Investigation of Air Resuspension Technique in Combination with Geotextile Bag Filtration for Remediation of High Phosphorus Content Lake Sediment

Antonio C. Pereira[1[0000-0002-1483-6795]], Dileep Palakkeel Veetil[1[1111-2222-3333-4444]], Catherine N. Mulligan[1,5[0000-0001-5337-4776]], Vaishnavi Shekhar Singh [2], Shourya Sinha[3] and Sam Bhat[4]

[1] Concordia University, Canada
[2] Indian Institute of Technology Kanpur, India
[3] National Institute of Technology, Tiruchirappalli, India
[4] Titan Environmental Containment Ltd., Canada
[5] mulligan@civil.concordia.ca

Abstract.

Phosphorus, a macronutrient, has been challenging for nations to cope with as the leading cause of eutrophication in inland waters (i.e., lakes). This nutrient has been overloading lakes due to diverse external and/or internal nutrient sources. Commonly most of this discharged phosphorus is incorporated into sediments, which in some circumstances are released back into the water column consequently triggering recurring eutrophication scenarios. From a possible water remediation perspective, practices commonly used, apart from dredging, do not directly address lake sediment. In this investigation, a resuspension technique followed by geotextile filtration was employed as a procedure for remediating/attenuating higher phosphorus concentrations in sediments of a mesotrophic lake, Lake Canard located in Sainte-Anne-des-Lacs, Quebec. The experimental study was simulated using a confined water column. Thus, this study aims to investigate the feasibility and efficiency of the resuspension method followed by geotextile bag filtration to reduce particles in the water suspension created. Water samples on this experiment were measured before and after resuspension and filtration for the following parameters: soluble reactive phosphorous (SRP), particle size, and total suspended solids (TSS). Sediment on the other hand was evaluated for total phosphorus before and after. Results on the water suspension filtration have indicated a reduction of around 80% in particle size with SRP reduction near to 65% after resuspension/filtration and TSS attenuation of 30%. Also, for TP attenuation on sediment, a reduction of 22% was achieved after resuspension/filtration, thus implying the feasibility of the procedure.

Keywords: Phosphorus; Sediment; Air Resuspension; Geotextile Filtration.

1 Introduction

Phosphorus, a non-renewable macronutrient and a crucial component for primary productivity in water bodies has been increasing its concentration causing diverse disruptions. Due to this unnatural phosphorus concentration increase in aquatic ecosystems, mainly due to anthropogenic activities, (i.e., sewage and contaminated effluent release, detergents, and agriculture and livestock practices) a natural process called eutrophication has been increasing and amplified. This unnatural phosphorus concentration intensification has been transforming low-nutrient water (i.e., oligotrophic waters) into eutrophic (i.e., high-nutrient concentration).

When phosphorus is introduced into water bodies via contaminated watershed runoff and polluted intake streams, it could be in two forms, particulates which are not directly used by phytoplankton, and dissolved which are directly available for algal/cyanobacteria development. For both forms, a portion remains suspended in the water column, while the other settles into the sediment and accumulates over time. This continuous phosphorus input into the sediment leads to its enrichment, causing the sediments to serve as both source and sink for regulating phosphorus availability in the water column [1]. Subsequently, interactions between the nutrient-enriched sediments and the overlying water can occur influencing the phosphorus bioavailability in the water column. This is the explanation of why the internal phosphorus source is able sustain eutrophication scenarios over the years.

Phosphorus in lake sediments exists in various forms, often bound to metals, minerals, and organic matter. The balance between phosphorus retention and release in the environment is influenced by the sediment's chemical composition and the specific forms of phosphorus present [2]. To attenuate and possibly reduce this scenario, remediation practices are proposed. The first methodology to combat eutrophication on shallow lakes is the reduction of phosphorus, considered the limiting nutrient, in the system, either in the particulate or dissolved form, in the water and sediment. This reduction has been identified as the most effective method for mitigating eutrophication scenarios and reoccurrence in lakes. This attenuation has been a difficult issue for nations to cope it, as they try to follow the SGD 6 with its target 6.6 of water-related ecosystems remediation, which is already behind schedule.

Focused on sediment remediation as a way of dealing with eutrophication scenarios, present practices in the specialized literature include sediment dredging, sediment capping, and sediment resuspension (i.e., sometimes followed by water-sediment suspension filtration). Sediment dredging produces a large amount of waste to be dewatered and finally to be disposed of, as well as secondary pollution that can occur. On the other hand, sediment capping only employs chemicals and other materials such as sand modified clays and coagulants introduced into the aquatic ecosystem to create an inactive or active binding layer on the sediment which diminishes the phosphorus sediment bioavailability.

To reduce the amount of wet waste generated as well as recover the contaminated sediment, the sediment resuspension practice is followed by geotextile bag filtration (of the water-sediment suspension). Yong et al. [3] proposed a two-phase resuspension method as a new in situ remediation technique for contaminated sediments. In the initial phase, the air is introduced into the water column to create strong turbulence to lift sediments. Coarser sediments settle afterwards while the finer sediments remain suspended. In the second phase, the suspended sediments are pumped and filtered. The technique allows the removal of the sediments that possibly contain higher phosphorus concentrations, thus reducing the potential for excessive algae growth. In other words, this technique is based on the premise that phosphorus is highly associated with smaller particles, which remain suspended in the water for a longer time than larger particles.

By using phosphorus-enriched sediment from a shallow mesotrophic lake located in *Sainte-Anne-des-Lacs*, Quebec municipality (i.e., Lake Canard), a laboratory investigation of air resuspension followed by geotextile bag filtration system was investigated. Consequently, the present study objectives are to understand which particles and how long they remain resuspended using the air resuspension technique as well as which particles and their associated phosphorus content can be attenuated using geotextile bag filtration of the suspension.

2 Materials and Methods

2.1 Study Area and Sediment Sampling

The study area of this paper is Lake Canard, situated in the Sainte-Anne-des-Lacs municipality - 74º 07' 09" W; 45º 50' 34''N (75 km from downtown Montreal). A semi-artificial lake of 369,000 m^3 water volume and covering a surface area of 187,000 m^2 with average and maximum depths of 2 m and 3.7 m, respectively [4]. According to the RSVL (*Réseau de Surveillance Volontaire des Lacs*) of Quebec, the lake water quality monitoring program, this lake is in a mesotrophic state possibly going towards an initial stage of eutrophication soon if no action is taken.

Located in the *Lac Castor* watershed, one of the *Riviere du Nord* watershed contributors [5], the area around this lake is mainly constituted of light vegetation and a few residents. The nutrient sources associated with this lake are watershed runoff, an external one, and organic matter degradation as an internal one. This lake has been enlarged in the past and there was no complete removal of tree stumps and plants from within the waterbody. Also, it is worth commenting that recurring macrophyte growth on this lake has been occurring. The sediment phosphorus content in this lake is not homogenous ranging from 902 to 1212 mg/kg. Figure 1 (a) represents the geographical location of the lake and Figure 1(b) shows the visual representation of it.

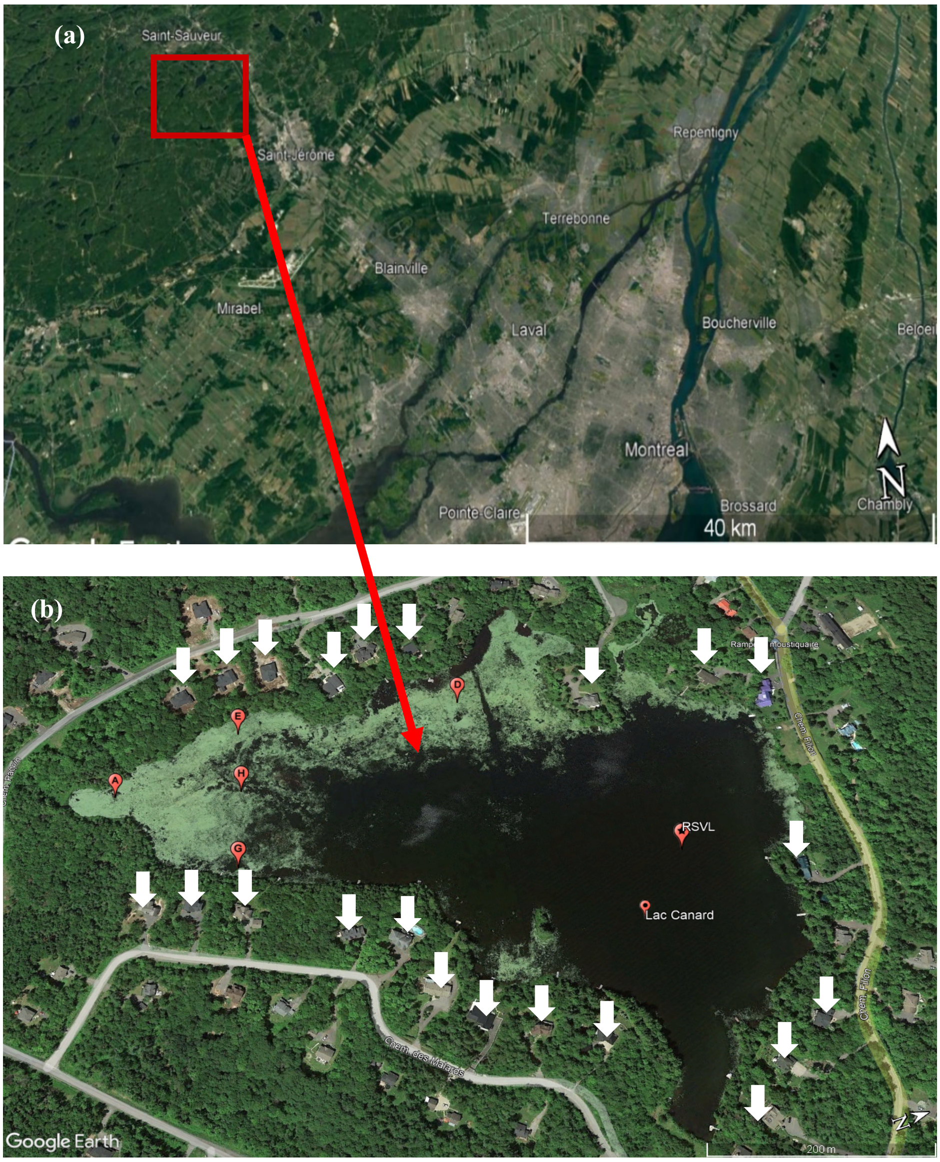

Fig. 1. (a) Inset map showing the study area location; (b) Lake Canard map with sampling stations as shown by the numbered indicators. White arrows indicate the nearest lakeshore households.

For the experiments, sediment samples were taken from the deepest part of the lake located at the RSVL sample location. The sediment samples were acquired using a grab sediment sampler and a 25 L polypropene bucket which was filled with fresh sediment and thus stored in a fridge for further experiment and analysis.

2.2 Sediment Settling Time and Suspended Solids Concentration and Size

This resuspension method was based on a laboratory adaptation to the sediment resuspension/filtration procedure presented by Fukue et al. [6]. Based on the idea that materials with a greater surface area per unit of mass (i.e., smaller particles) can hold more nutrients/contaminants on them. Consequently, by isolating and attenuating the fraction composed of those particles in a suspension, it can more effectively remove those substances from the original sediment. This method consists of (1) resuspension to segregate the sediment particles, (2) removal of lighter and smaller particles from the upper part of the suspended zone, (3) separation of water and solids, (4) dewatering of wet materials in permeable bags and (5) disposal of the solids. However, in this paper only the steps (1) and (2) were performed followed by a modification of step (4) which filtered the entire water/sediment suspension in geotextile bags of custom apparent opening sizes (AOS).

With this information a column experiment was performed to determine how fast the sediment would settle as well as how the suspended particle concentration, particle size and soluble reactive phosphorus would change over time. Furthermore, the best condition for the next experiment, geotextile cone filtration for the water/sediment suspension, was defined. It is hypothesized that the best condition should be a higher TSS after resuspension followed by the highest particle size and higher SRP in the suspension.

For this, the experiment was performed in a vertical plexiglass cylinder with 20 cm of diameter and 50 cm of height as presented in Figure 2(a). A ratio of 1:7 cm/cm was used for this experiment where 5 cm of wet sediment (around 1.5 kg of sediment) was added to 35 cm of water (8.8 L of tap water). For water placement, a peristaltic pump was used at its lower setting to permit lake water input on the system without any sediment disturbance.

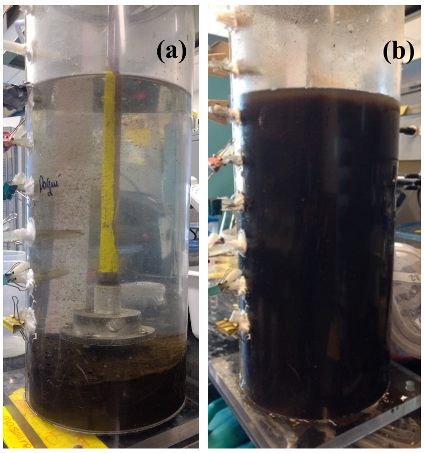

Fig. 2. Sediment resuspension setup where: (a) before resuspension, (b) 0.5 min after resuspension.

After placement and equilibrium between the phases as shown in Figure 2 (a), 1.0 SCFM of air (0.47 L/s) was introduced in the system using an air jet for a 3 min duration. This guaranteed that the entire 5 cm sediment resuspension occurred as presented in Figure 2(b). Water samples were retrieved from the cylinder at a fixed 15 cm height from the water surface at times of 0 (before resuspension-clean water), 0.5, 2, 5, 10, 15, 20, 30, 60 and 80 min after stopping the resuspension. Analyses were in triplicate. A laser diffraction particle analyzer (LA-960 Horiba laser particle size analyzer) was used to evaluate the average particle size of those samples. Total suspended solids determination followed the 2450 D method [7]. Also, SRP concentration was evaluated by the ascorbic acid method under the 4500-P E method [8] for water samples to further define if this phosphorus form, which can directly be taken up by aquatic organisms, is increasing.

2.3 Batch Cone Geotextile Filtration Experiment

With the best scenario for filtration, as previously mentioned, the column experiment was repeated in triplicate. However, instead of letting the particles settle after the resuspension, the liquid suspension was removed from the column using a submerged pump after a certain time of air jet. At this time, it should be guaranteed that the higher TSS after resuspension was followed by the highest particle size and higher SRP in the suspension without removing the bulk sediment. After removing the maximum of water without disturbing the sediment, suspension filtration has been performed. For this, geotextiles were used as the filtration media in the conic form, with 6.5 cm of radius (at the largest part).

2.4 Filter Media

Custom-made (by Titan Environmental Containment, MB) nonwoven geotextiles were employed as filter media in the experiment. These have been outstanding materials for the attenuation of suspended solids and particulate nutrients in lake water as previously investigated [9-11]. However, in this experiment, they will be employed as filter media for the water/sediment suspension. Table 1 displays the characteristics of the non-woven geotextile membranes employed in this investigation. A total of 7 different apparent opening sizes (AOS) 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-GTT170	Polypropylene	350	-	-	-	0.8
TE-GTN116	Polypropylene	300	-	2.0	-	
TE-GTN230	Polypropylene	212	-	1.5	-	-
TE-GTX300	Polyester	110	-	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

Except for the TE-GTX300, which was made of a continuous filament fiber polyester (PET), the remaining ones were made of 100% virgin staple, UV resistance, and thermally bonded polypropylene (PP) fibres. The AOS of the filter media were 350 µm, 300 µm, 212 µm, 110 µm, 100 µm, 90 µm and 70 µm for the TE-GTT170, TE-GTN116, TE-GTN230 TE-GTX300, TE-GTT100, TE-GTT120 and TE-GTT200, respectively. Figure 3 represents the cone filters employed in the experiment before the batch filtration process.

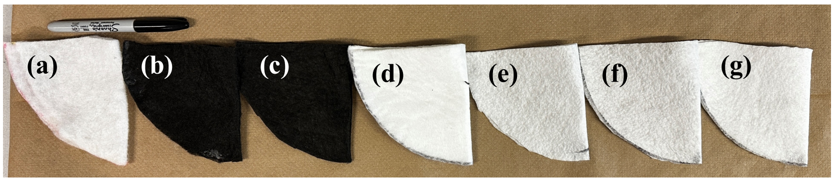

Fig. 3. Non-woven geotextile cones before the batch filtration process according to the AOS: (a) 350 µm (b) 300 µm (c) 212 µm (d) 110 µm (e) 100 µm (f) 90 µm and (g) 70 µm

For the experiment, a two-layer conic geotextile filter combination was used. The TE-GTT170, and TE-GTN116, the highest pore sizes, were used as a pre-filtration layer to remove any larger debris. They were combined with one of the remaining sizes (212 µm, 110 µm, 100 µm, 90 µm, 70 µm, 65 µm and 60 µm) for creating the two-layer filter totaling 11 possible combinations. Then 300 ml of this suspension was passed through the geotextile filters. SRP, TSS and particle size were measured in triplicate to determine the best condition for the following filtration bag experiment. Data is represented as percentage removal when compared to the raw suspension. It is hypothesized that the ideal condition for the next experiment should be higher attenuation of TSS, lowest particle size and lower SRP on the suspension.

2.5 Geotextile Bag Filtration Experiment

For investigating the phosphorus attenuation in the water suspension and sediment, the two best combinations of conic filtration, regarding attenuation of SRP, TSS and particle size reduction, were used in the experiment. However, instead of conic filters, a geotextile bag was produced with the following measurement 21cm per 29.7 cm shown in Figure 4. Thus, 5 cm of wet sediment was added to 35 cm of water (8.8 L of tap water) and resuspended with 1.0 SCFM of air (0.47 L/s) for 3 min. After this, the water/sediment suspension was pumped out using a submerged pump between 2 and 5 min. The water suspension was then filtered by the two-layer geotextile bag.

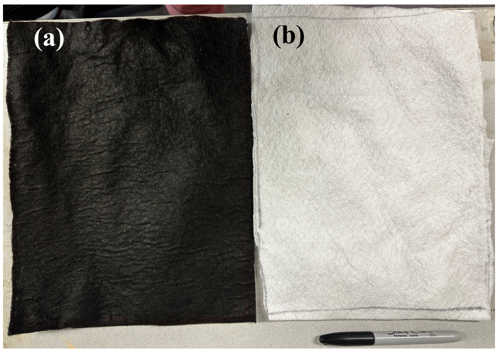

Fig. 4. Geotextile bag combination of (a) 300 µm and (b) 70 µm before the filtration process

The experiment was reproduced three times for each size. The water/sediment suspension was analyzed for SRP, TSS and particle size. In comparison, the resuspended/settled sediment was analyzed for Total Phosphorus (TP) 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 [12].

3 Results and Discussion

3.1 Sediment Characterization

The basic physiochemical properties of the original sediment are presented in the Table 2. This sediment has a representative phosphorus amount possibly related to the amount of organic matter which is still degrading. Also, when related to particle sizes, this sediment is classified within silt and fine sand magnitudes.

Table 2. Lake Canard basic physicochemical properties of original sediment

Parameters	Original Sediment
Bulk density (mg/L)	1.1 ± 0.1
Sediment TP (mg/kg)	1011.55 ± 58.33
D90[a] (µm)	251.33 ± 20.0
D50[a] (µm)	94.60 ± 4.0
D10[a] (µm)	20.36 ± 0.5

[a]D10, D50, D90 represents the 10/50/90 % of particles smaller than that size, respectively.

3.2 Sediment Settling Time and Suspended Solids Concentration and Size

Resuspension experiment results showed sediment settleability presented a fast equilibrium after 15 minutes. This equilibrium occurred for average particle sizes (D50) between 23 to 9 µm shortly after 15 min until 80 min, respectively, presented in Figure

5. TSS (94 to 81 mg/L) and SRP (ranges from 3 to 5 μg/L) also presented a steady behavior after this time. Additionally, the resuspended sediment particles were flocculent and showed increased sizes as they settled in the cylinder. This could be observed between 0.5 and 5 min when particle sizes were high, with higher TSS and SRP of the experiment. After the flocculent zone passed only smaller particles remained in suspension with lower TSS and SRP concentrations as noted in Figure 5. With the presented results, the best condition with higher TSS after resuspension followed by the highest particle size and higher SRP on the suspension for the following experiment would be between 2 to 5 minutes after the resuspension ceased.

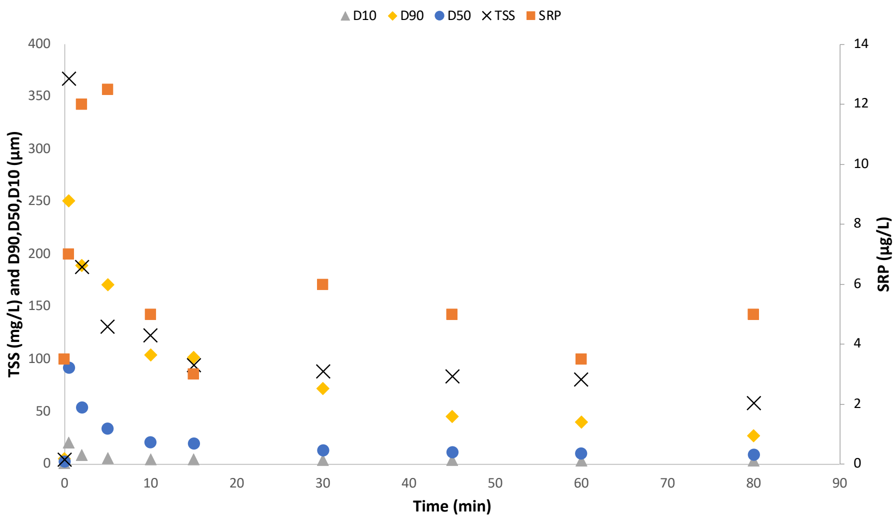

Fig. 5. Soluble Reactive Phosphorus – SRP (μg/L), Total Suspended Solids – TSS (mg/L) and D10, D50 and D90 (μm) in the resuspension experiment over time

3.3 Batch Cone Geotextile Filtration Experiment

The column experiment was repeated in triplicate alongside with the best scenario for filtration. For this, the liquid suspension was removed from the column using a submerged pump between 2 and 5 minutes after ceasing the air jet. The 11 cone filter combinations then filtered 300 ml of water/sediment suspension which results in removal compared to the raw suspension as shown in Figure 6. For this, it was considered first, that the condition with a lower SRP in the suspension then the lowest particle size (D90) and higher TSS attenuation was used for the next experimental condition. The 350/100 and 300/70 combinations were the ones which fulfill the circumstances. For the 350/100 combination, the TSS attenuation, SRP and D90 reduction were of 25%, 84% and 78%, respectively. In comparison, the 300/70 combination showed a TSS attenuation, SRP and D90 reduction of 28%, 85% and 80%, respectively.

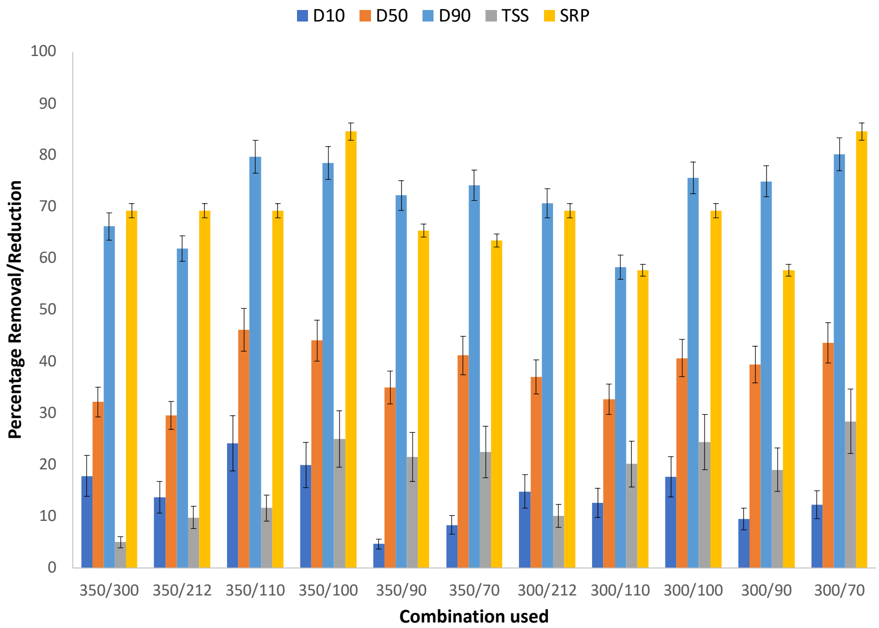

Fig. 6. D10, D50, D90, Total Suspended Solids – TSS and Soluble Reactive Phosphorus removal/reduction in the batch cone filtration experiment.

3.4 Geotextile Bag Filtration Experiment

The column experiment was repeated. The liquid suspension was removed from the column using a submerged pump between 2 and 5 minutes after ceasing the air jet and then the total water suspension (approximately 8.8 L) was filtered by the geotextile bag combination as defined previously, the (1) 350/100 and (2) 300/70 combinations. This experiment was performed in triplicate for each combination. Figure 7 presents one of the geotextile combinations after the filtration. TSS attenuation, SRP and D90 reduction of 25%, 65% and 79% were obtained for the water/sediment suspension (1) as presented on the Table 3. In comparison for the combination (2), the reduction/attenuation were 23%, 60% and 71%, respectively.

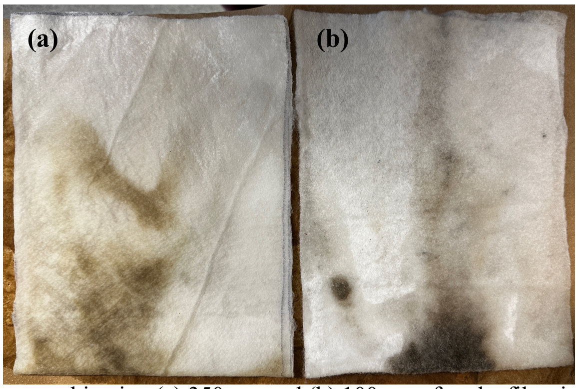

Fig. 7. Geotextile bag combination (a) 350 µm and (b) 100 µm after the filtration process

Table 3. Geotextile bag filtration experiment results regarding water suspension and sediments.

Parameter	Original Sediment	Original Suspension	(1) 350/100 Combination	(2) 300/70 Combination
SRP (µg/L)	-	10 ± 1.5	3.5 ± 0.5	4 ± 0.6
TSS (mg/L)	-	170 ± 5.0	127 ± 8.0	131± 6.0
D90[a] (µm)	251.33 ± 20.0	126.46 ± 15.0	27.20 ± 2.0	35.85 ± 4.0
D50[a] (µm)	94.60 ± 4.0	20.91± 5.0	10.35 ± 0.7	14.49 ± 0.5
D10[a] (µm)	20.36 ± 0.5	6.00 ± 0.8	3.64 ± 0.3	4.27 ± 0.4
Sediment TP (mg/kg)	1011.55 ± 58.33	-	789.71± 170.67	807.17 ± 110.68

[a]D10, D50, D90 represents the 10/50/90 % of particles smaller than that size, respectively.

Additionally, for the water suspension investigation, the sediment was analyzed for total phosphorus (TP) to verify its attenuation scenario. For the combination (1) TP reduction on the sediment was of 22%. In comparison for the combination (2) the attenuation achieved was 20%. Thus, the methodology used was able to remove some portion of the smaller particles which contain higher phosphorus concentrations associated with them, thus implying the feasibility of the procedure.

4 Conclusions

As investigated in the experiment, it was noticed that finer sediments particles can be easily removed with a combination of air resuspension and geotextile filtration. This caused an attenuation of TSS and reduction of SRP and particle size on the created suspension after filtration. This technique presented similar performance for batch and bag filtration for the water/suspension, probably suggesting that the applied methodology is reliable for geotextile combination selection and scale-up of this experiment is possible. Related to the sediment, the proposed procedure was able to attenuate high phosphorus content in lake sediment which thus proven this method feasibility for remediation. Future work for this project will be related to defining the phosphorus concentration by particle size and its bioavailability in the sediment studied. It is suggested to perform the resuspension/filtration in a larger vessel with higher sediment quantity for properly defining sediment attenuation. Lastly, as a possible suggestion the deployment of this experiment in a real-world scenario inside a lake should be considered.

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