Suspended Solids and Phosphorus Attenuation in Mesoeutrophic Lake Water using PET Geotextile Tubes

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ABSTRACT

Phosphorus has been accumulating in water bodies due to uncontrolled land activities, including, but not limited to, incomplete tertiary sewage treatment, improper final effluent discharge, contaminated watershed runoff, land-use changes, and climate change scenarios. These activities increase the number of suspended solids transported from land into water bodies, thereby raising particulate phosphorus levels, which are dated to settle and become part of the sediment. Practices that can potentially reduce suspended solids in the surface water column include water flocculation, settling, and/or filtration. When this pollution is already located in sediments, remediation strategies, such as mechanical sediment dredging and sediment capping, can address it. Therefore, the objective of this study is to investigate the attenuation of suspended solids and particulate phosphorus using a non-woven polyethylene terephthalate (PET) geotextile tube as the filtration medium. On-site continuous experiments at Lake Johanne, a mesotrophic lake located in *Sainte-Anne-des-Lacs, Quebec* (case study) were performed using a 300 L tank, a peristaltic pump to supply lake water with a one-day retention time, an overflow outlet, and expanded polystyrene foam as a floating device with a geotextile tube for continuous filtration. Water parameters monitored during the 91-day experiment included suspended particle concentration, particle size, total organic carbon (TOC), and total phosphorus (TP). Results demonstrate the method's feasibility. Continuous attenuation of suspended particles and particulate phosphorus was obtained by approximately 56% and 33%, respectively, compared to the inlet. Further research related to this work is needed to explore the capture of dissolved organic carbon using sorbents attached to the system and the reuse of wastes generated by this process (used filter media and captured suspended solids).

RÉSUMÉ

Le phosphore s'accumule dans les plans d'eau en raison d'activités terrestres non contrôlées, notamment le traitement tertiaire incomplet des eaux usées, le rejet final inapproprié des effluents, le ruissellement contaminé des bassins versants, les changements d'affectation du sol et les scénarios de changements climatiques. Ces activités augmentent la quantité de matières en suspension transportées des terres vers les plans d'eau, ce qui augmente les concentrations de phosphore particulaire. Ce dernier a tendance à se déposer et à s'incorporer aux sédiments. Parmi les pratiques susceptibles de réduire les matières en suspension dans la colonne d'eau de surface, on peut citer la floculation, la décantation et/ou la filtration. Lorsque cette pollution est déjà présente dans les sédiments, des stratégies de remédiation, telles que le dragage mécanique et le recouvrement des sédiments, peuvent être mises en œuvre. L'objectif de cette étude est donc d'examiner l'atténuation possible des matières en suspension et du phosphore particulaire à l'aide d'un tube géotextile non tissé en polyéthylène téréphtalate (PET) comme matériau de filtration. Des expériences continues in situ ont été menées au lac Johanne, un lac mésotrophe situé à Sainte-Anne-des-Lacs, au Québec (étude de cas). Un réservoir de 300 L, alimenté en eau par une pompe péristaltique (temps de rétention d'un jour), un trop-plein et un dispositif flottant composé de mousse de polystyrène expansé et d'un tube géotextile ont permis une filtration continue. Les paramètres d'eau suivis pendant les 91 jours de l'expérience comprenaient la concentration en particules en suspension, la taille des particules, le carbone organique total (COT) et le phosphore total (PT). Les résultats démontrent la faisabilité de la méthode. Une atténuation continue des particules en suspension et du phosphore particulaire a été obtenue d'environ 56 % et 33 %, respectivement, par rapport à l'eau d'entrée. Les recherches futures porteront sur la capture du carbone organique dissous à l'aide de sorbants et sur la réutilisation des déchets générés par ce procédé (médias filtrants usagés et matières en suspension capturées).

1 INTRODUCTION

Eutrophication remains one of the most persistent environmental challenges for freshwater lakes globally (Pereira & Mulligan, 2023), accelerating natural ageing processes in water through the accumulation of excess nutrients. Those nutrients are primarily phosphorus (P) and nitrogen (N), which may trigger harmful algal/cyanobacteria blooms, oxygen depletion, and biodiversity loss when a do-nothing scenario is taken as mitigation. These increased nutrient concentrations originate from diverse anthropogenic sources and activities, including, but not limited to, agricultural runoff laden with fertilizers, malfunctioning septic systems or tertiary wastewater treatment near shorelines, and urban stormwater. In some cases, even if all those possible external nutrients are controlled, the internal recycling of the ones that accumulate in lake sediments by wind or bioturbation makes them labile and possibly available for organisms' growth. In regions like Quebec, Canada, where thousands of lakes support recreation, fisheries, and drinking water supplies, mesotrophic lake systems such as Lake Johanne exemplify the potential increase in nutrient levels due to wetland discharge (Pereira, Veetil, Cotton, et al., 2023). On this lake, total phosphorus (TP) concentrations of 13-20 µg/L are at the eutrophic threshold (>20-30 µg/L), impairing ecological balance and economic value if no proper action is taken to reverse this situation.

Conventional surface water remediation strategies, such as mechanical sediment dredging or sediment capping (e.g., alum and/or lanthanum-modified bentonite dosing-LMB), often prove inadequate, counterproductive, generate a lot of waste for disposal or can cause other direct/indirect environmental issues. For example, dredging can disrupt benthic habitats and resuspend legacy contaminants. Chemical treatments such as alum and LMB dosing can pose a risk of secondary pollution and short-term efficacy if not properly planned and monitored. Emerging passive technologies, however, as non-woven geotextile filtration, offer viable alternatives by targeting particulate-bound nutrients and total suspended solids (TSS) at the water column interface. In aquatic systems, most nutrients and these substances are associated with fine particles; thus, filtration would prevent them from settling onto the sediment surface and from being incorporated into the lake's internal nutrient source.

With this understanding, non-woven geotextile filtration stands out for its simplicity, scalability, and low environmental footprint compared with well-established phosphorus remediation methods in water bodies. These synthetic materials, characterized by apparent opening sizes (AOS) of different ranges and filtering capabilities through dual mechanisms: direct straining of particles and progressive cake-layer buildup that enhances fine-particle retention over time, present themselves as outstanding filter media for this case. Pilot trials have demonstrated robust performance, with stacked geotextile configurations yielding 35-47% TP removal and 40-74% TSS reduction across batch and continuous-flow modes (Inoue et al., 2009; Mulligan et al., 2009; Palakkeel Veetil et al., 2021; Pereira, Mulligan, Veetil, et al., 2023), alongside moderate chemical oxygen demand (COD) attenuation, all without, without any chemical substances input on the aquatic system, aligning with Sustainable Development Goal 6 and target 6.6 (water-related ecosystem restoration).

Additional advances are required on this remediation technique for possible widespread adoption. This research extends prior efforts by selecting Lake Johanne (LJ), a shallow mesotrophic waterbody situated within the *Sainte-Anne-des-Lacs* area of Quebec, Canada, where gradual buildup of organic materials and nutrients may be hastening its ecological decline. Investigations pinpoint a key contributor to this degradation: wetland outflow entering from the lake's northeastern edge, which carries elevated levels of particulates, organic content, and nutrients relative to ambient lake conditions. Building on this understanding, an in situ tube filtration setup using PET nonwoven geotextile was deployed to treat water drawn specifically from this wetland source for targeted remediation. Therefore, the objective of this study is to assess lake water quality and evaluate the usefulness of on-site filtration using a PET tube geotextile for the removal of nutrients and suspended solids at the discharge, in a continuous experiment with a retention time of 0.5 day. By advancing this non-invasive approach, the aim is to equip water managers with practical tools to control eutrophication, fostering resilient aquatic ecosystems amid ongoing anthropogenic pressures.

2 MATERIALS AND METHODS

2.1 Study Area

The project focused on a site approximately 75 km northwest of central Montreal, centred on Lake Johanne, a shallow lake at coordinates 45°50′23″ N, 74°08′19″ W, located in the *Sainte-Anne-des-Lacs* region of Quebec (Figure 1 (a)). This semi-artificial water body holds roughly 74,900 cubic meters of water across 44,910 square meters, with typical depths around 1.7 meters and the deepest point of 3.5 meters (ABVLACS, 2024).

Within the *Riviere du Nord* basin, the *Masse* sub-watershed features a dispersed forest and few households, as depicted in Figure 1(b). Classified as a mesotrophic headwater lake, it has shown rising phosphorus levels, as tracked by Quebec's Ministry of the Environment and Climate Change (MELCC) through its voluntary lake monitoring initiative (RSVL program), prompting official guidance to curb human-driven nutrient inflows and safeguard its recreational and ecological roles.

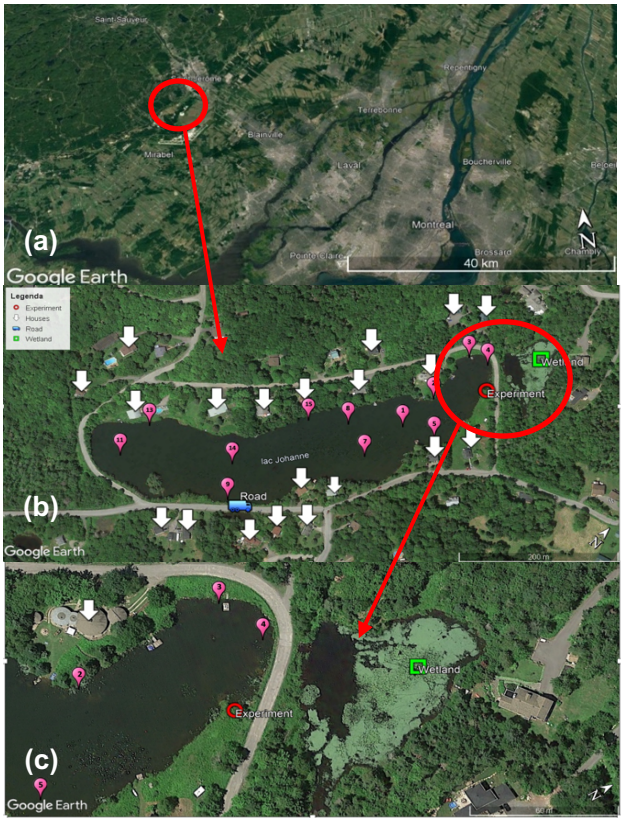


Figure 1. a) Inset map showing the study area location; (b) Lake Johanne map with sampling stations as shown by the numbered indicators. White arrows indicate the nearest households; (c) Detailed view from wetland and experiment location.

Figure 1(b) further illustrates adjacent roadways and a nearby wetland, expanded in Figure 1(c). The outflow from this wetland is accelerating the lake's natural succession towards eutrophic thresholds (>20-30 µg/L) by delivering elevated particulate loads, organic debris, and nutrient-rich fine suspended solids, which are expected to settle onto the sediments. The lake's internal phosphorus load is linked to tree stumps and residual vegetation left on the lakebed after previous expansions of the lake's area and volume, which were not fully removed. As incompletely removed, they decompose into the sediment, creating P fluxes from bottom deposits. Reportedly, P sediment concentrations vary from 1186 to 1451 mg/kg.

2.2 Filtration Unit and Onsite Experiment Setup

A field-based, onsite, continuous-flow experiment was configured with a 543-litre polyethylene tank (97.8 cm wide by 35.6 cm tall and 156.0 cm long) positioned close to the lakeside, as shown in Figure 2(a). At the start of the experiment, the tank was filled with 300 litres using a submerged pump. Then, water was continuously pumped from the wetland inlet, located roughly 50 meters away in the lake's northeast sector, using a peristaltic pump designed for a 0.5-day retention time (300 L/12 h), as shown in Figure 2(b). Treated effluent exited passively via overflow, draining back into the lake under gravity. The schematics of the system are shown in Figure 2 (c).

To shield the deployment from weather and any debris, a heavy-duty tarp enclosed the setup. Filter material was coiled in a spiral atop a buoyant polystyrene platform over a 5-meter-long perforated distribution line (3 mm openings spaced at 20 cm intervals, mimicking drip irrigation), thereby enabling free movement, as shown in Figure 2(c). Internal mixing was achieved using two mixing pumps.

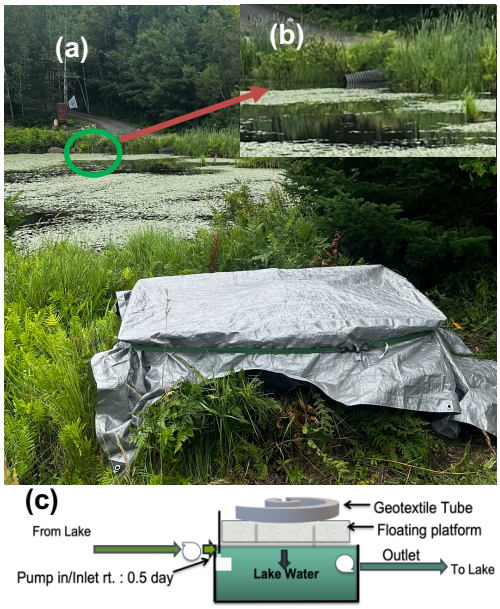


Figure 2: a) Wetland discharge location and system placement on the lakeshore; (b) Detailed view from wetland discharge culvert; (c) Schematics of the geotextile tube filtration deployment.

2.3 Geotextile Tube Filter Media

For experimental application, the geotextile was formed into a 5-meter tube with a 6.5-cm diameter, as shown in Figure 3. Geotextile characteristics are shown in Table 1. This replaced the previous work's filter media, which had employed only flat filter layers of 22 cm in a specific combination (Pereira, Veetil, Mulligan, et al., 2023). The objective was to improve the filter surface area and extend the filtration before complete fouling occurs.

Table 1. Non-woven geotextile tube characteristics used for the mesotrophic lake water filtration

Filter Layer	Apparent Opening Size (AOS) (µm)	Permittivity (sec^{-1})	Mass per unit area (g/m^2)	Thickness (mm)
TE-GTX300	110	1.62	300	3.1



Figure 3: Pristine filter media tube floating in the tank.

2.4 Water Quality Analysis

Water samples were collected using 1L amber bottles (high-density polyethylene (HDPE)) and 50 mL sterilized polypropylene test tubes. Samples were taken from the tank and the inlet every 2-3 days. Also, water samples were collected throughout the lake at specific locations (i.e., St. 1, St. 4, St. 7, St. 9, and St. 11) on certain dates from summer to mid-fall of 2025. All samples were kept at 4°C in the dark before any physicochemical study and acidified, when necessary (e.g., for phosphorus analysis), with analyses completed within 48 hours.

Particle size distribution (PSA), total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), and total organic carbon (TOC) were 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-$H2O_2$) 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, the APHA (2024) method (SM 2540D) was employed. Data have been represented with averages ± confidence intervals.

3 RESULTS AND DISCUSION

3.1 Water Quality Sampling

Table 2 summarizes the water-quality measurements collected from the lake towards summer to mid-fall. Based on total phosphorus (TP) alone, the system falls within the mesotrophic category, with total phosphorus averaging 18.5 ± 1.5 µg/L. If this nutrient input is not reduced, the lake may progress toward eutrophic conditions in the near future. In contrast, the nitrogen level, expressed as total nitrogen (TN), remains below Quebec's aquatic-life protection guideline of 2.9 mg/L, suggesting that it is not currently placing additional stress on the ecosystem. The organic fraction in the water is dominated by dissolved material, which accounts for about 80% of the total organic content (TOC). This is reflected in a chemical oxygen demand (COD) of 25.0 ± 2.0 mg/L and a total organic carbon concentration of 6.9 ± 0.2 mg/L.

Table 2: Lake Johanne's overall water quality from July-October 2025

Parameters	2025[a]
TP (µg/L)	18.5 ± 1.5
TN (mg/L)	1.2 ± 0.5
Particle Size (D50 - µm)	70.8 ± 12.4
COD (mg/L)	25.0 ± 2.0
TOC (mg/L)	6.9 ± 0.2
TSS (mg/L)	4.5 ± 1.6

[a]Average of 4 samplings at 5 lake stations

The average suspended particle concentration (TSS) was 4.5 ± 1.6 mg/L in this lake. The average particle size was 70.8 ± 12.4 µm. This indicates that the particulate matter in the lake is relatively fine and dispersed, which may be difficult to attenuate with larger opening sizes of filter media.

3.2 Filter Deployment

The geotextile tube filtration trial ran continuously for 91 days, spanning from mid-July through mid-October 2025, to capture seasonal shifts from peak summer into early fall conditions. Operating at a 0.5-day retention time within the tank volume, the filtered media maintained an average lifespan of approximately 45 days before breakthrough due to surface clogging and the need for filter media replacement. Also, the remediation removed approximately 30 cubic meters of wetland discharge from the tank throughout the experiment, and it was returned to the lake.

Progressive suspended particle buildup within the geotextile filter surface is illustrated in Figure 4: (a) captures the pristine state at setup; (b) shows accumulation after 20 days of runtime; and (c) depicts heavy particle accumulation after 45 days. This progressive particle buildup created a layer on the geotextile surface, which likely reduced the filtered pore size and increased retention of suspended matter and correlated water-quality parameters throughout the experiment.

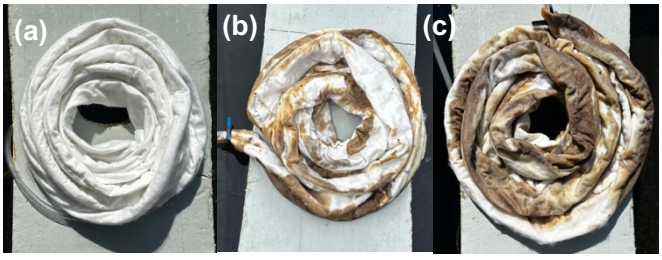


Figure 4. (a) Non-woven geotextile tube before the filtration process ; (b) Non-woven geotextile tube 20 days after the filtration experiment started; (c) Non-woven geotextile tube 45 days after the filtration experiment started.

3.3 Particle, TSS and Nutrient Attenuation

Suspended solids (TSS) levels in lake water rise substantially due to inflows from the adjacent wetland, as evidenced by the inlet concentrations. Figure 5 reveals a consistent average reduction of 55.87% in TSS through the system. Tank effluent averaged 1.61 ± 1.28 mg/L, compared to untreated wetland discharge at 4.68 ± 0.39 mg/L. The geotextile filter steadily captured inlet particulates throughout its operation. As surface deposition increased with runtime, maturing the filter cake, tank TSS levels showed progressive decline followed by steady-state performance. This dynamic reflects the shrinking of pore size, which ultimately balances flow distribution and capture efficiency.

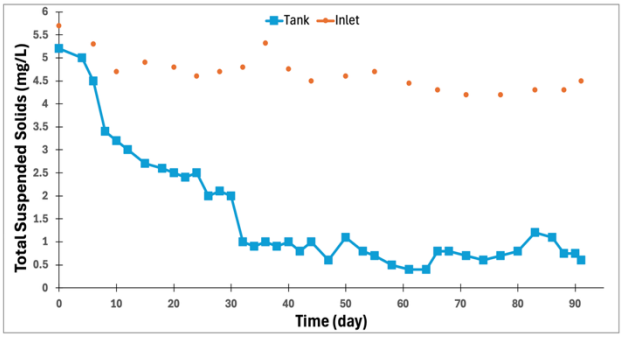


Figure 5. TSS concentration for the onsite experiment.

Once the experiment deployment system stabilized, as can be seen, this occurred over the first 5 days; the filter began to mature, and particle size distributions in the tank became steady (depicted in Figure 6). Average tank particle size was registered at 15.95 ± 12.04 µm, while raw wetland inlet water averaged 62.3 ± 4.08 µm, reflecting a robust 74.4 % reduction in characteristic particle diameter. A small TSS temporary uptick in the particle size of the tank and inlet was noticed in the middle of the experiment, and this aligns with media replacement during that period, requiring roughly two days for the assembly to re-equilibrate and restore baseline performance.

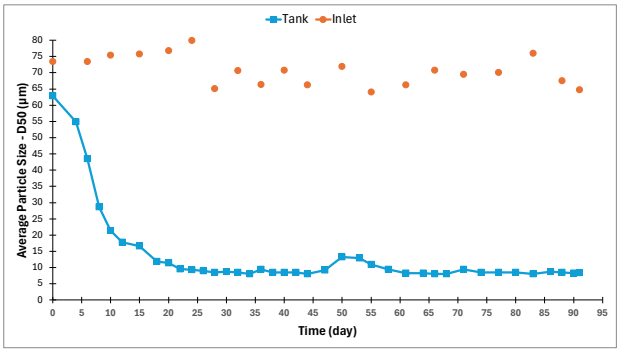


Figure 6. Average particle size for the onsite experiment.

The geotextile tube system consistently reduced total phosphorus (TP) by an average of 33.4%, as shown in Figure 7, underscoring its capacity to intercept particulate-bound P from wetland inflows before it reaches lake sediments. Tank effluent TP stabilized at 14.3 ± 1.93 µg/L, well below influent levels of 20.0 ± 2.92 µg/L—validating the wetland as a key vector in the lake's nutrient-driven succession. This performance aligns closely with a prior lab trial using synthetic wastewater and comparable geotextile sheets, which achieved 31% particulate P removal under similar pore and fabric specs (Morais et al., 2025). Transient TP spikes mirrored upticks in suspended solids, reflecting higher particle-associated fractions temporarily, yet the setup reliably captured fines and associated nutrients, attenuating both TSS and P and returning a cleaner wetland discharge back to the waterbody

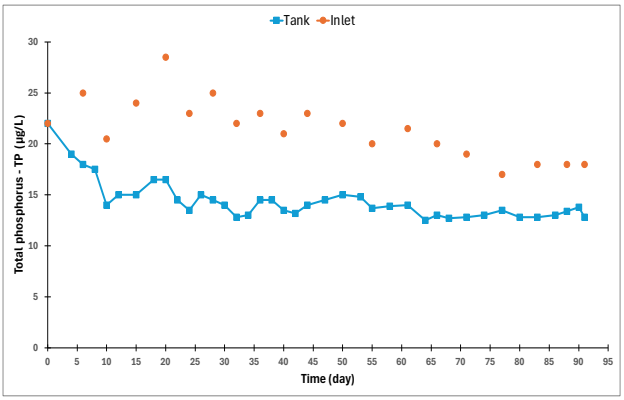


Figure 7. TP concentrations for the onsite experiment.

4 CONCLUSIONS

To enhance practicality for broader use and advance this non-invasive approach, the setup incorporated a 5-meter non-woven geotextile filter tube fitted with an internal distribution pipe, like an irrigation system, which expanded the effective treatment area and prolonged the operational life of the filtration material before filter media changes were required. Consequently, the on-site experiment successfully intercepted and attenuated a portion of the wetland outflow entering the lake, reducing the deposition of fine particulates onto underlying sediments and limiting the influx of particle-associated phosphorus by about 33.4% as well as 55.9% of TSS from this source. Thus, it returns cleaner water to the ecosystem and may reduce overall nutrient pollution pressures associated with this wetland discharge, fostering improved conditions for aquatic life. Further research related to this work includes exploring dissolved organic carbon capture using sorbents attached to the filter media and exploring sustainable handling of used filter media and captured suspended solids through a "4Rs-D" framework (rethink, reuse, reduce, recycle, dispose), aiming to minimize solid waste while maintaining performance of the filtration system.

5. ACKNOWLEDGEMENTS

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