YSI probe data for temperature, chlorophyll a and turbidity of contained water during filtration

The PSA of water samples collected from both in and out of the system during the filtration test is given in Figure 7.

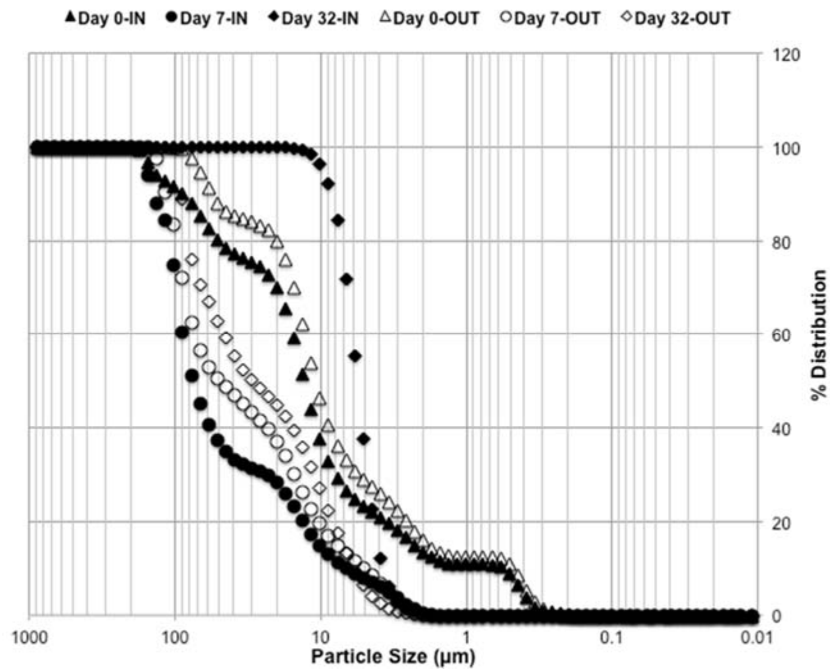

Figure 7. Grain size distribution of SS in Lake Caron water during the filtration test

Figure 7 shows the size distribution of SS in the lake water during the filtration test. Before the filtration, about 90 % (d_{90}) of the particles were below 89 µm and 59 µm for the samples from inside and outside the curtain. Increased algal growth accompanied with high temperature resulted an increase in particle's size in the lake water (Day 7). As can be seen, 90 % (d_{90}) of the particles in the final, filtered water was under 8.5 µm, which shows the efficiency of the geotextiles to capture SS of broader size range.

4 CONCLUSIONS

The results from this preliminary in-situ filtration test have shown the potential use of geotextiles as a filter media to improve the surface water quality under real lake conditions. The in-situ filtration allowed significant removal for TP (72%), chlorophyll a (48%) and turbidity (96%) from the lake water and the results could further be improved in the next phase by solving the problems experienced during the test. The simple design and flexibility make the floating filtration unit ideal for targeting and treating a specific area of the lake with a massive algal bloom and SS, without disturbing the aquatic life, with no chemical addition, and by isolating the treatment area using a turbidity curtain. In the next phase of this project, the filtration test will be evaluated for the flow rate through the filter and solids and P removal rate per filter per area.

Acknowldgements

The authors thank NSERC and Concordia University for financial support for this project. The authors are also grateful to their industrial partner, Titan Environmental Containment Ltd., for supplying geotextiles and providing financial support for this project.

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