



WETLAND WATER DISCHARGE REMEDIATION USING ON-SITE NON-WOVEN GEOTEXTILE FILTRATION

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Abstract: Lake Johanne, a shallow mesotrophic lake located in the *Sainte-Anne-des-Lacs* municipality in Quebec is receiving water from a wetland discharge. This wetland water could be possibly contributing to this lake's ageing. Thus, as an initial investigation, an on-site potential remediation of this wetland water discharge using a non-woven geotextile filtration technique is proposed. The method was based on a tank located near the lakeshore with a floating geotextile filtration system in continuous mode (i.e., 0.5-day retention time). On deployment, wetland water was pumped into the tank using a calibrated peristaltic pump (inlet), filtered by a selected set of non-woven geotextiles with distinct apparent opening sizes and then returned to the lake (outlet) by gravity. This experiment ran throughout the summer and mid-fall of 2021. Samples from both the inlet and tank were taken every 2 days and filter layers were changed upon clogging. The objective of this study was to improve the quality of this discharge before entering the lake by filtration. The water quality parameters monitored during the experiment from both inlet and tank samples were total phosphorus, total nitrogen, nitrate, chemical oxygen demand, total suspended solids, particle size, and turbidity. The nonwoven geotextile filters removed nutrients, organic matter, and suspended particles at levels of 32%, 17%, and 29% for total phosphorus, COD, and turbidity removals, respectively when the tank inlet and outlet were compared during the entire experiment. In addition, it was proven that the proposed method is easy to install, deploy and quickly adapt to water quality changes. Even though the results have pointed out that additional investigation is needed, the treatment improved the quality of a portion of this wetland water. Thus, the feasibility of treatment has been shown for this possible remediation.

1 INTRODUCTION

Ageing of waters is intensified around the globe due to climate change scenarios synergically associated with well known human-made variables such as land modifications (Zheng et al., 2021; Meyer-Jacob et al., 2019), watershed pollution (Cooperrider et al., 2020; Morabito et al., 2018) and consumption behavior (Belgacem et al., 2021; Hamilton et al., 2018). Triggered by organic matter and nutrient input increase from allochthonous sources (i.e., catchment-derived sources also known as external loads) and autochthonous sources (i.e., internal loads), this aging is hastening trophic level changes and increasing eutrophication scenarios in water resources.

In these possible eutrophication scenarios, benthic primary productivity (macrophytes and periphyton) will be shifted to pelagic primary production (phytoplankton) (Alexander et al., 2017), causing plankton biomass to increase. Generally, this will cause a shift to a cyanobacteria-dominated phytoplankton community (Senar et al., 2021) in the water column. Therefore, with the increase of cyanobacteria-dominated phytoplankton communities in waters, issues of recreational and drinking advisories due to harmful toxin production (Li et al., 2022; Yindong et al., 2021), as well as water anoxia, obnoxious scum and smells, will occur more frequently.

In this view, for definition purposes, allochthonous sources are conveyed by watershed runoff or incomplete treated effluent discharge. Autochthonous sources, on the other hand, are associated with past catchment-derived emissions, internal releases from sediment disturbances (e.g., natural summer lake turnover), and/or organic matter decomposition into the water. It should be emphasized that whereas external nutrient loads are predominantly in the particulate form (i.e., phosphorus), and not directly available for plankton communities, internal loads are mostly in the dissolved form and openly available for cyanobacteria growth (i.e., blue-green algae) (Bormans et al. 2016). Both of the sources are composed of macronutrients like nitrogen and phosphorus, organic matter characterized by carbon components, and some micronutrients in low concentrations. They are extremely important for further plankton development.

On the elements presented, phosphorus could be highlighted as a limiting nutrient, which can trigger the uncontrolled growth of photosynthetic aquatic microorganisms in natural waters (Zheng, et al., 2019). Therefore, remediation methods to inhibit possible trophic changes or attenuate eutrophication scenarios on water resources are focused on the removal or reduction of this element. In the specialized literature, the following methods are highlighted as go-to approaches: sediment dredging, hypolimnetic water withdrawal, sediment capping by inert elements, and phosphorus inactivation in the water column and bottom sediments via chemical addition. Those practices are highly technical, drastic, energy-demanding, expensive, and could be harmful to water organisms and end-water users.

Conversely, methods that take advantage of a lake ecosystem's natural response to changes made within it, called ecological methods are in development and study. One of those methods is been investigated by our research group. Through the use of in situ/onsite filtration units with geotextiles as filter membranes, removal of particulate nutrients, organic matter, and total suspended solids are being achieved (Pereira, 2021; Veetil et al. 2021; Pereira et al. 2020; Mulligan et al. 2009). In other words, the lake/pond water geotextile filtration has been extensively investigated, indicating the potential of this technique as flexible, responsive, and environmentally-safe remediation that can be adjusted to other surface water types.

To continue this investigation, Lake Johanne (LJ) has been chosen as the study area. A shallow mesotrophic lake, located in *Sainte-Anne-des-Lacs* Quebec municipality, is being possibly degraded and aged throughout the slow increase of organic matter and nutrients on it. Our studies have been emphasizing that the wetland discharge, located on the northeast lake corner is one of the possible ageing factors (Pereira et al. 2021; Pereira et al., 2020). This discharge presents higher particle size, organic matter, and nutrient content than the overall lake quality. On this understanding, the on-site non-woven geotextile filtration treatment, for this lake water remediation was applied in 2021. However, a different methodology was taken, as the system inlet was modified from the lakeshore to the wetland discharge. Therefore, 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 solid removal on the discharge in a continuous experiment with a retention time of 0.5 day.

2 MATERIALS AND METHODS

2.1 Influent Study Area

Lake Johanne (45°50'23"N; 74°08'19"W) a shallow mesotrophic lake in *Sainte-Anne des-Lacs* municipality, Quebec (situated around 75km north of downtown Montreal near to *Laurentian* Mountains) was chosen for the study area. Located in the *Masse* watershed (i.e., one of the contributors to the *Rivière du Nord*), which is mainly composed of vegetation and few households. This mesotrophic head lake had passed through some recreational advisories in the past associated with excessive algae/cyanobacteria growth.

This lake is an artificial water body with maximum and average depths of 3.5 and 1.7 m and approximately surface area and water volume of 44,910 m² and 74,900 m³, respectively (ABVLacs Org., 2021). Also, the main sources of water renewal are associated with wetland discharge, precipitation, surface runoff, and snow melting and its renewal time is 0.48 years. Figure 1 shows Lake Johanne's location with sampling stations, wetland, and other details.

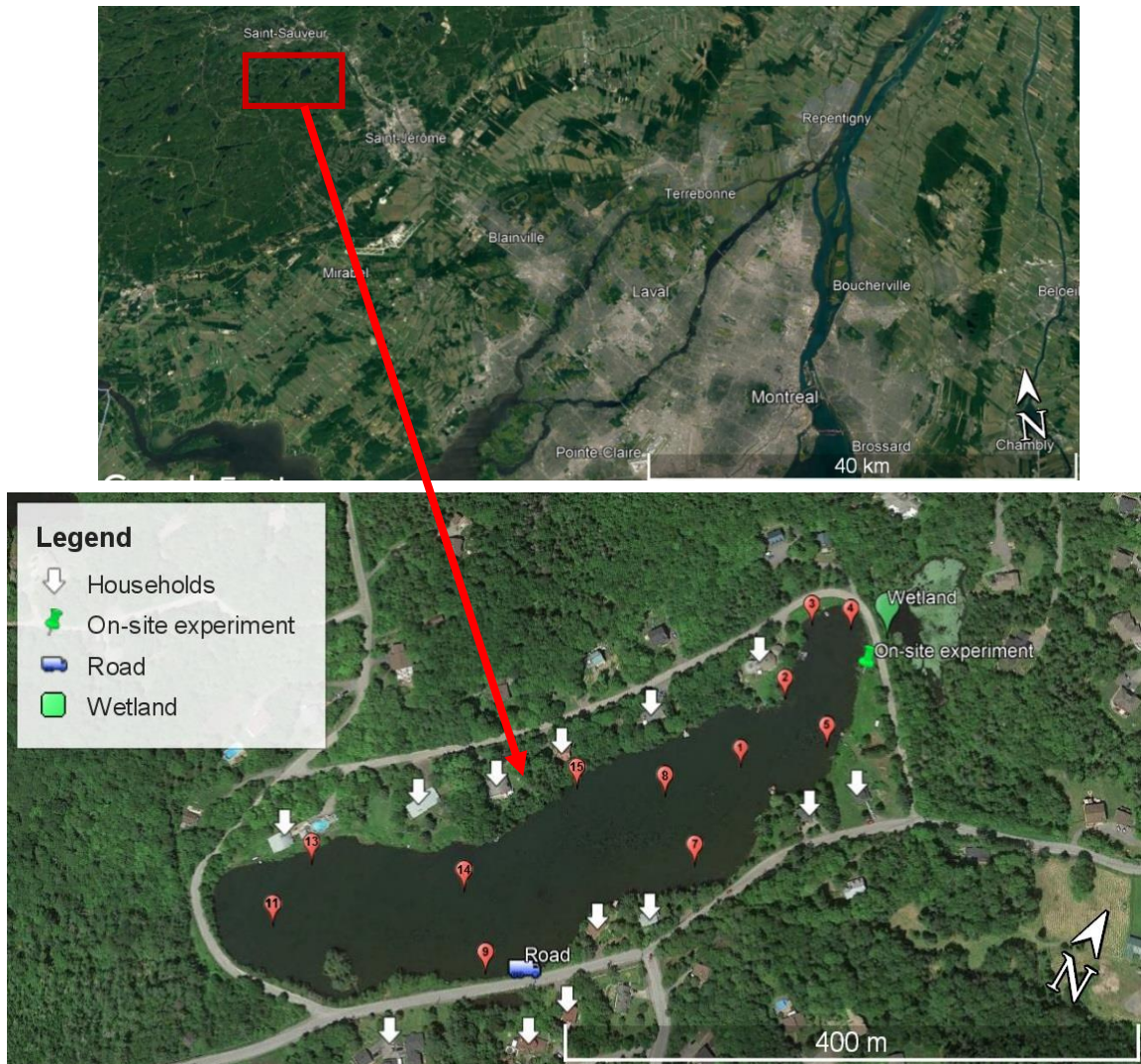


Figure 1: Lake Johanne location with sampling stations as shown by the numbered indicators. White arrows indicate the nearest lakeshore household

Related to the nutrients, external phosphorus loads occurrence on this lake comprises runoff from a nearby road (i.e., near Station 9) and the wooded land around it, as well as plant decay in the water. Internal loads are, however, attributed to phosphorus sediment release, wetland discharge at the lake inlet, and possibly diffuse pollution from septic tanks. Also, the sediment phosphorus content in this lake is not homogenous and according to Veetil et al. (2018) ranges from 1186 to 1451 mg/kg.

2.2 Geotextile Filtration Setup – Onsite experiment

For the onsite geotextile filtering deployment, a 543 L plastic tank (35.6 cm in height and 97.8 cm in width) was installed near the lakeshore. Different from previous studies where the system inlet was located near station 2, this was altered to be near the wetland discharge on the lake's upper northeast corner, almost 50 m from the tank, as presented in Figure 2. For the experiment start, a submersible pump was used to fill up the tank until 300L. After that, a peristaltic calibrated pump was used to continuously feed the tank with the wetland water (i.e., considered the system input), with a retention time of 0.5 days throughout the 72 experiment days. Additionally, the treated wetland discharge water was returned to the lake using gravity (i.e., system output). For system protection from external influences, a tarpaulin was used as a cover.



Figure 2: Wetland discharge location and system placement on the lakeshore

Regarding the floating filtration unit, where the geotextile layers were placed, this was made as a cylindrical Plexiglas column with an internal diameter of 20 cm and a height of 25 cm. In addition to a square-shaped base, which serves as a filter holder and has a circular hole in the center with the exact filtration column diameter (20 cm) shown in Figure 3. (a), capable to sustain a maximum hydraulic head of 18 cm above it. The filtration unit with the sandwiched geotextile combination was mounted on a polystyrene foam sheet with a center 20 cm circular hole. (Figure 3 (b)). With this combination, the filtration unit was able to float over the tank water and allow the filtered water to return to the tank. Every 2-3 days, the experiment was evaluated for geotextile clogging, pumping status, output, and input clogging, sampling, and any other external impacts.

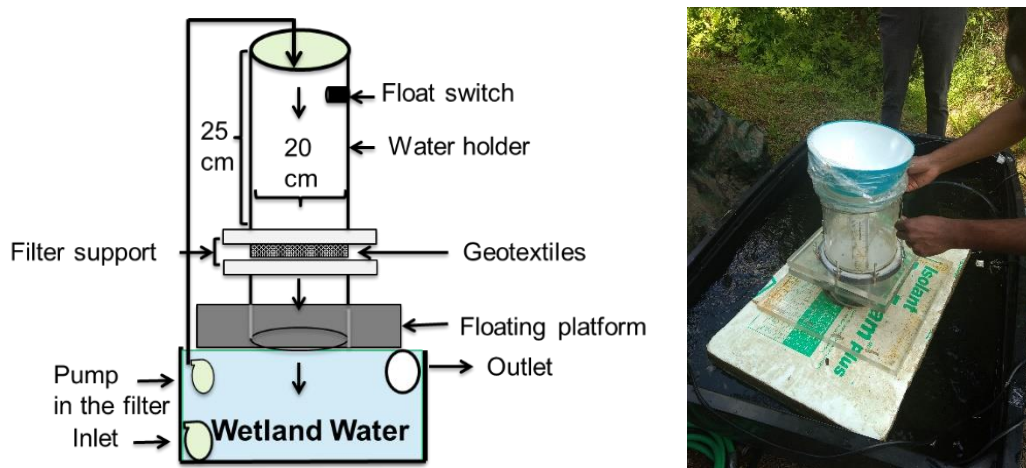


Figure 3: (a) Schematic of the on-site filtration setup (b) On-site filtration unit deployed.

2.3 Filter Media

Five custom-made geotextiles were employed as filter media to capture suspended particles and particulate nutrients in this onsite remediation of this mesotrophic lake water. The filter selection and combination were based on earlier on-site research conducted in 2017-2018, which were validated by project data from 2019 and 2020 (Pereira et al., 2020; Pereira et al., 2021). Titan Environmental Containment manufactured the geotextiles based on the particle size of 90 percent of the particles in this lake water (D90). Table 1 shows the parameters of the six non-woven geotextile membranes applied (TE-GTX300, TE-GTT100, TE-GTT120, TE-GTT200, TE-GTN350B, and TE-GTP250), and Figure 4, the non-woven geotextiles before the filtration process in the apparent opening size (AOS) descending order.

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	Polyester	110	65	1.62	300	-
TE-GTT100	Polypropylene	100	75	-	150	0.8
TE-GTT120	Polypropylene	90	70	-	120	0.8
TE-GTT200	Polypropylene	70	50	-	200	1.5
TE-GTN350B	Polypropylene	65	45	0.56	350	-
TE-GTP250	Polypropylene	60	41	0.83	200	-

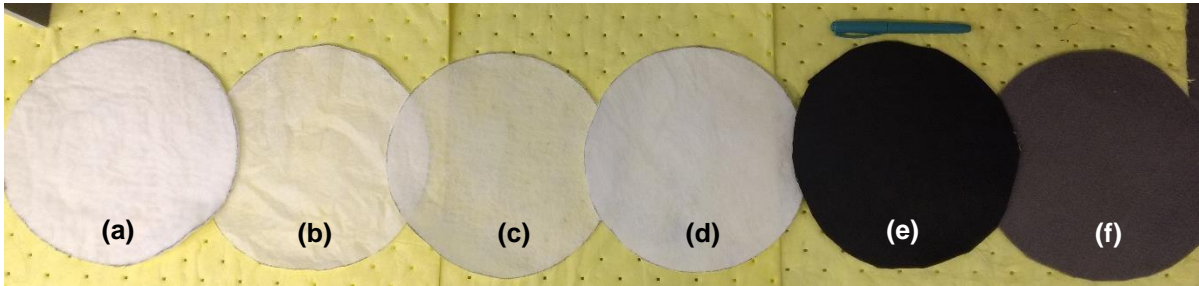


Figure 4: Non-woven geotextiles before the filtration process according to the AOS: (a) 110 μm (b) 100 μm (c) 90 μm (d) 70 μm (e) 65 μm and (f) 60 μm

The four geotextile membranes (i.e., from 4b to 4f) were comprised of polypropylene (PP) fibers, except for the nonwoven geotextile TE-GTX300 (i.e., 4a), which was produced using PET fibers. They are all exceedingly flexible, with dimensionally stable fabrics that are ideal for use as filtering membranes. For experiment deployment, these geotextile layers were cut to 22 cm diameter and arranged in decreasing order of their AOS (110 μm , 100 μm , 90 μm , 70 μm , 65 μm and 60 μm) using one layer of each. The overall thickness of the five layers when combined was roughly 20.0 mm. The combination was changed on the deployment depending on how fast geotextile clogging was experienced. The ideal filter run was adjusted to every sampling day (i.e., every 2-3 days). The base geotextile layer combination was composed of AOS from 110 μm to 70 μm arranged in descending order. The 65 μm geotextile, was added and removed from the combination when found necessary. Also when colloidal particles accumulation was noticed in the tank water, in the middle of the experiment, a further layer of 60 μm was then added, making up from 4 to 6 layers as the used combination.

2.4 Water Quality Analysis

Every 2-3 days, water samples were collected from the tank and the inlet. Additionally, overall lake quality was assessed by sampling in the lake (St. 1, St. 4, St. 7, St. 9, and St. 11) from the summer to mid-fall of 2021. All samples were taken in 1L amber bottles (high-density polyethylene (HDPE)) and 50 mL sterilized polypropylene test tubes, kept at 4°C in the dark before any physicochemical study, and acidified when necessary (i.e., in the case of phosphorus analysis) with analysis completed within 48 hours.

Particle size distribution (PSA), turbidity, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), nitrate (NO_3^-), and Chemical Oxygen Demand (COD) were all measured in the water samples collected. For TSS, the specific APHA method (SM 2540D) was used technique, and turbidity was assessed using an Oakton turbidity meter. A laser diffraction particle analyzer (LA-960 Horiba laser particle size analyzer) was used to perform particle size analysis (PSA). Thus, Hach chemicals test kits were used to analyze TN (TNT 826, Method 10208, persulfate digestion) and COD (TNT 820, Method 10221, reactor digestion method).

Phosphorus was evaluated by elemental analysis performed by ICP-MS with a quadruple mass analyzer following partial acid-peroxide digestion ($\text{HNO}_3\text{-H}_2\text{O}_2$) of water samples (USEPA 3050B). Nitrate, on the other hand, was measured using a Metrohm Ion Chromatography under isocratic conditions with a Metrosep A Supp 5 - 150/4.0 analytical column (150x4mm), suppressed conductivity detection, and 3.2 mM $\text{Na}_2\text{CO}_3\text{-1.0 mM NaHCO}_3$ as the eluent. The injection volume was 100 L/ml, and the eluent flow rate was 7.0 ml/min.

3 RESULTS AND DISCUSSION

3.1 Overall Lake Water Quality Assessment

The *Réseau de surveillance volontaire des lacs* (RSVL, 2021) by the Minister of the Environment and the Fight Against Climate Change (MELCC) in Quebec has a specific trophic status designation for lakes. Lake Johanne (LJ) on this classification is classified as a mesotrophic lake (13-20 g/L) from the 2017 to 2020 reports. Our findings, when based only on total phosphorus content, pointed to the same classification. Also, the same report recommended the adoption of measures to limit nutrient sources to avoid further degradation and further loss of use. Table 2 shows the overall lake water quality for the years 2020 and 2021.

Table 2: Lake Johanne overall water quality from July-Sep, 2020 and July-Sep, 2021

Parameters	2020 ^a	2021 ^b
TP ($\mu\text{g/L}$)	15.1 \pm 1.5	17.1 \pm 2.5
COD (mg/L)	21.0 \pm 2.5	25.0 \pm 3.5
NO_3^- (mg/L)	0.4 \pm 0.3	0.8 \pm 0.7
TN (mg/L)	1.0 \pm 0.7	1.3 \pm 0.8
TSS (mg/L)	4.6 \pm 1.1	5.2 \pm 1.1

^aAverage of 7 samplings at 5 lake stations; ^bAverage of 5 samplings at 5 lake stations

Particle size analysis from the overall lake quality was D90 in the range of 60 to 79 μm and the diameter of 50% particles (D50) under the 8 to 16 μm range over the 5 samplings of 2021. The COD concentration shown for this lake water is slightly higher than the average found in surface water of 20 mg/L, according to Chapman and Kimstach (1996). Additionally, total suspended solids (TSS), even though not too representative in the overall lake water quality, they have particulate nutrients associated with them and thus need to be attenuated.

3.2 Filtration Deployment

The remediation experiment on this wetland discharge by the onsite floating geotextile filtration proposed was executed shortly after the start of summer until the mid-fall of 2021. More specifically from July 23, 2021, to October 2, 2021, a total of 72 experimental days were done. In this deployment, a retention time of 0.5 day (12 hours) was maintained when possible, filtering a volume of 51 m^3 using 30 geotextile filter layer combinations (a total of 1.15 m^2 for each AOS). Thus the cost related only to geotextile layers was 5.81 CAD.

Additionally, geotextile layer fouling was observed after some hours of the filter run and increased until it needed to be changed. It was observed that this has aided in the decrease of AOS in the geotextile combination employed, ensuring the removal of suspended solids and nutrients in the tank water being remediated. The cake layer formed after one week of filtration is presented in Figure 5. For this onsite filtration process, two filtration mechanisms have occurred. It was noted that the first filtration mechanism that occurred was straining or surface filtration. This filtration mechanism happens when the porous surface retains the particles solely based on particle size (Berk, 2018). After that, solids then penetrate the surface of the media to block the open pores, thus forming a filter cake on the surface of the media called depth

filtration (Ebnesajjad, 2016). Thus, by particle accumulation, on the top of each geotextile layer, the surface filtration mechanism was improved and combined with depth filtration.

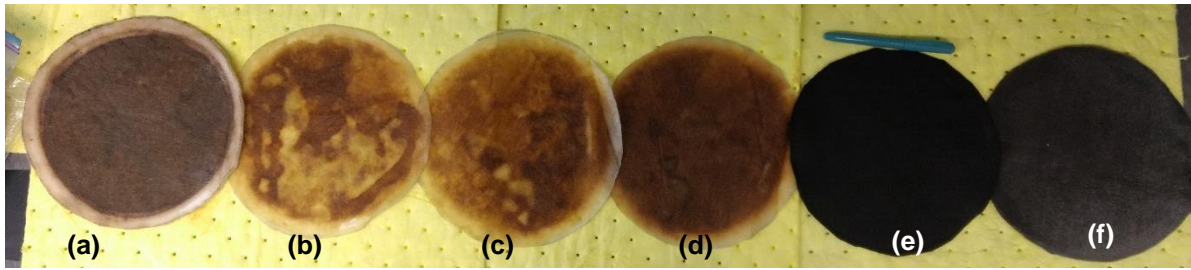


Figure 5: Non-woven geotextiles after the filtration process in the AOS order: (a) 110 μm (b) 100 μm (c) 90 μm (d) 70 μm (e) 65 μm and (f) 60 μm

3.3 Continuous Deployment

To assess the system's responsiveness and versatility for the onsite geotextile filtration application, a continuous experiment was piloted near the LJ lakeshore. The filtered water by the onsite method has shown a lower average particle size than the lake overall. The same behavior was captured for turbidity removal as well as for nutrients that were attenuated in the process. This assured that the onsite filtration was able to remove any particulate endogenous phosphorus and organic matter entering the lake.

3.3.1 Particle Follow-up

By particle size determination in the tank water, a slow reduction was observed in both the TSS amount and particle size from the start of the experiment until 35 days as shown in Figure 6. This could be justified as the system was performing well in this scenario, and any pumped water was being constantly filtered. After the decrease, a small increase was noticed in the tank TSS concentration but with particle sizes below 10 μm . This might be explained as the fine colloidal particles, which had passed through the geotextile combination had accumulated in the first 35 days into the tank and the system needed some days to adapt to this modification. Therefore, as the tank water was well mixed in the following days, TSS concentration decreased but particle size increased. The average TSS concentration on the entire experiment on the tank was $2.87 \pm 1.36 \text{ mg/L}$ and D90 (diameter of 90% of particles) was $21.84 \pm 15.07 \mu\text{m}$. Both were lower than the lake's overall quality. It was understood that by removing TSS quickly and consistently, a continuous D90 reduction in the tank water occurred, demonstrating that geotextile AOS reduction due to cake formation enhanced the filtering process.

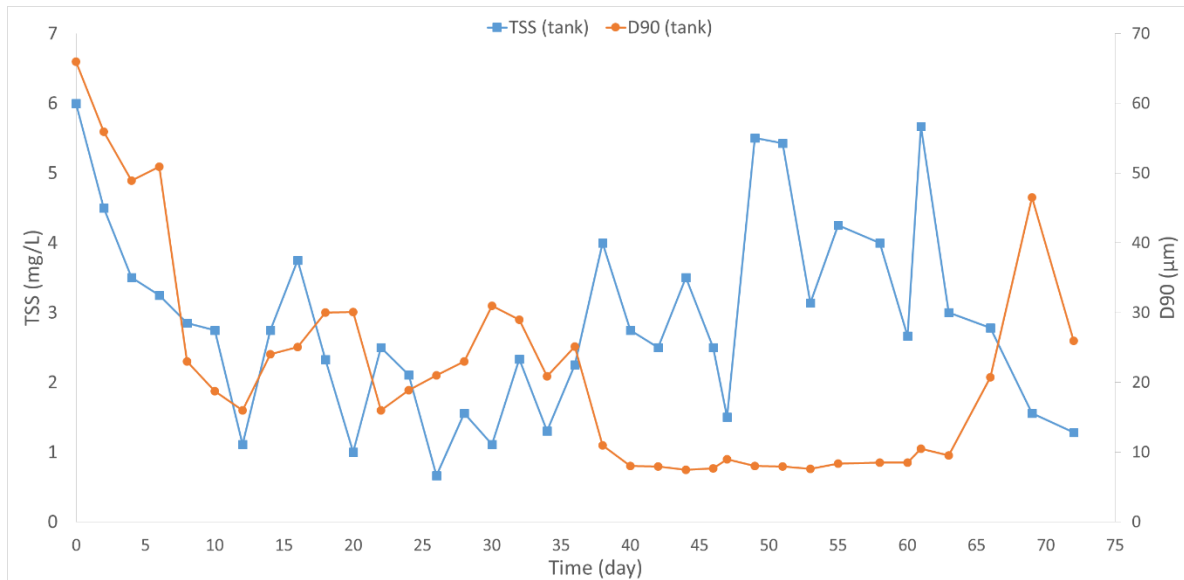


Figure 6: TSS concentration (mg/L) and D90 diameter (µm) follow-up in the tank water

3.3.2 Turbidity and Organic Matter Removal

Following the same behavior of TSS decrease in the tank followed by an increase after 35 days, it was observed that even with constant replenishment of higher turbidity water from the system input, the floating filtration unit was able to ensure particle removal. As presented in Figure 7, an average of 29% removal was obtained. In this view, less turbid water was being returned to the lake throughout the whole deployment. Average tank turbidity (same as the effluent) was 2.88 ± 0.82 NTU and the inlet was 4.07 ± 1.11 NTU.

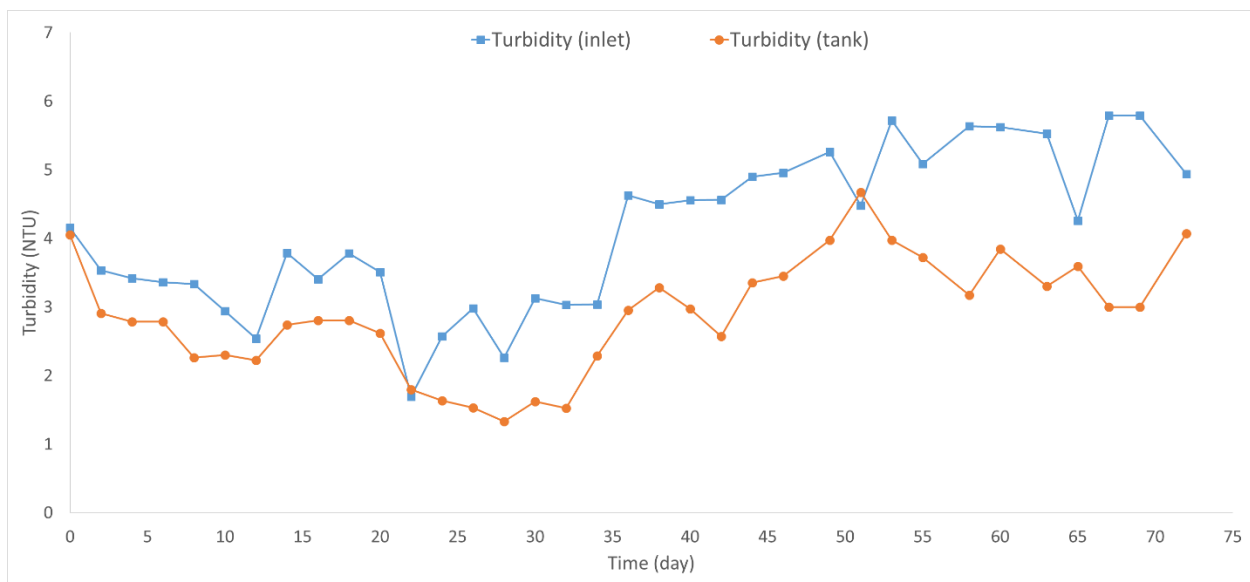


Figure 7: Turbidity removal (NTU) for 0.5 day retention time

As mentioned, the wetland discharge was suggested as one of the contributors to this lake's ageing. After the follow-up on the organic matter (OM) concentration from the system inlet, the hypothesis was corroborated, presenting itself as an OM pollution source to the lake. This OM concentration from the inlet, presented as COD concentration, was always higher (36.12 ± 7.68 mg/L) than the overall lake water quality

(25.0 ± 3.50 mg/L). Also, on the experiment deployment, shown in Figure 8, it can be perceived as a constant replenishment of OM in the tank by the inlet, where some removal has been achieved (i.e., average removal of 17%). This slight attenuation can be clarified as the only OM attenuated was particulate and the dissolved OM present was not removed. Tank water presented an average COD of 29.87 ± 3.80 mg/L.

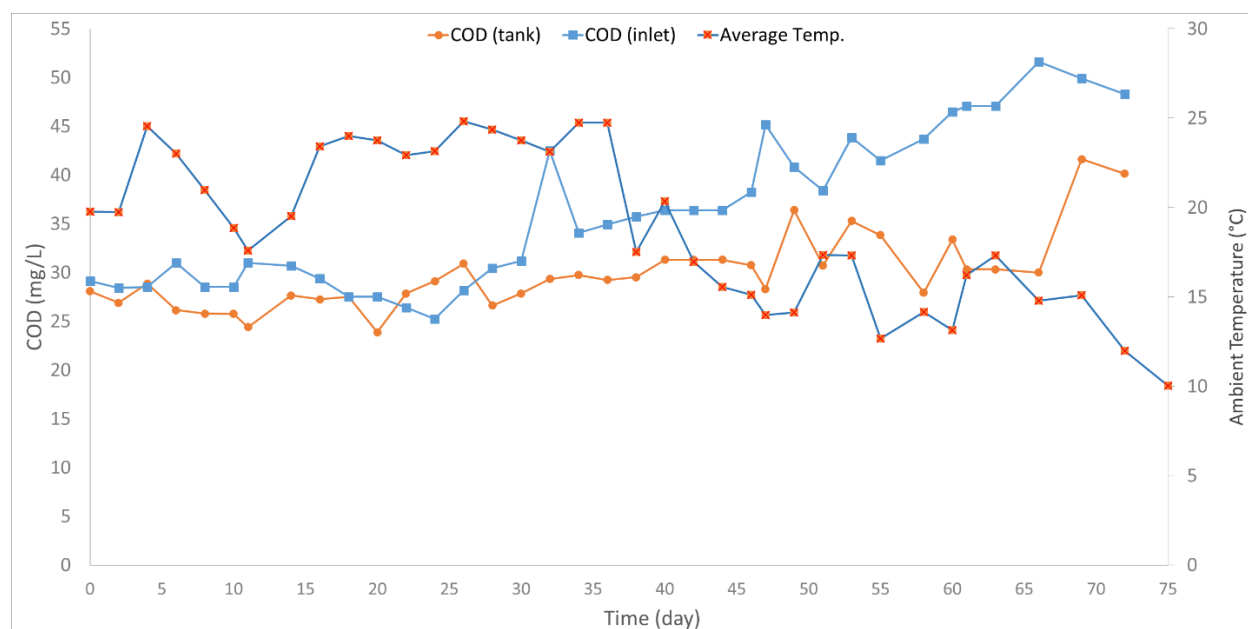


Figure 8: COD concentrations (mg/L) for a 0.5-day retention time. Ambient temperatures were obtained from Almanac Average Extremes Montreal Mirabel intl A. - 7034900 (2022)

As in any filtration process, the assumption was that the removal of suspended solids in the study water is related to the reduction of particle magnitude and cloudiness in a well-mixed system. The proposed onsite filtration has also prevented new OM from being inputted in the lake and possible settling and accumulation on sediments, which can be transformed into an internal source in the near future. In this way, water with less TSS will be inputted into the lake, which will allow the lake to naturally respond to this change for a better ecosystem.

3.3.3 Nutrient Removal

Likewise, as for the OM, the total phosphorus (TP) was always higher (27.75 ± 5.03 μ g/L) than the overall lake water quality (17.1 ± 2.50 μ g/L) supporting, even more, the suggestion of wetland discharge as one of the strong contributors to this lake ageing. It was observed that the geotextile filtering system, in addition to maintaining continuous removal of turbidity, suspended solids, and some organic material, also ensured that the water returning to the lake had a phosphorus concentration near the average lake's overall quality. In other words, the system was capable of removing some of the endogenous phosphorus being inputted into the lake by the wetland discharge, an average of 32%. Then filtered water returned to the lake and had a phosphorus concentration of 18.9 ± 2.78 μ g/L.

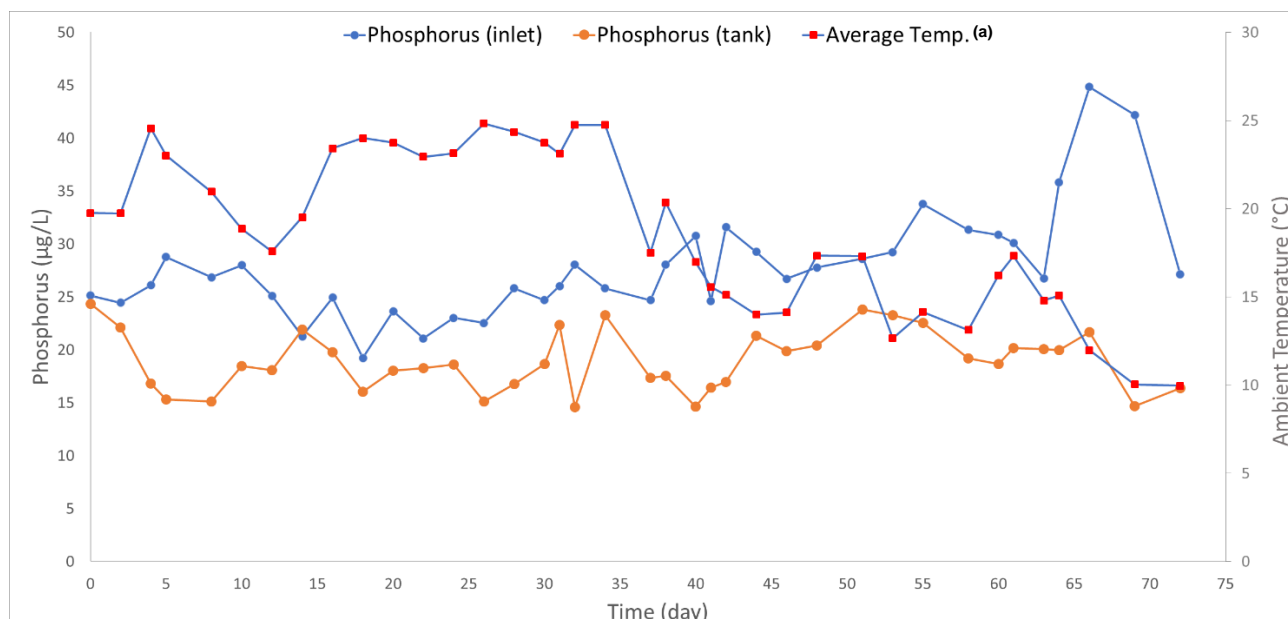


Figure 9: TP concentrations (µg/L) for 0.5-day retention time. Ambient temperatures were obtained from Almanac Average Extremes Montreal Mirabel intl A. - 7034900 (2022)

Throughout the experiments, no significant change in the concentrations of TN and nitrate was observed as they were mainly in the dissolved form. The average value was kept below the values present in the influent and within the Quebec regulated values. For TN, the value was kept at an average of 1.25 ± 0.54 mg/L, and for nitrate, its average was 0.28 ± 0.3 mg/L.

4 CONCLUSIONS

Wetland discharge is further contributing to this lake aging by inputting water with higher particle sizes, higher organic matter concentration, and higher particulate phosphorus levels. The flexible, reactive, and environmentally friendly technology, onsite geotextile filtration, was able to enhance the water quality of a representative amount of lake water. By using the geotextile layer combination not only the straining filtration mechanisms had occurred but also depth filtration, which was able to reduce the AOS of the filter layers and increase filtration performance. Results showed that any endogenous suspended solids and particulate phosphorus being inputted by the wetland were removed by the geotextile filtration and could prevent any further degradation or trophic level change of the lake. Regarding the geotextiles used, methods to reuse, reduce, and recycle are under study to assure waste reduction and promote a circular economy and sustainability in the process. Investigation of in-lake filtering testing, dissolved COD characterization, attenuation methods, and the reuse of clogged geotextile filters can be considered for future work.

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