Lake Phosphorus Sediment Attenuation using Low-Air Resuspension and Non-woven Geotextile Bags

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Abstract. Phosphorus has been accumulating in surface-water sediments worldwide, mainly due to human activities such as improper effluent discharge, contaminated runoff from watersheds, land-use changes, and climate change. When this nutrient enters a water body in particulate form, it tends to settle on the sediment surface, acting both as a sink and a potential source in the water column. This contributes to water pollution and, in some cases, eutrophication scenarios. To address this, sediment remediation has been employed. Sediment remediation methods include capping, dredging, and more recently, resuspension with geotextile filtration, which is under investigation. The process of sediment resuspension followed by geotextile filtration involves introducing a small amount of air to induce water turbulence, resuspending sediments, then stopping the mixing and allowing coarser particles to settle, while finer sediments remain suspended and are removed by pumping and filtered through nonwoven geotextile bags. This study examines phosphorus reduction in high-phosphorus lake sediment using low-air resuspension combined with nonwoven geotextile filtration. Samples were taken from Lake Caron, a mesotrophic lake in Sainte-Anne-des-Lacs, Quebec. Suspension quality was monitored for suspended particle concentration, particle size, soluble reactive phosphorus, dissolved organic carbon, turbidity, dissolved oxygen, and heavy metals. Sediment analysis included total phosphorus, total nitrogen, organic matter, and particle size. Initial results showed the approach is feasible, with no significant leaching of heavy metals or soluble reactive phosphorus from disturbed sediments. Further experiments demonstrated that the filter media achieved at least 80% efficiency in capturing suspended particles. Ongoing studies aim to expand these findings and observations.

1 Introduction

Phosphorus (P) pollution remains a significant challenge for nations to address and is the main driver of eutrophication [1]. This nutrient often enters water bodies in amounts that consistently exceed outflow, causing sediment enrichment [2]. This enrichment is primarily driven by anthropogenic activities, including incomplete or poorly treated sewage and effluent discharges into water bodies [3], land impermeabilization around water bodies, removal of riparian buffer zones, and unsustainable agricultural and livestock practices. Additionally, ineffective policies and regulations often fail to hold polluters accountable.

When contaminants enter a water body in particulate form, they tend to slowly settle onto the sediment surface and remain there as a “legacy”[4]. Thus, the sediment is considered the ultimate sink of diverse contaminants. In the case of P, the settled nutrient can occur in various forms and is often associated with metals, minerals, and organic matter[5], [6]. This nutrient does not remain trapped in the sediment, and environmental conditions can influence the balance of P retention and release, including water temperature, redox potential, and pH. The retention-release process provides favourable conditions for recurring eutrophication scenarios, even when external inputs are attenuated, reduced, or removed from the water ecosystem.

Current in situ over-enriched phosphorus remediation strategies encompass water-column and sediment-based techniques, as well as biological methods. These include, but are not limited to, water aeration, sediment capping, dredging, and more recent methods such as resuspension with geotextile filtration, as well as the management of macrophytes and fish.

Focusing solely on sediment remediation methods, it is well known that they can produce significant amounts of wet waste, such as dredged

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sediment, which must be dewatered and properly disposed of [7], [8]. Moreover, these methods may cause secondary pollution by leaching metals and contaminants from the sediment mixing into the water column [9], [10]. Sediment capping can also lower phosphorus levels by covering over-enriched sediment with an active or inactive layer. Nevertheless, this strategy is often regarded as a temporary measure [11] and may shift the burden to future generations.

Therefore, this study explores sediment remediation using air resuspension followed by geotextile filtration to attenuate P. A laboratory air-sediment resuspension experiment induced turbulence, suspending surface sediments within the water column. These suspended particles were then removed and filtered using a nonwoven geotextile filter. Thus, this research focuses on a case study involving phosphorus-enriched lake sediments from Lake Caron, a shallow, semi-artificial, mesotrophic lake located in *Sainte-Anne-des-Lacs*, Quebec. The objective is to understand the leaching of heavy metals and soluble reactive phosphorus into the water during resuspension and to evaluate phosphorus attenuation in disturbed sediments after filtration.

2 Materials and Methods

2.1 Study Area

Lake Caron (45°50'28''N; 74°08'50" W) is a shallow mesoeutrophic lake located in the *Sainte-Anne des Lacs* municipality, Québec (75 km north of downtown Montreal). This lake has average, maximum, and minimum depths of 1.4 m, 2.6 m, and 0.5 m, respectively and approximate water volume and surface area of 48,400 m^3 and 35,300 m^2. It is in the *Lac Ouimet* watershed, which is predominantly covered by wild vegetation and has a few residents, as shown in Figure 1a.

The main sources of phosphorus in this lake likely include external inputs, such as watershed runoff contaminated with fertilizers, decaying leaves, and plant matter during fall. Internal phosphorus loading, in contrast, may result from septic tank outflows from nearby residents and phosphorus release from sediments caused by previous lake enlargement. This process left vegetation and tree stumps inside the lake. Sediment phosphorus levels range from 866 to 1298 mg/kg [12], and relatively high P concentrations were found in sediments from St. 4 and St. 8, as presented in Figure 1b. For experimental purposes, sediment was collected between the two mentioned stations using a grab-type surface-sediment sampler, and a 20 L polypropylene bucket, which was transferred to the laboratory, and used within 15 days.

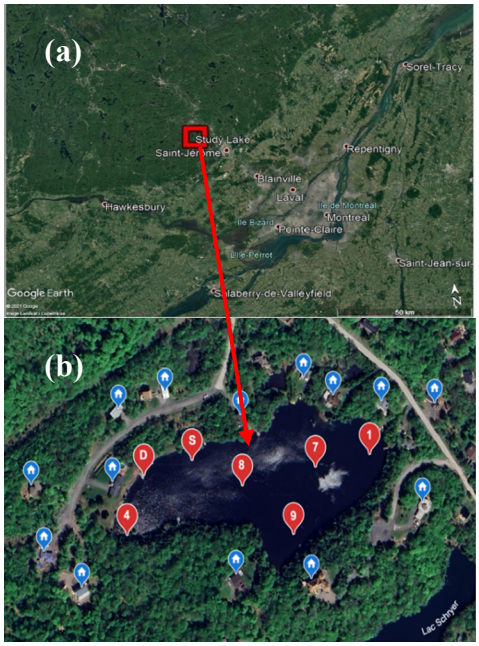


Fig. 1. (a) Lake Caron location and (b) details with sampling stations and household locations

2.2 Resuspension Method

To evaluate the leaching of heavy metals and soluble reactive phosphorus into water during resuspension and to assess phosphorus attenuation in disturbed sediments after geotextile filtration, a laboratory adaptation of the sediment resuspension/filtration procedure presented by [13], [14] was done.

The resuspension experiment was conducted as shown in Figure 2. On this, 5 cm of wet sediment (approximately 1.5 kg) was added to a plexiglass column, and 35 cm of water (10.5 L of type-1 water) was placed on top of it with a peristaltic pump in its lower setting for no disturbance of the sampled sediment. Thus, the sediment was resuspended with 1.5 SCFM of air (0.7 L/s) for 3 min with the air jets placed 5 cm above the sediment [15]. The water-air jet consists of a showerhead, and a rotameter was also used to regulate airflow. Lastly, after 3 min of air resuspension, the water suspension was pumped by pump to facilitate the separation of water and solids and the dewatering of wet materials within the geotextile filter.

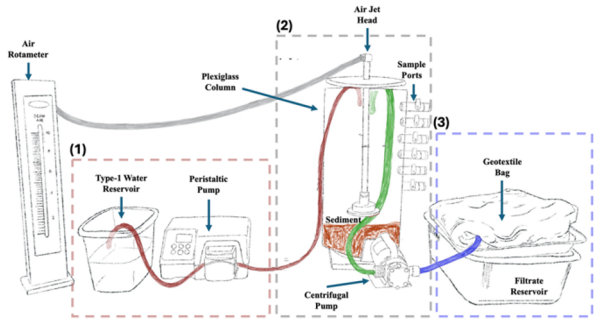


Fig. 2. Experiment setup for air-induced sediment resuspension followed by suspension bag filtration

2.3 Filter Media, Batch and Bag Filtration

This experiment used nonwoven geotextiles from Titan Environmental Containment, MB, as filter media. Table 1 shows the apparent opening size (AOS) of the nonwoven geotextile membranes, based on data from Titan Environmental Containment's datasheets. Nine distinct apparent opening sizes (AOS) were tested.

Table 1. Non-woven geotextile characteristics used in the lake sediment remediation experiment

Filters	Material	Apparent Opening Size (AOS) (μm)
TE-GTT170	Polypropylene	350
TE-GTT120	Polypropylene	300
TE-GTT200	Polypropylene	212
TE-GTT270	Polypropylene	180
TE-GTT400	Polypropylene	150
TE-GTX300	Polyester	110
TE-GTT100	Polypropylene	100
TE-GTT120	Polypropylene	90
TE-GTT200	Polypropylene	70

The initial experiment employed a column-resuspension test to evaluate the leaching of heavy metals, soluble reactive phosphorus and dissolved organic carbon into water during resuspension. The setup was configured, as shown in Figure 3. Samples were collected at 0, 2, 3, 5, 10, 15, 30, 60, and 80 minutes from two heights: 15 cm above the sediment surface and 15 cm below the water surface. These samples were analyzed chemically and physically to determine the best suspension-pumping conditions for a subsequent filtration batch experiment.

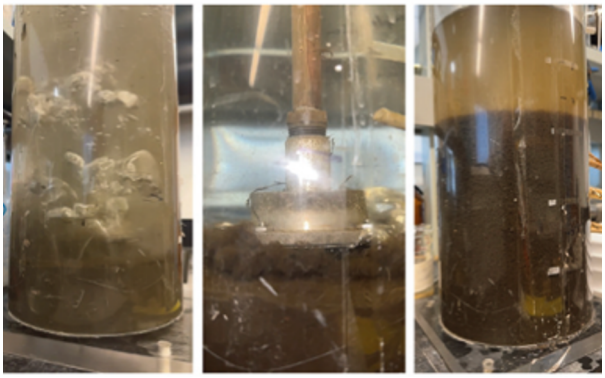


Fig. 3. Column-resuspension test with representation of the shower head and settling

Under optimal suspension-pumping conditions, the resuspension was then performed. Instead of allowing particles to settle after resuspension and evaluating subsequent leaching, the liquid suspension was retrieved from the column using a centrifugal pump after an air-jet duration of 2-3 minutes and a defined settling time, thereby allowing larger particles to settle. Subsequently, the suspension was filtered in a batch experiment using a conical geotextile filter combination.

The geotextile conic filtration media had a maximum radius of 6.5 cm, as shown in Figure 4. The two initial sizes, 350 μm and 300 μm, were used as pre-filters and combined with all other sizes, as well as with each other, yielding 15 combinations tested. The goal was to pre-filter with 350 μm and 300 μm filters and to use the second layer as the capture layer to process 400 ml of sediment-laden suspension during the experiment, aiming to identify the filter combination that provides the best particle attenuation and thus other contaminant reduction.

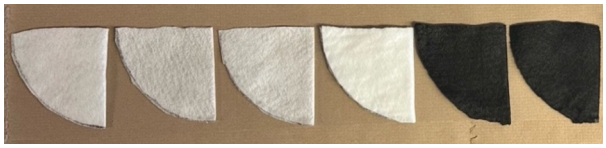


Fig. 4. Pristine non-woven geotextile cones

With the best combination of filter layers for particle attenuation, a column resuspension was performed in triplicate as presented in the sediment resuspension method. However, a geotextile bag was used instead of conical filters to filter the entire column suspension, approximately 10.5 L. The bag measured 21 cm by 29.7 cm.

2.4 Chemical Analysis of the Suspension and Sediment

In summary, the analysis performed in this experiment was based on the following. Curves were based on determining whether sediment-air resuspension causes leaching in the water column and on defining the optimal pumping time for the following experiment: cone filtration. The optimal time was determined by suspended particle concentration, particle size, soluble reactive phosphorus, dissolved organic carbon and heavy metals. For the cone filtration trial, the goal was to identify the optimal combinations of geotextile pore sizes for water-suspension attenuation. This was based on particle-size reduction and on attenuation of total suspended solids, total organic carbon, and soluble reactive phosphorus.

Following the cone filtration experiment, bag filtration was performed on a column scale (10.5 L) to capture enough sediment on the filter media for further sediment analysis. The water suspensions before and after filtration were evaluated for suspended particle concentration, particle size, soluble reactive phosphorus, dissolved organic carbon, and heavy metals. The raw, suspended, and filtered sediment samples were analyzed for iron, heavy metals and total phosphorus.

3 Results and Discussion

3.1 Resuspension Method

The column experiment was conducted as follows: 1.5 SCFM (0.7 L/s) of air for 3 minutes, with the air jet positioned 5 cm above the sediment in a plexiglass column. Following the collection of two initial samples, subsequent samples were obtained from ports situated at (1) 15 cm from the water surface and (2) 15 cm from the sediment surface over an 80-minute period. Variations in the concentrations of total suspended solids (TSS), particle size, soluble reactive phosphorus (SRP), dissolved organic carbon (DOC), and heavy metals and iron were measured.

For particles, their size and concentration decreased drastically within 5 min of sediment resuspension (i.e., due to their fast-settling velocities), as shown in Figure 5, either 15 cm above the sediment surface or at the water surface. Higher TSS concentrations were observed within 2-3 min in both samples, with D50 (average particle size) slightly higher (70-33 µm) than the particle size with the highest phosphorus mass and concentration (<45 µm).

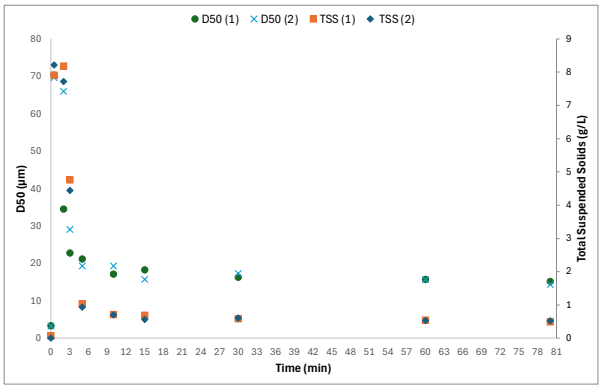


Fig. 5. Total Suspended Solids – TSS (g/L) and D50 (µm) - average particle size in the resuspension experiment over time.

It is decided to remove the suspension at this time (2-3 min) for further geotextile filtration, which would not only ensure the removal of the targeted particles but also provide sufficient TSS to produce a pronounced change in the phosphorus sediment concentration.

Changes in the dissolved organic carbon (DOC) and soluble reactive phosphorus (SRP) were observed for the water/sediment suspension, as presented in Figure 6. The two heights sampled showed greater variance, with the one near the sediment being more disturbed. Soluble Reactive Phosphorus (SRP) increased by 15 cm near the sediment surface from 1-2 µg/L to 4-6 µg/L (200% increase). This increase was also observed in the entire system DOC following resuspension. Its value increased from 1.5 mg/L to approximately 4.2 mg/L (180% increase) and remained constant for the remainder of the 80 min.

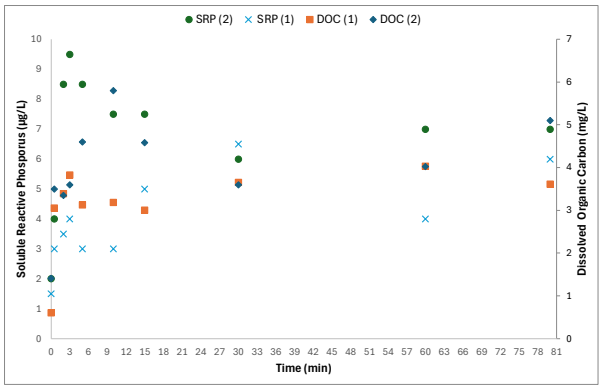


Fig. 6. Soluble Reactive Phosphorus – SRP (µg/L) and Dissolved Organic Carbon (mg/L) in the resuspension experiment over time.

No significant amounts of heavy metals and iron were dissolved in the system after 3 minutes of resuspension, as indicated by the 80-minute follow-up analysis, as shown in Table 2. This ensures that this

sediment resuspension (Lake Caron) will not cause secondary pollution due to metal leaching into the water.

Table 2. Heavy metal and iron dissolution after the resuspension experiment within 80 min

	Before	Water Surface (15cm)		Before	Sediment Surface (15cm)		Max. Allowed* (µg/L)
	(µg/L)	Min (µg/L)	Max (µg/L)	(µg/L)	Min (µg/L)	Max (µg/L)	
Cr	0.06	0.06	3.92	0.15	0.16	0.48	10
Fe	3.68	24.3	43.14	4.72	33.76	42.28	300
Ni	0.38	0.19	1.3	0.48	0.59	1.8	20
Cu	5.44	2.66	36.22	24.08	12.3	35.58	2000
Zn	31.41	3.62	35.34	17.23	13.05	54.66	3000
Cd	0.01	0.01	0.03	0.01	0.01	0.03	10
Pb	0.1	0	0.36	0.05	0.07	0.21	5

Batch and Bag Filtration Experiments

The optimal pumping and filtration interval, as well as the pumping height, were defined as 2-3 minutes and 15 cm above the sediment surface, respectively. Suspension filtration was conducted after extracting the maximum possible water without disrupting the sediment layer. A total of 15 combinations were examined by filtering 400 ml of water and sediment, and the results were compared with the initial raw-suspension values. The cone filters employed after the use are shown in Figure 7.

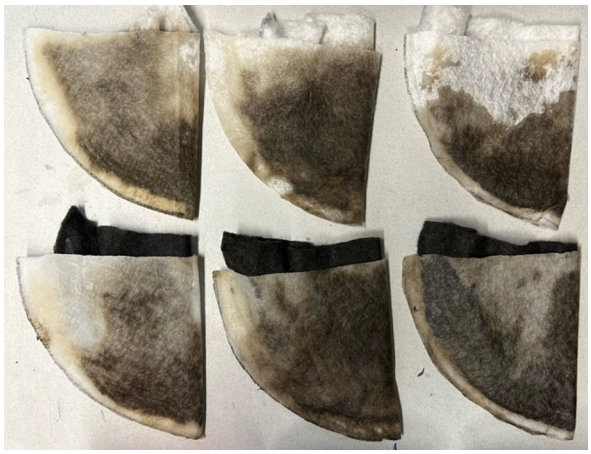


Fig. 7. Geotextile filter cones after filtering 400 ml of water/sediment suspension

Across all proposed combinations, at least 80% removal of solids was observed, as shown in Figure 8. As the removal of particles was quite similar on all combinations evaluated, the best-performing ones for the following experiment (bag filtration) were based on the DOC and SRP attenuation in the filtrate.

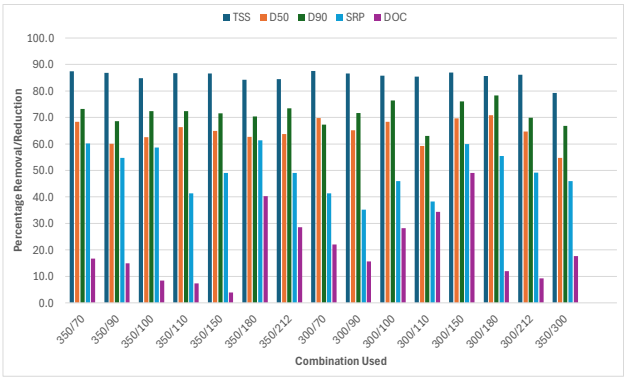


Fig. 8. D50, D90, Total Suspended Solids (TSS) and Soluble Reactive Phosphorus (SRP) and Dissolved Organic Carbon (DOC) removal/reduction in the batch cone filtration experiment.

The combinations Filtration Case 1 (350/180) and Filtration Case 2 (300/150) were selected for the following experiment, namely, bag filtration. For the 350/180 combination, a 61% reduction in SRP and a 40.3% reduction in DOC were observed. In comparison, for the 300/150 combination, removals of 60% and 49.0% were observed for SRP and DOC, respectively. In the column experiments on sediment remediation, phosphorus attenuation was observed to be 13.4% for filtration case 1 and 20% for case 2, as shown in Table 3.

Table 3. Geotextile bag filtration experimental results regarding sediments

Parameter	Raw Sediment	Captured Sediment	Filtration Case 1	Filtration Case 2
Sediment Total Phosphorus (mg/kg)	1153.20 ± 307.49	1373 ± 150.90	998.27 ± 170.67	925.00 ± 110.67

4 Conclusions

The results of the experiments suggest that investigating sediment resuspension followed by geotextile filtration is feasible in this lake sediment. No significant leaching of heavy metals, iron, or soluble reactive phosphorus was observed in the water suspension, and the disturbed sediment settled quickly (within 2-3 minutes). Additionally, batch cone filtration achieved at least 80% TSS removal and a reduction in particle size across all tested combinations. Column experiments on sediment remediation achieved a 20% reduction in phosphorus

under the best scenario. Future research will aim to scale up the resuspension unit and explore its use in an enclosed area on-site and in situ, utilizing various sizes and types of geotextiles. Further characterization of particle surface charges, as well as coagulant performance in lake water, may assist in the attenuation potential of this remediation method. Additionally, further tests of this resuspension method on various lake sediment samples will be conducted for testing reproducibility.

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