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ENVIRONMENTAL REMEDIATION OF A SHALLOW MESOTROPHIC LAKE WATER USING ON-SITE NON-WOVEN GEOTEXTILE FILTRATION TREATMENT

Pereira, Antonio C.[1], Palakkeel Veetil, Dileep [2], Mulligan, Catherine N.[3, 5], and Bhat, Sam[4]
1 Concordia University, Canada
2 Concordia University, Canada
3 Concordia University, Canada
4 Titan Environmental Containment Ltd., Canada
5 corresponding author: mulligan@civil.concordia.ca

Abstract: For remediation of eutrophic waters, which are often shallow and inland, such as lakes, several processes are applied. Present techniques include one or a combination of the following: contaminated sediment removal by dredging, chemical substances or inert element addition in the water column, and water aeration. These processes are often inadequate, invasive, and intricate, changing the natural biota. To respond to this concern and present an environmental, easily applicable, deployable, and operational method on-site non-woven geotextile filtration treatment has been proposed. The experiment was deployed throughout the summer until mid-fall of 2020, using the water from Lake Johanne, a shallow mesotrophic lake located in the *Sainte-Anne-des-Lacs* municipality in Quebec. Based on a tank located near the lakeshore with a floating geotextile filtration system in batch and continuous mode (i.e., of 2-, 1-, and 0.5-day retention time), lake water was filtered using non-woven geotextiles. The water parameters monitored during the experiment were total phosphorus (TP), nitrate, chemical oxygen demand (COD), total suspended solids (TSS), particle size, and turbidity. The non-woven geotextile filters were effective for removing nutrients, organic matter, and suspended particles in the contained water and resulted in about 86% TSS removal and an average of 75% and 11% for TP and COD removal, respectively. All treated water was returned into the lake. The feasibility of treatment has been proven for the possible remediation of this shallow mesotrophic lake.

1 INTRODUCTION

Surface water is heavily affected due to new climate change patterns combined with anthropogenic actions. These patterns are characterized by precipitation increase in some regions (de Wit et al. 2016; Morabito et al. 2018), dry period intensification in others (Rocha Junior et al. 2018), water temperature stratification changes in lake systems (i.e., affecting water mixing) (Wolway et al. 2019) or simply the anthropogenic action of releasing waste in to those waters directly or indirectly without previous treatment (Bhagowati & Ahamad 2019).

By these variables, the concentration of nutrients and sediments in lake systems is increasing, resulting in the possible eutrophication and browning of those aquatic bodies (Hayden et al. 2019). This human-induced fertilization leads to an increase in water color and excessive cyanobacteria/algae growth possibly affecting the aquatic system's natural processes. In addition, it can bring potential recreational and health advisories by the government due to possible cyanotoxin release in to the water. As those stressors will not cease in

the near future, the number of affected lakes will increase over the years (Le Moal et al. 2019) and may bring nutrient enrichment of lakes to be a rising concern soon.

Although nutrients from catchments are partly in the particulate form that settles in the water column (i.e., external loads) and are not directly used by phytoplankton until released from particles, internal loads are predominantly in the dissolved form directly available for algal growth (Bormans et al. 2016). In addition, the spatial distribution of those nutrients is not uniform throughout the whole lake (Veetil et al. 2018), making it difficult to assess and remediate in a possible eutrophication case.

The first methodology to combat eutrophication on shallow lakes is the reduction of phosphorus availability on the system either in the particulate or dissolved form. This element is considered the limiting nutrient (Søndergaard et al. 2017). Several methods in the literature address internal and external nutrient loads. For example, there are sediment dredging and lanthanum-modified bentonite addition (Yin, et al. 2021), cement addition (Liu et al. 2020), water intake, and oxygen nanobubble aeration (Zhang et al. 2020).

These remediation techniques can decrease the water volume, in the case of additives, and adversely disrupt lake biota in the water column and sediment and thus are not ideal remedial alternatives (Pereira et al. 2020). To answer this problem, geotextiles have been employed as membranes by our research group for lake/pond water remediation by nutrient and suspended solids removal using filtration (Veetil et al. 2021; Pereira et al. 2020; Mulligan et al. 2009), indicating its strong potential as a flexible and reactive environmental remediation technique that can be adapted to shallow lakes and other surface water types.

Therefore, over the years, our environmental engineering research team has been deploying a flexible and reactive approach, an on-site non-woven geotextile filtration treatment, for lake water remediation. In 2020, the on-site trials have been applied at Lake Johanne, a shallow mesotrophic lake, located in a Quebec municipality, which has suffered in the past recreational advisories due to water quality. Consequently, the objectives of this present study are to assess the lake water quality and evaluate the usefulness of the geotextile on-site filtration for nutrient and suspended solids removal.

2 MATERIALS AND METHODS SCHEDULE

2.1 Study Area

The study area of this project was Lake Johanne (45°50′23″N; 74°08′19″W), shown in Figure 1, a shallow mesotrophic lake located in the *Sainte-Anne des-Lacs* municipality in Quebec. This is considered the head lake in the Masse watershed, composed of vegetation with few residents (Couture et al. 2013). The approximate surface area of the lake is 44,910 m^2, water volume is 74,900 m^3 also with a maximum and average depths of 3.5 and 1.7 m, respectively (ABVLacs Org. 2018).

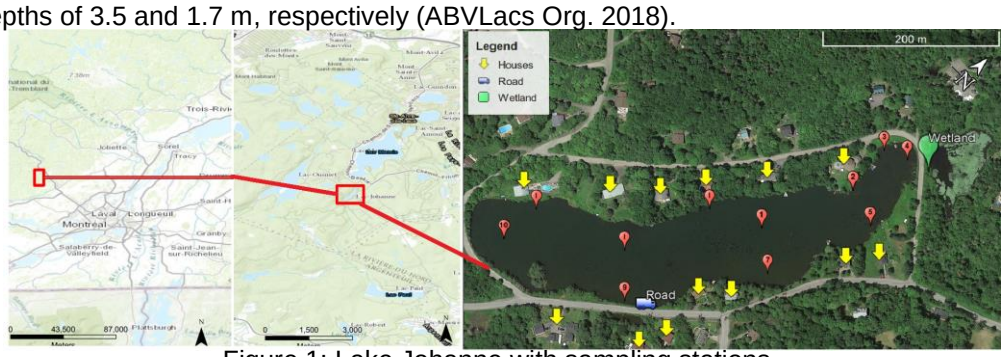

Figure 1: Lake Johanne with sampling stations

Increased phosphorus occurrence on the lake has been correlated to external loads as runoff from a nearby road (i.e., Station 9) and the forested area as well as plant decomposition in the water. Furthermore, internal loads are associated with wetland discharge at the lake inlet, possible diffuse contamination from septic tanks, and phosphorus sediment release. According to Veetil et al. (2018), the sediment phosphorus concentration in this lake varied between 1186-1451 mg/kg.

2.2 Filter media

Geotextiles were used in this onsite treatment as filtration media for capturing suspended solids and particulate nutrients to remediate this mesotrophic lake water. The filter selection and combination were based on the previous on-site studies during 2017-2018, corroborated by 2019 project results (Pereira et al., 2020). The geotextiles were made by Titan Environmental based on the particle size that 90% of solids in this lake water is under (D90). The characteristics of the five non-woven geotextiles membranes used (TE-GTX300, TE GTT100, TE-GTT120, TE-GTT200, and TE-GTN350B) are represented in Table 1.

Table 1: Non-woven geotextile characteristics used in this study.

Filters	Material	Apparent Opening Size (AOS) (µm)	Flow rate ($L/s/m^2$)	Permittivity (sec^{-1})	Mass per unit area (g/m^2)	Thickness (mm)
TE-GTX300	[a]PET	110 µm	65	1.62	300	-
TE-GTT100	[b]PP	100 µm	75	-	150	0.8
TE-GTT120	[b]PP	90 µm	70	-	120	0.8
TE-GTT200	[b]PP	70 µm	50	-	200	1.5
TE-GTN350B	[b]PP	65 µm	45	0.56	350	-

[a]PET: Polyester; [b]PP: Polypropylene

With the exception of the nonwoven geotextile TE-GTX300 that was made with PET fibers, the four other geotextile membranes were made of polypropylene (PP) fibers. They were all extremely flexible with a dimensionally stable fabric that is an excellent material to be used as a filtration membrane.

For use in this research, geotextile layers were cut in a 22 cm diameter and arranged in decreasing order of their AOS (110 µm, 100 µm, 90 µm, 70 µm, and 65 µm) using one layer of each one. When combined the total thickness of the five layers was approximately 10.0 mm. Identical filter combinations were employed for both batch and continuous experiments. Also, the combined layers (CL) were entirely changed upon clogging or by the end of each experiment, whichever happened first. Figure 2 shows three non-woven geotextiles before the filtration process.

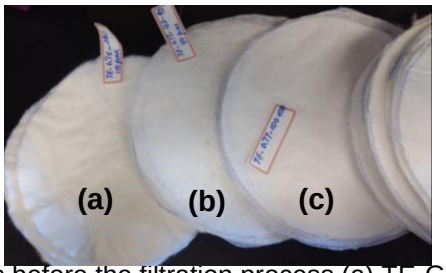

Figure 2: Non-woven geotextiles before the filtration process (a) TE-GTX300-110 µm (b) TE-GTT120-90 µm (c) TE-GTT100-100 µm

2.3 On-site geotextile filtration setup

The setup used on this project was based on a plastic tank of 543 L, width of 97.8 cm and height of 35.6 cm, placed in a cleared and leveled area near to the lakeshore (i.e., station 2) with a floating unit recirculating water to be filtered by the combined non-woven geotextile layers. Additionally, four small pumps were submerged in the tank with a very low flow rate to prevent short-circuiting in filtering the entire tank water.

The floating unit was made of plexiglass consisting of a square-shaped base, a filter holder, and a cylindrical tube with 20 cm, 25 cm of internal diameter and height, respectively. shown in Figure 3 (a). The circular

void at the center, where the water column contacts the geotextiles, has a column diameter of 20 cm. The filtration column was placed on a square base to support a maximum hydraulic head of 18 cm. Screws were used to fix and attach the filtration column to the base and the membrane combination.

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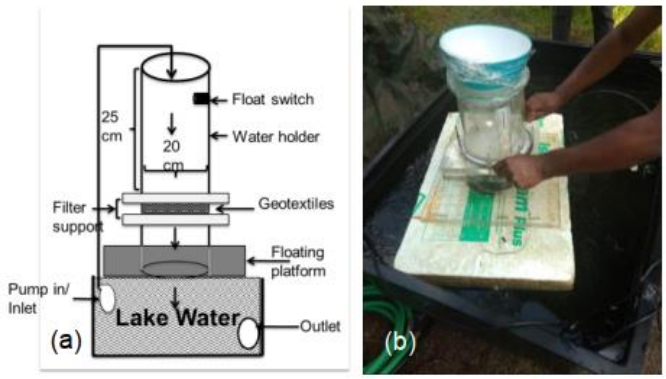


Figure 3: (a) Schematic of filtration set up and (b) On-site filtration unit.

For the experiment deployment, the tank was filled up to 300L of lake water using a submersible pump. After this, the filtration unit with the sandwiched geotextile combination was placed on the polystyrene foam sheet with a circular hole of 20 cm at the center, to float the component on the tank water and to permit the filtered water to return to the tank (Figure 3 (b)).

In this study, two different filtration tests were deployed: (i) 3 batch experiments, and (ii) 3 continuous filtration experiments with retention times of 2, 1, and 0.5 day. While the continuous experiment was performed using an inlet (with a previously calibrated medium flow rate peristaltic pump fed by lake water) and outlet by overflow, the batch experiment only treated 300L for an average of 6.6 days. The experiment was checked for geotextile clogging, pumping status, outlet and inlet clogging, sampling, and other external influences every 2-3 days. A tarpaulin was used for covering the system.

2.4 Water Quality Analysis

Water samples from the tank and the inlet (when the continuous experiment was deployed), were taken every 2-3 days. Also, water samplings of the entire lake were done at selected stations (St. 1, St. 4, St. 7, St. 9, and St. 11) for accessing water quality in the 2020 summer to-midfall. Water samples were collected in 1L high-density polyethylene (HDPE) amber bottles and 50 ml sterilized polypropylene test tubes. Both were stored at 4°C in the dark prior to any physico-chemical analysis and all analyses were performed within 48h.

The water samples were analyzed for the following parameters: particle size distribution (PSA), turbidity, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), nitrate (NO_3^-), and Chemical Oxygen Demand (COD). Test kits from Hach chemicals were used for analyzing TN (TNT 826, Method 10208, persulfate digestion) and COD (TNT 820, Method 10221, reactor digestion method). Particle size analysis (PSA) was performed with a laser diffraction particle analyzer (LA-960 Horiba laser particle size analyzer). Turbidity was measured with an Oakton turbidity meter, and TSS followed the APHA procedure (SM 2540D).

Nitrate was determined using a Metrohm Ion Chromatography applying isocratic conditions with a Metrosep A Supp 5 - 150/4.0 analytical column (150x4mm) and suppressed conductivity detection. The eluent used was composed of 3.2 mM Na_2CO_3 –1.0 mM $NaHCO_3$. The injection volume was 100 µL/ml, and the eluent flow rate was 7.0 ml/min. Phosphorus, on the other hand, was determined by elemental analysis done by ICP-MS with a quadruple mass analyzer after partial acid-peroxide digestion (HNO_3-H_2O_2) of water samples (USEPA 3050A).

3 RESULTS AND DISCUSSION

3.1 Lake Johanne water quality assessment

Using the MDDEP trophic status classification, Lake Johanne (LJ) is a mesotrophic lake (13-20 µg/L) possible going towards the high range of mesoeutrophic classification in the future. Our results when only based on total phosphorus concentration have shown the same classification. It is worth commenting that LJ has an average depth of 1.7 m and no significant microscopic algae/cyanobacteria in suspension and other comprehensive methods used for trophic classification (chlorophyll-a and transparency) are not applicable for shallow lakes. Table 2 presents the results of samplings for the year 2020.

Table 2: Lake Johanne water quality during July-Sep, 2020

Parameters	2020[a]
TP (µg/L)	15.1±1.5
COD (mg/L)	21.0±2.5
NO_3^- (mg/L)	0.4±0.3
TN (mg/L)	1.0±0.7
TSS (mg/L)	4.6±1.1

[a]Average of 7 samplings of 5 lake stations

Regarding PSA results, the D90 was under the range of 60 to 74 µm and 50% of the particles have (D50) diameters under the 8 to 16 µm range over the 7 samplings of 2020. Large particle sizes were found at St.4, near the wetland as this is one of the internal sediments/nutrient inputs of the lake. Nitrate and TN concentrations are under Quebec guidelines (i.e., MDDEP, 2012) for protecting aquatic life, and are 2.9 mg/L and 1.0 mg/L, respectively.

Related to the total suspended solids (TSS) concentration in this lake water, even though the guideline value for concentration presents a value of 13 mg/L in the IQBP (*l'indice de qualité bactériologique et physicochimique*), this parameter needs to be addressed because TSS is an excellent indicator of physical and esthetic degradation of this surface water. The COD concentration showed that LJ water is slightly elevated above the guideline of 20 mg/L according to Chapman and Kimstach (1996). All those results corroborate the MELCC (2018) recommendation on *Réseau de surveillance volontaire des lacs* (RSVL) for the adoption of measures to limit nutrient inputs and avoiding further degradation of this lake and further loss of uses.

3.2 Filtration experiments

Treatment experiments ran for 91 days from July 17 to October 15 of 2020 (i.e., divided into 3 batch experiments and 3 continuous experiments) shortly after the start of summer until the mid-fall season. For the whole experiment, 26 sets of filters cut 22 cm in diameter (5 layers) were used, totaling approximately 1 m^2 for each AOS in the experiment with a total cost of $5.05 for treating 34.5 m^3 of lake water. It is worth commenting that when the retention time was at the lowest value (0.5 day or 12 hours), filters were changed every 3 days due to clogging.

Cake layer formation was observed on the top of the geotextile combination in all experiments. For a more graphic representation, Figure 4 shows one set of used geotextile filters after 1 week of lake water filtration. As can been perceived, not only the straining filtration mechanism has occurred on this process but also depth filtration due to the initial ripening and further cake formation. Those mechanisms were efficient in reducing the AOS of the membranes and further explain the reduction of particle size and quantity of suspended solids of treated lake water.

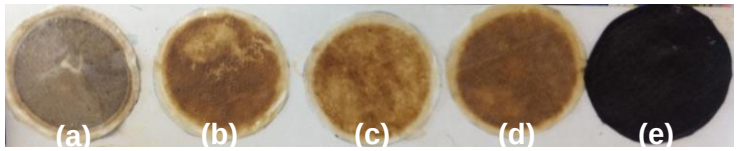


Figure 4: Non-woven geotextiles after the filtration process in the AOS order: (a) 110 µm (b) 100 µm (c) 90 µm (d) 70 µm and (e) 65 µm

3.3 Batch Experiments

As with any filtration process, the first and foremost removal that occurs is the suspended particles. These mechanics were observed in this remediation technique showing the efficiency of this on-site non-woven geotextile filtration method. With an average of 6.6 days, three batch experiments were performed using 300L of lake water. Due to the particle accumulation on the top of the filters and cake formation after the second day of deployment, those experiments presented an expressive reduction in the suspended particles. The TSS results and the diameter of 90% of the particles (D90) observed are shown, in Figure 5 (a) and (b). This represented a 75% and 86% particle size and TSS reduction, respectively.

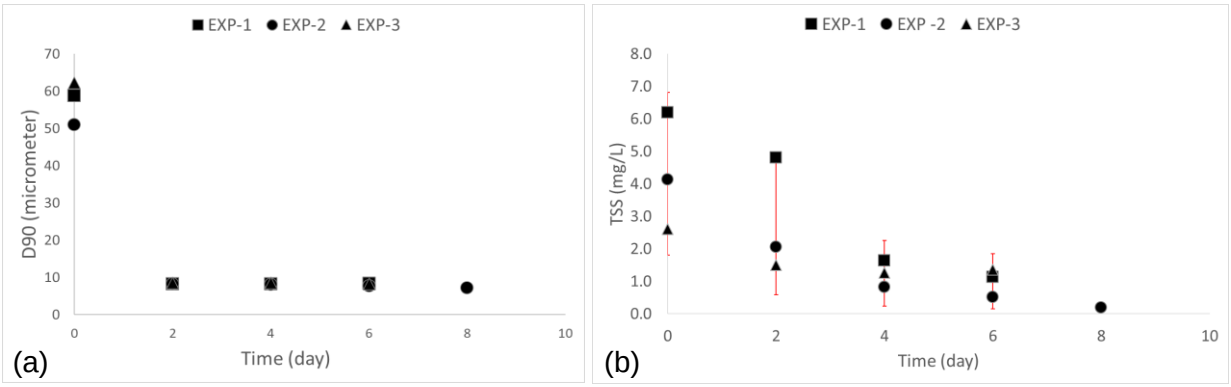


Figure 5: (a) D90 diameter (µm) and (b) TSS concentration (mg/L) in the tank water

Furthermore, the removal of suspended particles in the water has caused the same reduction in the organic matter, represented by COD, and particulate phosphorus, represented by total phosphorus (TP), as shown in Figure 6 (a) and (b). In other words, removing suspended particles from this lake water by this environmental treatment has demonstrated a reduction in the nutrient concentration in water. The direct remediation of this lake water allows removing particles that would settle with time to be uptaken by the phytoplankton. Total removal in the system was approximately an average removal of 75% of TP and 11% of COD in the experiments. By the end of batch experiments, the limit value for unpolluted oligotrophic surface waters was reached.

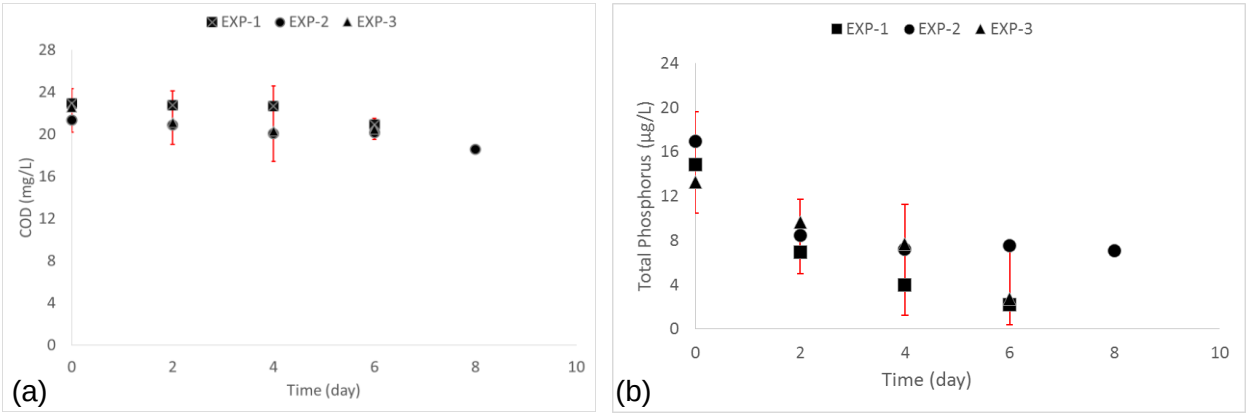


Figure 6: (a) COD concentrations (mg/L) and (b) TP concentrations (µg/L) in the tank water

Throughout the experiments, no significant change in the concentrations of TN and nitrate was observed. The average value was kept below the values present in the raw water and within the Quebec regulated

values. For TN, the value was kept at an average of 0.89 ± 0.14 mg/L, and for nitrate, its average was 0.18 ± 0.02 mg/L.

3.4 Continuous Experiments

To test the reactivity and adaptability of the system, 3 continuous experiments were performed, using a peristaltic pump for the inlet (lake water) and overflow for outlet (returning to the lake). This was a continuation of the experiments done in 2019. In the experiments, it was observed that a fast and stable removal of TSS brought a steady D90 reduction in the tank water proving that AOS reduction can improve filtration. This reduction in the geotextile's pore sizes, long after the second day of filtration can be seen in Figure 7 (a) and (b) with removals of TSS and particle sizes. The size of 90% of particles in the tank/outlet (D90) was kept below 8.45 ± 0.23 µm from the second day of the first experiment done (1 -day) until the end with the other retention times (2 and 0.5 days). The average reduction on D90 was 99.9% in this experiment.

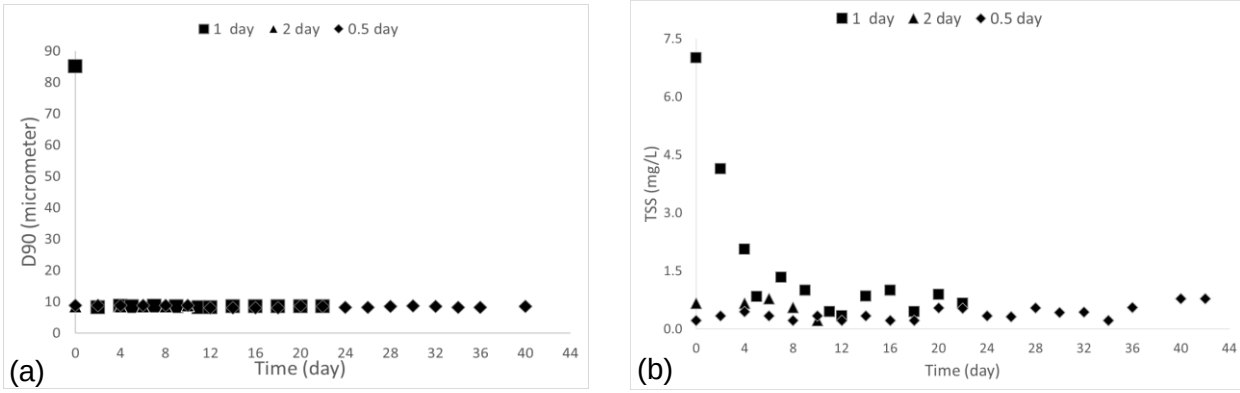
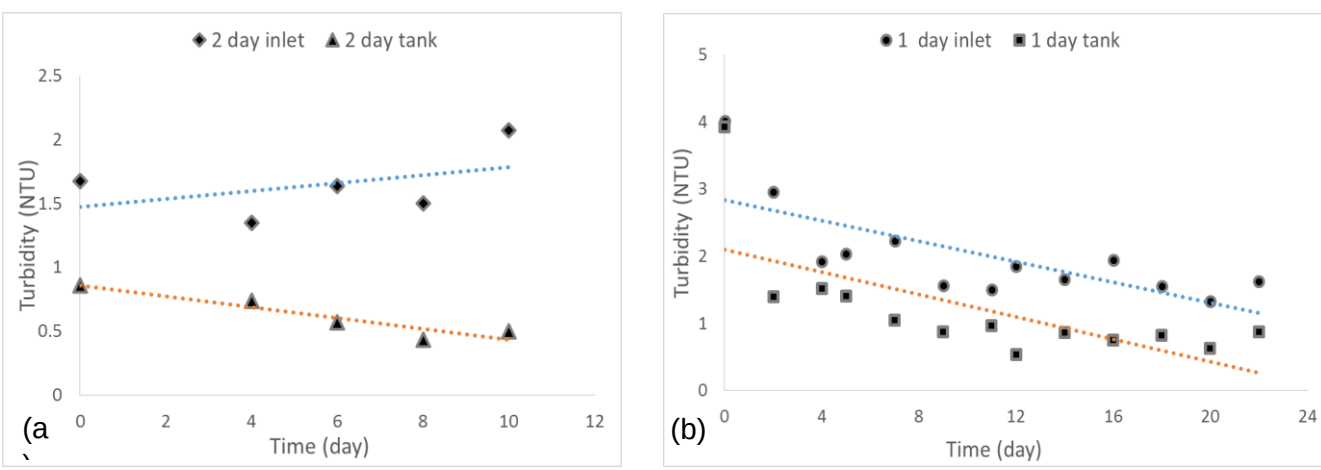


Figure 7: (a) D90 (µm) in the tank water for specific retention time and (b) TSS concentration (mg/L) for 1- ,2- and 0.5-day retention time in the tank water

Likewise, the treated water discharged into the lake presented TSS values below 2.0 mg/L after two days of filtration in the 1 -day retention time (Figure 7(b)). For 2- day and 0.5- day retention times, the removal was maintained values even below 2.0 mg/L, realizing a cleaner output water at the same level. The average removal was 94%, for a 1 -day retention time keeping the TSS values at 0.66 ± 0.67 mg/L until the end of the experiment. Removal of TSS in the lake water also reduced the turbidity (Figure 8 (a), (b), and (c) in the returning lake water, presenting the values always below the initial values of the lake. For the retention time of 1 day, an average removal of 41% was achieved when comparing the inlet and outlet. Greater removal was achieved for the 2 day and 0.5-day retention times where the averages were 62% and 67%, respectively.



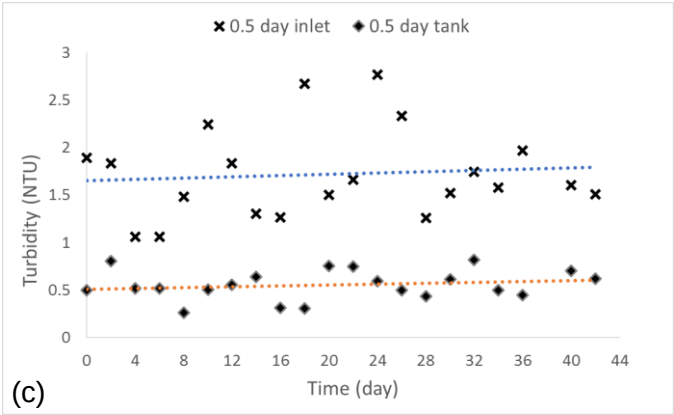


Figure 8: (a) Turbidity removal (NTU) for 2- day retention time, (b) Turbidity removal (NTU) for 1-day retention time and (c) Turbidity removal (NTU) for a 0.5-day retention time

Oligotrophic water was returned to the lake shortly after 2 days of filtration remaining steady during the whole experiment, as can be seen in Figure 9 (a), (b), and (c). Even with constant input going into the tank, the floating filter unit was able to achieve constant removal of particulate phosphorus. This was accomplished because as previously presented, removal of TSS, turbidity, and reducing particle size occurred. In other words, suspended particles have phosphorus associated with it. It was noticed that average removal was 63%, 63%, 35% with decreasing retention. This lower value is explained because when water temperature started to drop the TSS level reduced.

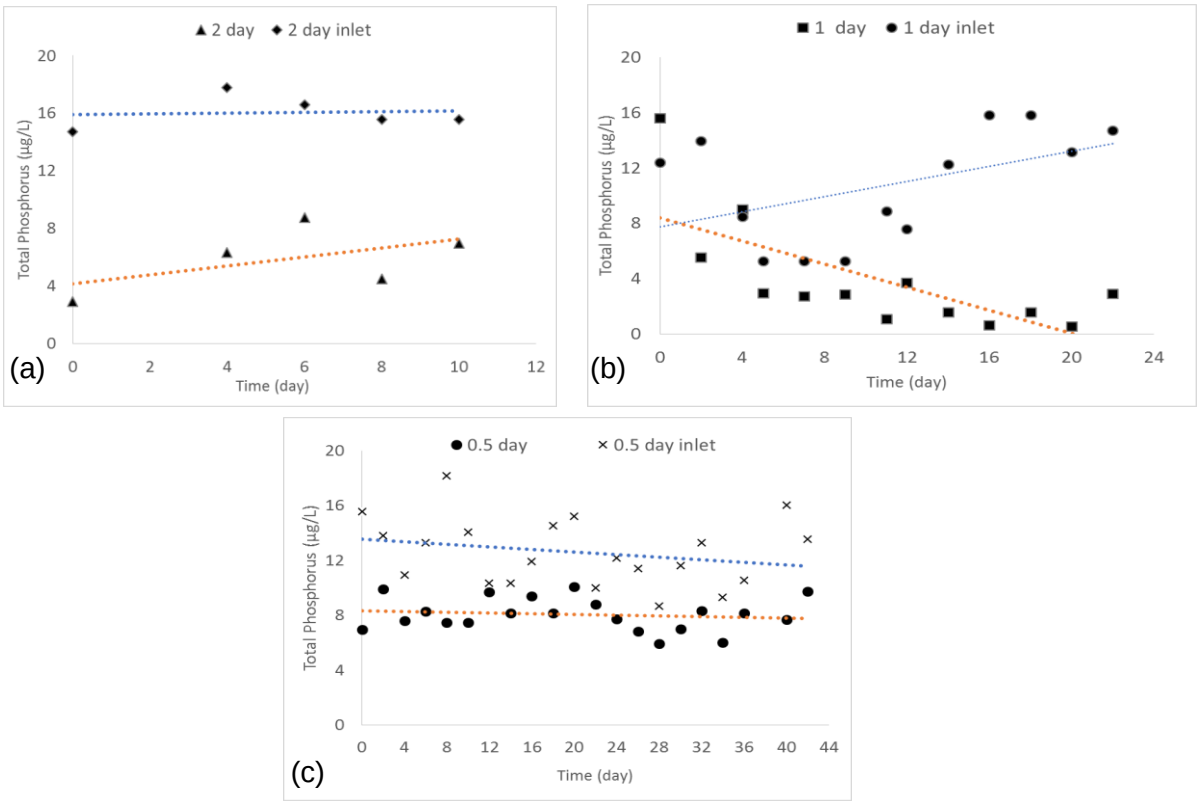


Figure 9: (a) TP concentrations (µg/L) for 2 -day retention time, (b) TP concentrations (µg/L) for 1-day retention time and (c) TP concentrations (µg/L) for a 0.5-day retention time

Similar to the batch experiments, in the 3 continuous tests, no significant alteration of the concentrations of TN and nitrate were found. The TN value remained 0.95 ± 0.21 mg/L and for nitrate, the average value was 0.17 ± 0.05 mg/L which did not affect the experiment. On other hand, the COD presented continuous removal of approximately 12% in the 3 retention times presented. Figure 10 (a), (b), and (c) demonstrates the removal of COD in the experiments. Due to the nature of the COD in this lake water, which is found mainly in the dissolved form, particle removal does not significantly affect this value. Additionally, the higher removal in batch experiments could be explained by the higher retention time that causes uptake of some dissolved COD.

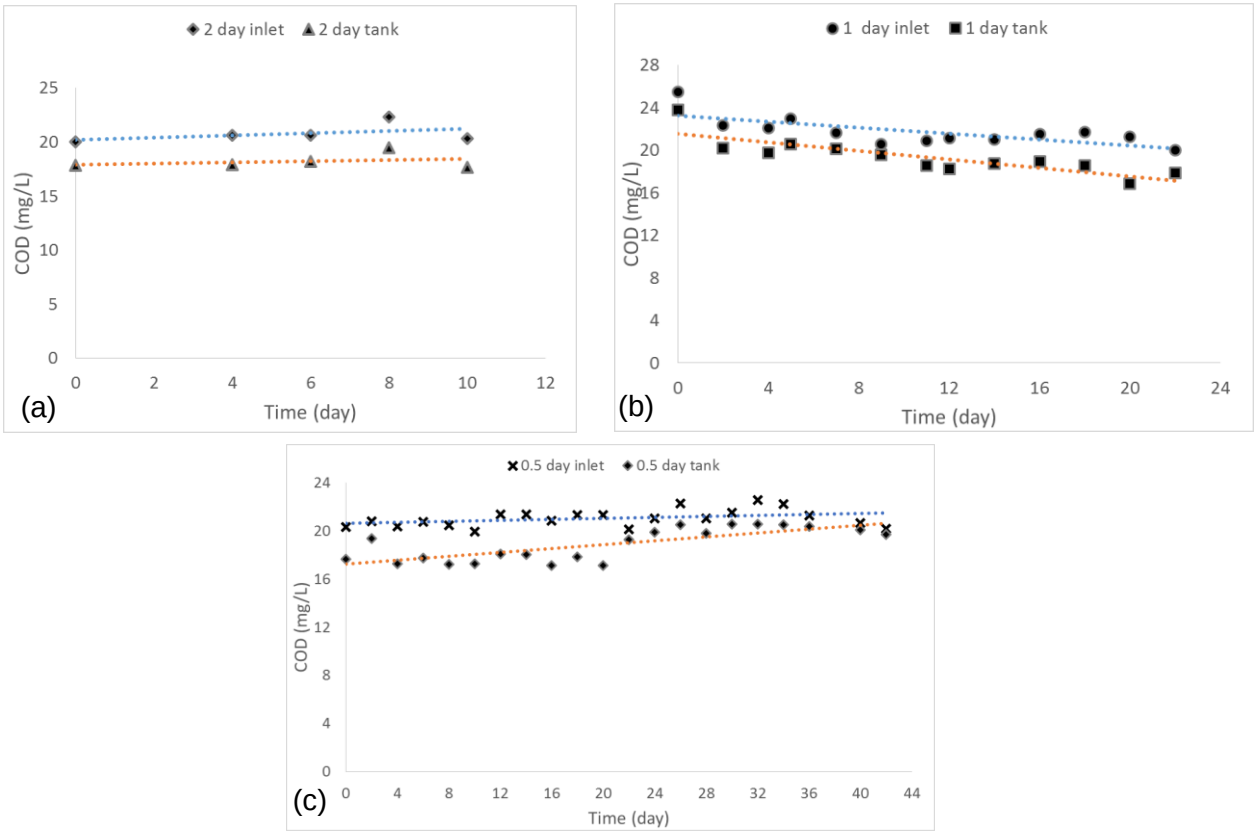


Figure 10: (a) COD concentrations (mg/L) for 2- day retention time, (b) COD concentrations (mg/L) for 1 day retention time and (c) COD concentrations (mg/L) for a 0.5- day retention time

4 CONCLUSIONS

With this adaptable, reactive, and environmentally-friendly remediation technique a representative amount of lake water was improved thus proving the method's feasibility. The combined non-woven geotextile thin layers in the floating unit have reduced the number of particles and their sizes in the water by sieving and cake filtration that lowers the membrane AOS. With reduced suspended particles and turbidity, lake levels of phosphorus and organic matter were lowered as well and cleaner water was returned to it. These on-site non-woven geotextile experiments have shown to be a potentially economically efficient and strong technique to be applied not only for preventing new sediment settling but also particulate phosphorus uptake that can be directly applied to water quality management in lakes. Incineration of clogged membranes (i.e., volume reduction) and final disposal in landfills is the most convenient way to dispose of used geotextiles membranes. However, in the direction of circular economy and sustainability to ensure waste reduction, routes to reuse, reduce, and recycle of membranes are being addressed. For future work, in situ filtration tests, dissolved COD removal, and clogged geotextile filter reuse will be investigated.

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