Wetland Discharge Water Filtration of a Mesotrophic Lake

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Abstract. Contaminated watershed discharge has been impairing surface water with excessive suspended solids, organic matter, and particulate nutrients. Those contaminated suspended particles are dated to settle in the water column and will be further on its sediment. Lake Johanne, a shallow mesotrophic lake located in the *Sainte-Anne-des-Lacs* municipality in Quebec (i.e., the study area of this work) has been receiving wetland discharge water through the years. In this paper, on-site remediation of this water employing non-woven geotextiles as filter media is investigated. The method was based on a tank near the lakeshore with a floating geotextile filtration system operated continuously (either with a 1-day or 0.5-day retention time). Wetland water was pumped into the tank, filtered by a selected non-woven geotextile combination with distinct apparent opening sizes, and returned to the lake by gravity. This experiment ran during the summer and mid-fall of 2022. Samples from both the inlet and tank were acquired every 2-3 days and filter media were changed upon clogging. Therefore, the study objective was to improve the discharge water quality before entering the lake. Water quality parameters evaluated on the deployment (i.e., from both inlet and tank) were total phosphorus, total organic carbon, total suspended solids (TSS), particle size, and turbidity. The onsite experiment provided an average attenuation of suspended particles, water cloudiness and nutrients around 25%, 42%, and 76% for total phosphorus, turbidity and TSS parameters, respectively. Furthermore, the proposed remediation improved the water quality of the evaluated wetland water discharge, consequently, proving the feasibility of this possible remediation.

Keywords: Water Quality, Eutrophication, Nonwoven Geotextiles, Phosphorus.

1 Introduction

Water stress has been a recurrent concern for nations around the globe [1-2]. Essentially associated with the current production/consuming model, population increase [3], lack of strict environmental policies [4-6] and new climate change scenarios [7-

8], water resources have become scarcer in some regions and more polluted in others and in some cases the combination of both scenarios.

Among the diverse means of anthropogenic water pollution highlighted nowadays, those caused by the watershed-contaminated runoff with plant nutrients are significant and have been causing unnatural fertilization of water bodies. The eutrophication process is recognized as the stress of aquatic ecosystem primary productivity (i.e., excessive growth of algae/cyanobacteria) from excessive nutrient input of nitrogen, and phosphorus from external and internal sources. This excessive growth of phytoplankton, cyanobacteria, algae, and other organisms will often lead to oxygen depletion [9], scum and smells, and possible toxin production [8,10]. Therefore, further causing the inhibition of water body uses well as bringing health and economic damage [11] to society in general.

From an ecological standpoint of view, eutrophication is a natural process, in which a waterbody goes through organism growth-promoting processes [12] over a long-time frame. However, the macronutrient increase in waterbodies has been amplified. Although two macronutrients are the key for those scenarios, phosphorus is regarded as the limiting one. As mentioned by [13] "it is not important whether phosphate is currently the limiting factor or not, or even that it has ever been so; it is the only essential element that can easily be made to limit algal growth".

With this understanding, it is compulsory to propose methodologies for internal and external phosphorus load attenuation. This idea aligns well with the Sustainable Development Goals (SDG) 6 (i.e., clean water and sanitation) from the UN (United Nations) agenda to be achieved by nations in 2030, which is further detailed in the 6.6 goal as restoration of the water-related ecosystems.

Two possible remediation methods that can be emphasized are the common and not well-investigated ecological ones. While the first one is based on the addition or removal of elements in the water body for its remediation. The second one is based on using the own waterbody capacity for its restoration [14]. Based on specialized literature the common methodologies used are sediment dredging [15], hypolimnetic water aeration [16], sediment capping by inert elements [17-18], and phosphorus inactivation in water and bottom sediments by chemical addition [19]. From an ecological perspective, a possible knowledge gap in ecological remediation techniques is found. The procedures that support natural restoration have been lacking research. To counteract this, geotextile filtration is a method which has been recently studied [20-23]. This method is based on the use of geotextiles as filter membranes for the removal of particulate nutrients, organic matter, and total suspended solids. It is a less invasive, easily deployed, and cheaper methodology when compared with available technologies. It has been shown to be efficient in reducing nutrients for the entire recreational season in an environmentally safe way.

As this methodology is still under development, further investigation was done in 2022. By using a wetland discharge from a shallow mesotrophic lake located in *Sainte-Anne-des-Lacs*, Quebec municipality (i.e., Lake Johanne), an on-site non-woven geotextile filtration system was applied, to remediate a portion of this water. Consequently, the present study objectives are to understand the lake water quality and assess the effectiveness of the geotextile on-site filtration for nutrient and suspended solid removal on the wetland discharge in a continuous experiment.

2 Materials and Methods

2.1 Study Area

The studied area from this project was located 75 km from downtown Montreal, in a shallow lake called Lake Johanne - 45°50′23″N; 74°08′19″W (i.e., located in *Sainte-Anne des-Lacs* municipality). This semi-artificial lake has a water volume of 74,900 m3 and covers a surface area of 44,910 m^2 with average and maximum depths of 1.7 m and 3.5 m, respectively [24].

Situated in the *Massé* watershed, the area around this lake is mainly composed of sparse vegetation and few homes. As can be seen in Figure 1(b). This lake is also considered a mesotrophic headwater body, which has been increasing its phosphorus concentrations over the years in accordance with the Minister of the Environment and the Fight Against Climate Change (MELCC), Quebec in his RSVL program (i.e., *Réseau de Surveillance Volontaire des Lac*s). This situation made MELCC provide the following recommendation for it: the adoption of measures to limit nutrient inputs from human activities to avoid further degradation and loss of its uses.

Figure 1(b) also shows the nearby road as well as a wetland location with more details highlighted in Figure 1(c). This wetland water discharge is further contributing to this lake's ageing/succession process by slowly feeding the lake with higher particle contents and increased concentrations of organic matter and particulate nutrients. In contrast, when nutrient internal loads are considered, the incomplete organic matter removal (i.e., tree stumps still degrading within the lake) when the water body was enlarged. The sediment phosphorus content in this lake is not homogenous and according to [25] ranges from 1186 to 1451 mg/kg.

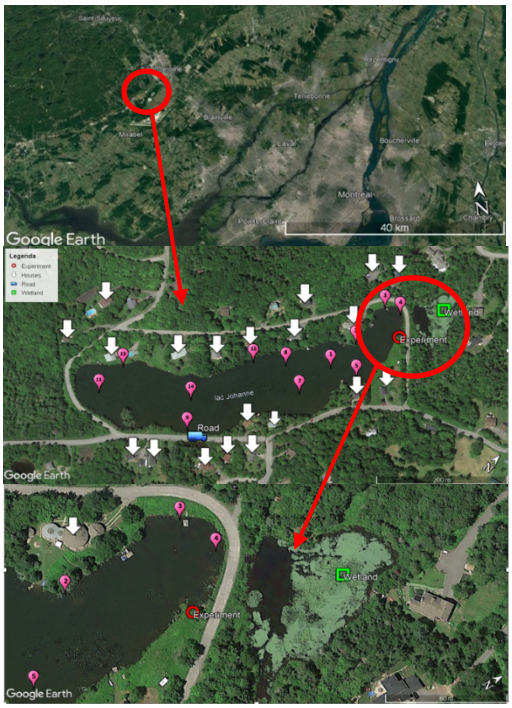

Fig. 1. (a) Inset map showing the study area location; (b) Lake Johanne map with sampling stations as shown by the numbered indicators. White arrows indicate the nearest lakeshore households; (c) Detailed view from wetland and experiment location

2.2 Filtration Unit and Onsite Experiment Setup

A cylindrical plexiglass filtration unit has been employed for this experiment, shown in Figure 2. (a). This unit has 20 cm of diameter and 25 cm of height (made to withstand an 18 cm hydraulic head) and was positioned on a square base to hold the filter media. The mentioned square base has also a hole in the center with the same diameter as the filtration unit to permit filtered water flow. The geotextile combination was sandwiched together between the square bases using screws and bolts. The geotextile combination was based on a previous experiment [22].

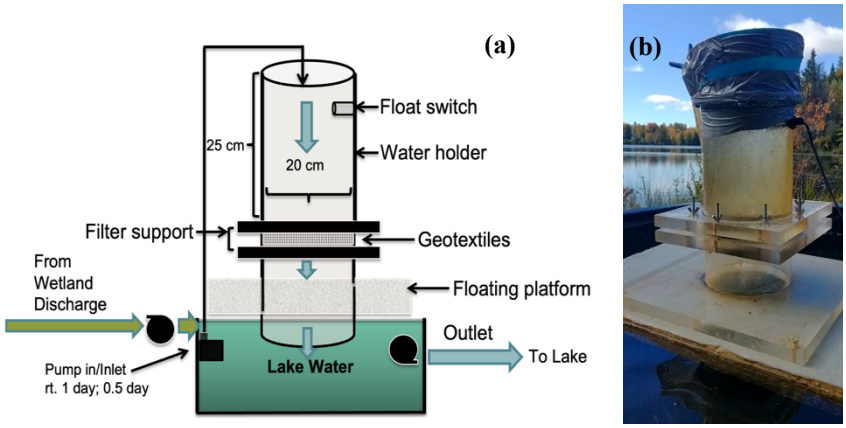

Fig. 2. (a) Schematic of the on-site filtration setup (b) On-site floating filtration unit in deployment.

To implement the experiment, the filtration unit was prepared to float with the support of a polystyrene foam sheet. This sheet also had a center 20 cm circular hole on it. Both (filtration unit and foam sheet) were placed in a plastic tank of 543 L (width of 97.8 cm and height of 35.6 cm) previously filled with lake water using a peristaltic pump. This tank was placed near the wetland location on the onsite experiment location presented in Figure 1 (c). Continuous deployment was performed using an inlet (i.e., calibrated medium flow rate peristaltic pump fed by wetland water) and an outlet by overflow. The retention time started at 1 day during the 16 days for system acclimatization and then was decreased for 0.5 days during the rest of the experiment in a total of 71 days. Lastly, to maintain the system fully functioning during the proposed timeframe, geotextile clogging and pumping operation were verified, and water sampling were performed every 2-3 days.

Fig. 3. (a) Wetland discharge location and system placement on the lakeshore; (b) Detailed view from wetland discharge tubing.

2.3 Geotextile Filter Media

Custom-made nonwoven geotextiles were employed as filter media in the experiment. These geotextiles are commonly used materials for strata separation, soil improvement, reinforcement, and drainage. However, few studies have investigated their use for water filtration. In comparison with other filtration methods/materials in the specialized literature, these layers are dimensionally stable fabrics, highly flexible, lightweight, and low cost. The geotextiles are used in this research as filtration layers in a floating unit. These have been outstanding materials for the attenuation of suspended solids and particulate nutrients in lake water as previously investigated. They were manufactured by Titan Environmental Containment, MB with apparent opening sizes (AOS) definition based on the particle size follow-up (D90) on the lake. Table 1 displays the characteristics of the non-woven geotextile membranes used. A total of 6 were employed.

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	3.1
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	2.1
TE-GTP250	Polypropylene	60	41	0.83	200	1.7

For experiment deployment, decreasing AOS geotextile layers were cut in a 22 cm diameter and arranged using one layer of each and then sandwiched together on the filtration unit. Figure 4 shows non-woven geotextiles before the filtration process. With the exception of the TE-GTX300 geotextile which was made of a continuous filament fibre polyester (PET), the others were made of 100% virgin staple, UV resistance, and thermally bonded polypropylene (PP) fibres. The AOS of the filter media were 110 µm,100 µm, 90 µm, 70 µm, 65 µm and 60 µm for the TE-GTX300, TE-GTT100, TE-GTT120, TE-GTT200, TE-GTN350B TE-GTP250, respectively.

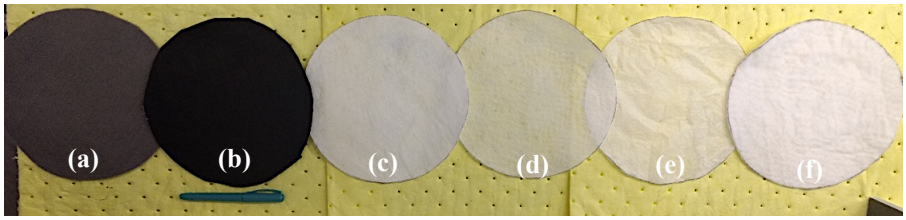

Fig. 4. Non-woven geotextiles before the filtration process according to the AOS: (a) 60 µm (b) 65 µm (c) 70 µm (d) 90 µm (e) 100 µm and (f) 110 µm

Organized in descending order, the base geotextile layer combination was of AOS from 110 µm to 70 µm. The 65 µm geotextile was added and removed from the combination when required for a greater particle removal. Also, when colloidal particle accumulation was noticed in the tank water, a further layer of 60 µm was added to enhance filtration. Therefore 4 to 6 layers were used as the combination. The set of filter layers was entirely changed every week of the experiment or when clogged, whichever occurred first.

2.4 Water Quality Analysis

Water samples on this project were retrieved using 1L amber bottles (high-density polyethylene (HDPE)) and 50 mL sterilized polypropylene test tubes. The samples were taken from the tank and inlet every 2-3 days (i.e., experiment deployment). Also, some samples were taken from the lake at specific locations (i.e., St. 1, St. 4, St. 7, St. 9, and St. 11) on certain dates from the summer to mid-fall of 2022 for access lake water quality. All samples were 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), and Chemical Oxygen Demand (COD) were all measured in the collected water samples.

Phosphorus was assessed using an elemental analysis performed by ICP-MS with a quadruple mass analyzer following partial acid-peroxide digestion (HNO_3-H_2O_2) of water samples (USEPA 3050B). Turbidity was assessed using an Oakton turbidity meter (T-100). To perform particle size analysis (PSA), a laser diffraction particle analyzer (LA-960 Horiba laser particle size analyzer) was used. Thus, Hach chemicals

test kits were used to analyze TN (TNT 826, Method 10208, persulfate digestion) and TOC (TOC-L - Shimadzu). Lastly for TSS determination APHA method (SM 2540D) was employed. Data has been represented with averages ± confidence interval.

3 Results and Discussion

3.1 Lake Water Quality Assessment

The MELCC in Quebec classifies Lake Johanne as a mesotrophic lake (13-20 µg/L) under its RSVL sampling program [26]. This same sampling program also suggests in its annual report that a higher primary productivity in this lake may occur in the future if no remediation action is taken.

Table 2. Lake Johanne's overall water quality from July-Sept. 2021 and July-Sept. 2022

Parameters	2021[a]	2022[b]
TP (µg/L)	17.1 ± 2.5	15.2 ± 1.5
COD (mg/L)	25.0 ± 3.5	23.0 ± 2.7
NO_3^- (mg/L)	0.8 ± 0.7	0.7 ± 0.3
TN (mg/L)	1.3 ± 0.8	1.0 ± 0.8
TSS (mg/L)	5.2 ± 1.1	3.8 ± 1.3
TOC (mg/L)		7.1 ± 0.7

[a]Average of 7 samplings at 5 lake stations; [b]Average of 5 samplings at 5 lake stations

Related to organic matter, most of it is in dissolved form (80%) and is represented by a COD of 23.0 ± 2.7 mg/L and the Total Organic Carbon (TOC) concentration of around 7.1 ± 0.7 mg/L. Those are slightly high when compared to unpolluted sources and should characterize that some biological degradation still occurs in the lake. TSS in another hand is 3.8 ± 1.3 mg/L characterized by small particles of D90 around 60 µm. Lastly, TN concentrations and nitrate are below the protecting aquatic life guidelines of Quebec, which are 1.0 mg/L and 2.9 mg/L, respectively and do not seem to affect the lake ecosystem.

3.2 Filtration Deployment

Experiment deployment was run for 71 days from July 20, 2022, to September 29, 2022, shortly after the start of summer until the mid-fall season. As mentioned, the experiment was based on continuous deployment with a 1-day retention time in the 16 days for system acclimatization followed by a 0.5-day retention time until the end of the experiment. The proposed system also ran without major issues due to constant checking on the geotextile, pumps, inlet, and outlet. Roughly 37.8 m^3 were treated with approximately 1 m^2 of each AOS size, with an associated cost of CAD 6.30 when only geotextile filters are taken into consideration.

As presented in Figure 5, suspended particles accumulated on geotextile filter media, and probably enhanced the filtration process further than predicted. With this understanding, the filtration mechanism occurred by sieving by this media but also a reduction of AOS (i.e., depth filtration). This improved the particle reduction in the tank water and all related attenuation parameters.

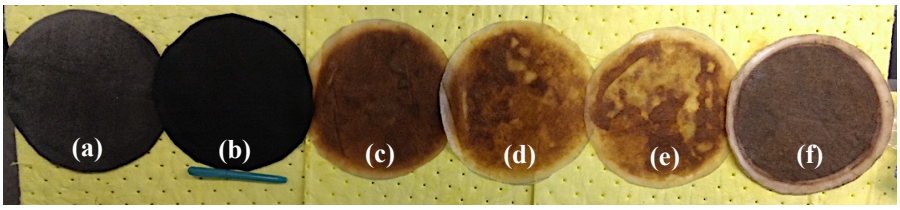

Fig. 5. Non-woven geotextiles after the filtration process in the AOS order: (a) 60 µm (b) 65 µm (c) 70 µm (d) 90 µm (e) 100 µm and (f) 110 µm

At first, straining or surface filtration happens when the size of a particle is larger than the pore diameter [27]. After that, solids then penetrate this media surface and are trapped within the medium, thus forming an external filter cake on its surface which could be characterized as a deep/cake filtration mechanism [28]. Thus, by particle accumulation, on the top of each geotextile layer, as presented in Figure 5, the surface filtration mechanism was improved in combination with depth filtration. No chemical and/or biological mechanisms were involved in this filtration.

3.3 Continuous Experiment

The onsite continuous method proposed in this research was able to remediate a portion of the wetland water only by employing filtration. With a particle size reduction, which conveyed turbidity and suspended solids attenuation some particulate phosphorus was removed as presented in the results. This has prevented some suspended solids possibly contaminated from entering the lake, which would settle, causing further degradation of this aquatic environment. Thus, the system objective is being achieved.

3.3.1 Particle Removal and Follow-up

As mentioned, this wetland discharge water is slowly feeding the lake with higher particle contents and increased concentrations of organic matter and nutrients. This behavior has also been captured with the experiment samples obtained. Related to suspended particles, as presented in Figure 6, after 2 days of system acclimation the tank water quality was improved compared to the inlet until the experiment ended. The filter geotextile membranes performed well in removing particles and debris from the wetland water. An average TSS attenuation of 76%, was maintained. Inlet and tank water TSS were at 0.87 ± 0.3 mg/L and 3.63 ± 1.26 mg/L, respectively. Tank particle size were maintained below the size of 10.5 µm (D90) from the second day of the experiment until the end.

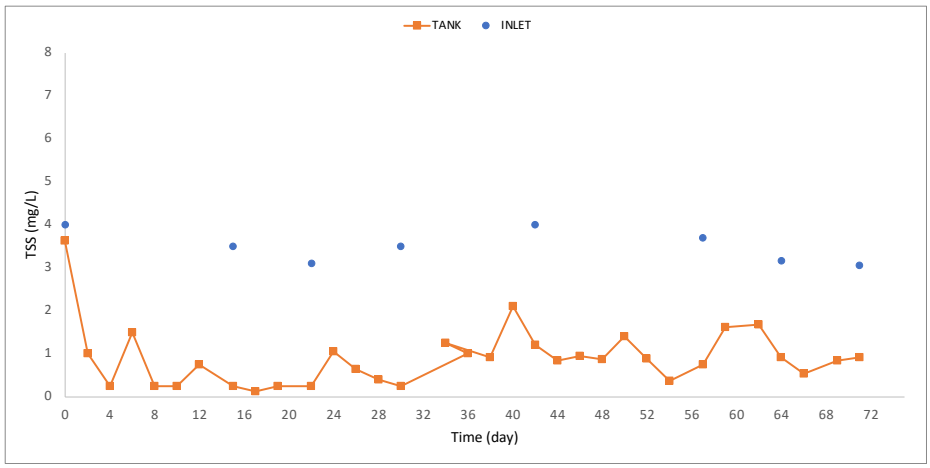

Fig. 6. TSS concentration (mg/L) follow-up on the onsite experiment

The turbidity of the water in the tank was kept always below the inlet. The average on the tank (which is the same as the effluent) was 1.06 ± 0.21 NTU and the inlet was 1.85 ± 0.28 NTU, which guaranteed a 42.7 % attenuation.

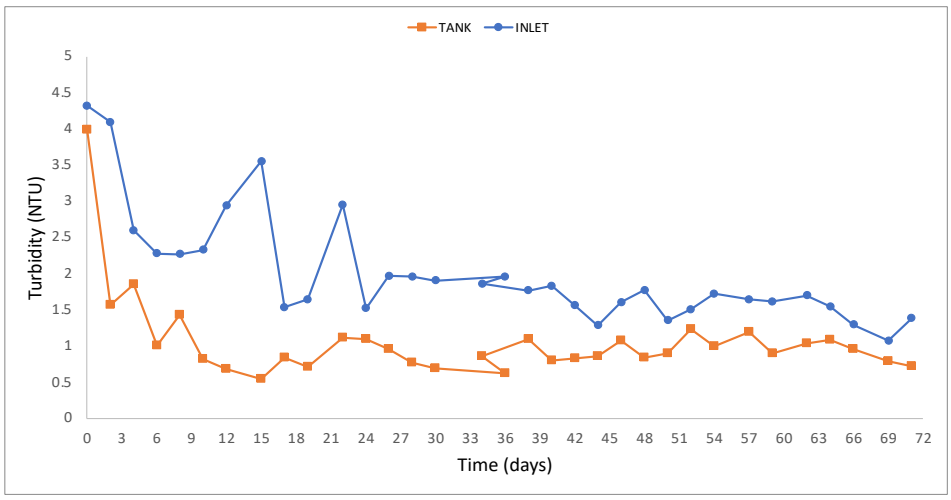

Fig. 7. Turbidity (NTU) follow-up for the onsite experiment

3.3.2 Organic Matter and Nutrient Attenuation

Total organic carbon concentrations were similar between the inlet (average of 7.80 ± 0.78 mg/L) and tank (average of 7.05 ± 0.35 mg/L) in this experiment. As presented in Figure 8, a minor average removal of 9.7 % was obtained. The low removal could be associated with the fact that most of the organic matter in this lake being was in the dissolved form (80%) as characterized by a light tea colour. Further enlightenment on this performance is shown in Figure 8. A higher inlet TOC was present from the ex-

periment start until day 24. This may be associated with warmer temperatures in summer and increased particle content in the water column as presented in Figure 7.

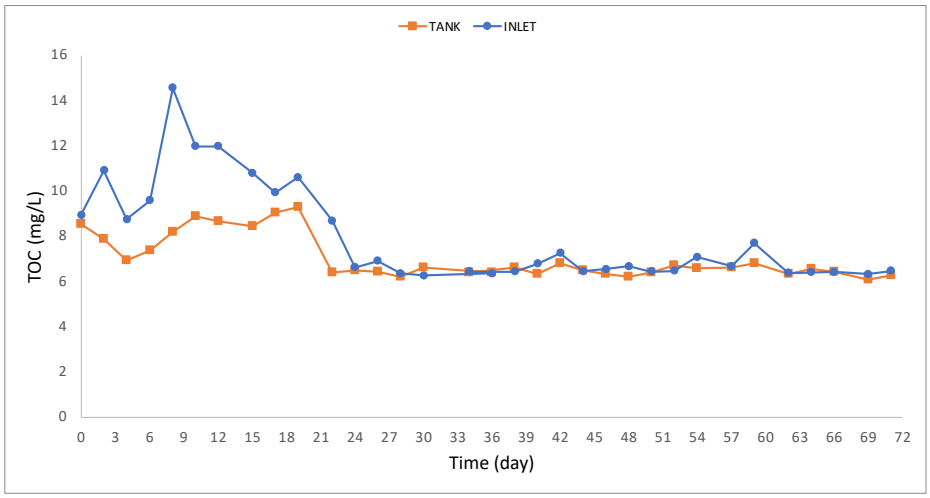

Fig. 8. TOC concentrations (mg/L) for the onsite experiment

The performance of this onsite filtration methodology regarding phosphorus is presented in Figure 9. On deployment, total phosphorus (TP) was always higher (20.26 ± 2.16 µg/L) than the overall tank water quality (15.15 ± 1.65 µg/L). This indicates that cleaner water was returned to the lake. In other words, the deployment was able to remove a portion of the phosphorus entering the lake by the wetland discharge. An average removal of 25% was obtained.

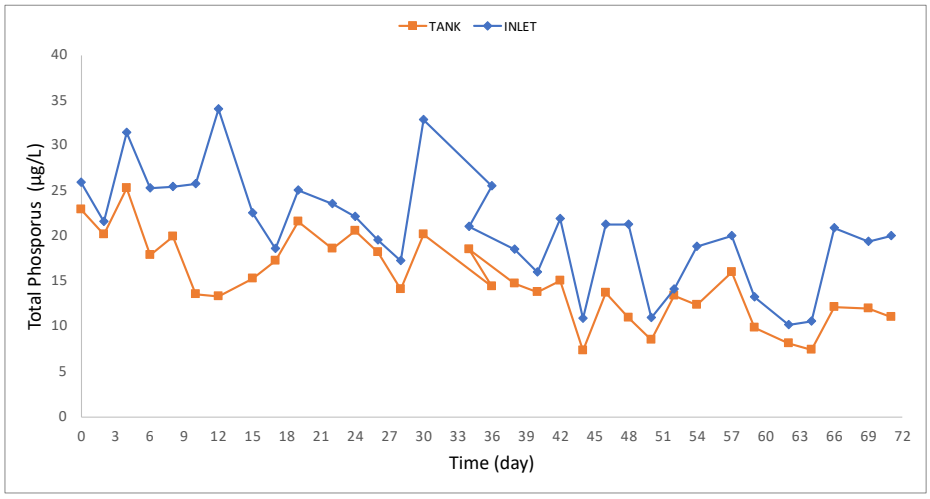

Fig. 9. TP concentrations (µg/L) for the onsite experiment

4 Conclusions

The wetland discharge for this experiment deployment has been an important factor in causing Lake Johanne's ageing. As investigated in the experiment, it was noticed that larger particles with a higher phosphorus and organic matter content are being introduced within the lake by this wetland water. These if not properly remediated are going to settle in the water column and further accumulate in the sediment. The onsite geotextile filtration proposed method remediated a portion of this wetland discharge. Treated water with reduced suspended solids and nutrients was returned to the lake. By inputting cleaner/treated water further contamination caused by this wetland would decrease. Future work for this project will be done to enhance the filtration efficiency and a possible filtration unit scale-up and/or in-lake application. Regarding the filter media, methods for applying the 4Rs (i.e., rethink, reuse, reduce, and recycle) on the geotextile membranes are under study to reduce waste as much as possible.

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