REMOVAL OF PHOSPHORUS AND OTHER COMPONENTS FROM EUTROPHIC LAKE WATER

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ABSTRACT

Increasing phosphorus (P) content and decreasing water quality of shallow Lake Caron has led to the implementation of many management strategies to restore the lake. Despite the perceptible reduction in external sources, except drainage from nearby forest areas, the P level in lake water still remain high and constitute a major challenge to the lake restorers. As part of the restoration plan, a laboratory study was performed to assess the effectiveness of non-woven geotextiles in reducing the nutrients (P and nitrogen, N) concentrations and improving the lake water quality. Two geotextile filters (TE-GTN350 and TE-GTX400) with different apparent opening sizes and materials were tested in three different combinations: (i) TE-GTN350/TE-GTN350, (ii) TE-GTX400/TE-GTN350 and (iii) TE-GTX400/TE-GTX400. Apart from geotextile filters, clean sediments were incorporated onto the filters, and these sediments may act as adsorbent materials for nutrients and enhance the treatment efficiency. Due to filtration, the total P (TP) content was reduced from 40 µg L^{-1} to 10 µg L^{-1}, which is the safest level of P for the protection of aquatic life in Quebec surface waters. Overall TP removal efficiency by filters was between 62.5 and 75% and a slightly higher efficiency was observed with TE-GTN350/TE-GTN350 combination. Apart from TP removal, these filters were effective in reducing the turbidity by 77-85% and total N (TN) by 37-52%. The water quality improved in terms of nutrients and turbidity removal rendering an effective treatment system with potential for on-site testing as the next step.

Keywords: lake water, phosphorus, eutrophication, non-woven geotextiles, filtration unit.

1 INTRODUCTION

Since the 1960's, the problem of eutrophication has become evident in many lakes in Canada and rapid increases in algal growth causes deterioration of water quality. Depending on the degree of eutrophication, severe water quality problems can develop. Increased phytoplankton biomass can decrease clarity, and reduce levels of light and oxygen, all of which eventually have negative consequences for organisms that live in the lake (Schindler 2006). Therefore, there has been a considerable pressure for action for governments and aquatic scientists to ameliorate the situation and reduce the symptoms of cyanobacterial blooms as citizens lose water uses and become aware of health and ecological risks associated with the eutrophication. Phosphorus (P) is often cited as a growth-limiting nutrient factor which initiates a bloom of phytoplankton (Lewis and Wurtsbaugh 2008), and thus is the primary macronutrient targeted for reduction by most lake restoration strategies. Although source control action has been initiated since the late 1980's for some of the Canadian lakes, the recovery of a lake is often less rapid than predicted. This is apparently due to the internal loading of P from sediments to the water column (Cooke et al. 2005).

Lake Caron (Quebec, Canada) is an example of such a P-enriched lake that has undergone eutrophication. Since 2008, the lake water P concentrations exceeded the critical limit for aquatic life (30 µg total P L^{-1}) set by the Ministère du Développement Durable, de l'Environnement et des Parcs (MDDEP) and the massive algal blooms were seen in 2008 and 2012 (MDDEP 2012). Hence, MDDEP has prohibited the inhabitants around the lake from using the water even for recreational purposes. No industrial or agricultural effluents were accumulating inside the lake, however in the past there have been fertilizer runoff and septic tank discharges, in addition to organic matter degradation in the lake. Sediments continuously accumulate at the bottom of the lakes as there is constant erosion from rocks and lands. Also microbial uptake, growth and death are taking place inside the water contributing to the total P (TP) load. That is why preventing eutrophication is difficult (Karim et al. 2012). So far, no in-lake treatment strategies have been executed on this lake to reduce the P level in water that still remains as a eutrophic lake. Several methods such as use of chemicals (alum, calcite and lime) (Prepas et al. 1990, Cooke et al. 1993) and sediment dredging (Reddy et al. 2001) have been proposed, and successfully tested in many lakes for managing eutrophic lakes. However, they are not economically feasible to apply in small shallow lakes or they may increase the toxicity of water (e.g., increased Al concentration in water due to alum application) (Cooke et al. 1993). Therefore, cost-effective and ecologically compatible materials must be identified for their use in treating small lakes.

In the present study, an attempt was made to reduce the P level in Lake Caron water by direct filtration using geotextiles. Geotextiles are informally referred to as filter fabrics and their applications include layer or strata separation, soil improvement, reinforcement, filtration and drainage (Quaranta and Tolikonda 2011, Franks et al. 2012). Geotextiles are in two forms: (i) woven and (ii) non-woven. In general, non-woven geotextiles are felt-like materials, very permeable and compressible, and their application as filtration media in surface water remediation is very limited. An efficient technology to address nutrients enriched water via the use of geotextiles can have a major impact on managing the eutrophic lakes. The main objective of this study is to develop a filtration technique, capable of *in situ* application, using different customized non-woven geotextiles for the removal of contaminants (especially P) from eutrophic lake and to improve the overall water quality of lake.

2 MATERIALS AND METHODS

2.1 Study area

Lake Caron ($46^0 18^0$N, $75^0 28^0$W) is located within the municipal limit of Sainte-Anne-des-Lacs in the province of Quebec, Canada (Figure 1). The approximate area and average water volume of the lake are 35,300 m^2 and 46,400 m^3, respectively. It is a shallow artificial lake, with an average depth of 1.3 m. It remains frozen usually from late October to the middle of May. During heavy downpours, it overflows at some points to maintain the water level of the lake. The watershed is dominated by wild trees and there are some privately owned houses surrounding the lake.

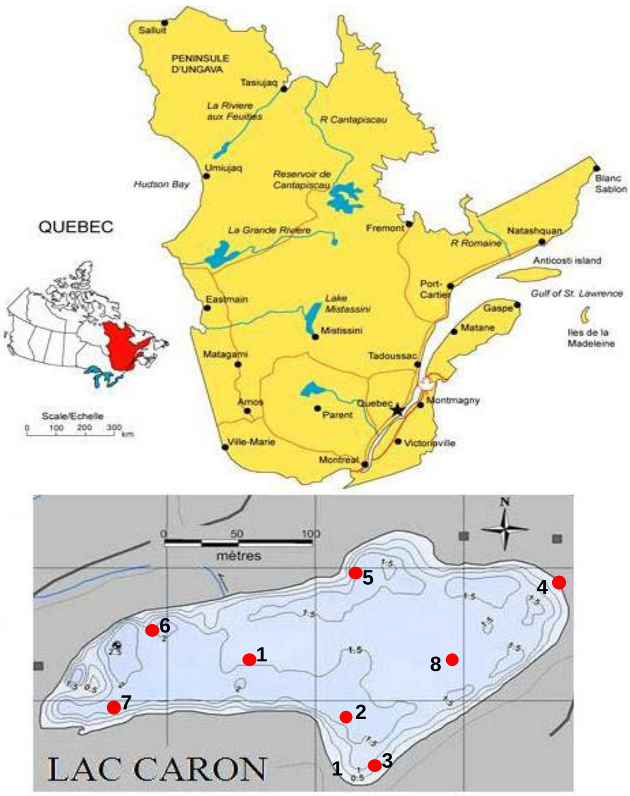

Figure 1. Map showing the geographical location of Lake Caron and sampling stations (1 to 8)

2.2 Sampling and analysis

The surface water samples (0 – 30 cm) were collected from eight different sampling points in the lake (Figure 1). The choice of stations was done in order to present an overview of the surface water quality of Lake Caron. Sampling was done at monthly intervals, from June to October 2013, using a pedal boat and the samples were collected in 1L amber polyethylene bottles. Prior to sampling, *in-situ* measurements were taken for various parameters such as pH, electrical conductivity (EC), temperature (T), dissolved oxygen (DO) and cyanobacterial cells count using YSI 6600 V2 Sonde (Hoskin). The turbidity of lake water was measured using turbidimeter (Oakton). The collected samples were then transported to the laboratory under cold conditions, and were stored in the refrigerator at 4 °C until further analyses. The samples were analyzed for TP (Method 8190, PhosVer 3 with Acid Persulfate Digestion; Hach 2008), chemical oxygen demand (COD; reactor digestion method, TNT 821; Hach 2008), total nitrogen (TN; persulfate digestion method, TNT 826; Hach 2008) by following Hach protocols. Adequate blanks, standards and replicates (n=2 to 4) were processed for all analyses in order to ensure data quality.

2.3 Geotextiles-based filtration set up

A cylindrical filtration column made of plexiglass with an internal diameter of 20 cm and a height of 25 cm was used at the top of the base to hold water and support hydraulic head of 18 cm above the filter. A square shaped base, with a circular hole at the centre with the exact internal diameter of the filtration column (20 cm) was used as filter holder. There was a hole at a height of 18 cm of the cylinder which acted like an emergency spillway. The whole unit was kept on a plastic tank with a capacity 15 litres. Figure 2 shows the schematic diagram of the filtration unit used in this study.
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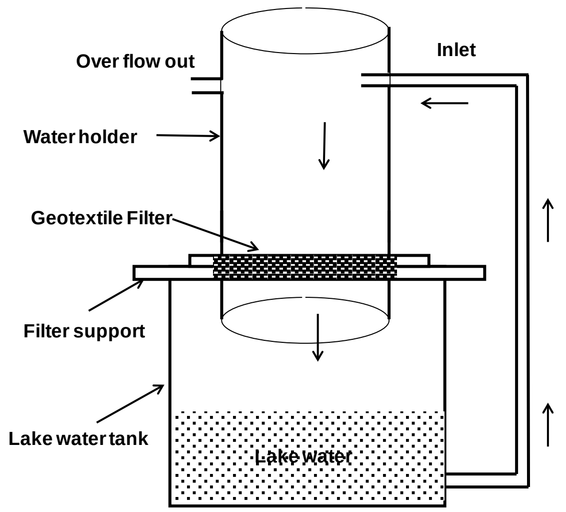

Figure 2. A schematic diagram of geotextile filter unit employed in the P removal from lake water

Two different nonwoven geotextiles, which were developed and supplied by Titan Environmental Containment Ltd, MB, were used as filter medium. Some important characteristics of filters are given in Table 1. The TE-GTN 400 is produced from 100% polypropylene (staple fibre), whereas TE-GTX is made from 100% polyester (long fibre). Another main difference between these two filters is that they have different apparent opening sizes (AOS; TE-GTX400 - 90 µm; TE-GTN350 – 75 µm). The filters were cut in a circular shape with a diameter of 22 cm before placing them on the filter support.

Table 1: Characteristics of the geotextile materials used in this study

Filter	Type of material	Apparent opening size (AOS) (µm)	Mass/area (g m^{-2})	Water flow rate (L s^{-1} m^{-2})
1. TE-GTX400	Polyester	90	400	120
2. TE-GTN350	Polypropylene	75	350	90

2.4 Filtration Tests

In this study, three different combinations of filters were tested for the removal of TP from lake water and to improve the overall water quality. The combinations were: TE-GTX400/TE-GTX400, TE-GTX400/TE-GTN350 and TE-GTN350/TE-GTN350. While using a combination of TE-GTX400/TE-GTN350, TE-GTX400 was kept on top since it has a higher AOS (90 µm) and it would retain larger suspended particles in the filter water. Apart from geotextile filters, sediments were incorporated onto the filters prior to pass the lake water. The idea was that the sediments, including organic materials, may act as adsorbent materials for nutrients (TN and TP) and it could enhance the treatment efficiency. A quantity of 20 g sediments, collected from Lake Caron (Station 7), was mixed well with 5L of tap water and passed through the filters. Then the unit was run for 2 hours with 5L deionized (DI) water for better sedimentation of particles and removing the P from sediments. At the end of 2 hours, by testing the DI water for TP, it was confirmed that there was no leaching of TP (TP values were below the detectable limit) from the sediment as well as the filters. Then the DI water was removed and the sediment incorporated filter unit was run with lake water.

Ten litres of Lake Caron water (collected in November, 2013 and refrigerated at 4 °C) were poured into the filtration tank. The water was passed through the filter using pump and returned to the tank for subsequent refiltration. A flow rate of 8-10 L per minute was used for filtration. The unit was run for a week and the treated water was collected at different time intervals. The changes in water quality of lake and the efficiency of geotextile filters were assessed by analyzing the samples for TP, turbidity and TN. The analytical procedures followed are given in section 2.2.

3 RESULTS AND DISCUSSION

3.1 Lake water quality

The changes in water quality variables were monitored at 8 different stations in Lake Caron during June to October, 2013. The results revealed that there were no significant differences between the stations, indicating the free movement of water masses allows better ion-exchange there between, hence, only the range values are presented in Table 2. The pH of water varied between 6.1 and 7.5. The conductivity of lake water was found between 28.5-33 µS cm^{-1}. A slight increase in EC was observed at the end of summer can be attributed to the increased dissolved salts concentrations in water due to T. According to Canadian Environment Quality Guidelines (6 to 6.5 mg DO L^{-1}; CEQG, 1999), the lake water has high enough DO to support aquatic life, with the average DO level of 8.3 mg L^{-1}. During the sampling period, a moderately high (>1 mg L^{-1}) TN concentrations were observed in the lake water and this may contributed to eutrophication of lake. It could be seen from the Table 2 that the cyanobacterial cells (2270 – 6300 cells ml^{-1}) were within the maximum allowable limit for recreational purposes (100,000 cells ml^{-1}) set by Health Canada (2012).

Table 2: Quality of water samples collected from Lake Caron during June-October, 2013.

Parameters	Values
pH	6.1-7.5
Temperature (^{0}C)	12.1-29
Electrical conductivity (EC; µs cm^{-1})	28.5-33
Turbidity (NTU)	1.3-15
Dissolved oxygen (mg L^{-1})	7.4-9.1
Total N (mg L^{-1})	0.3-1.5
Chemical oxygen demand (COD; mg L^{-1})	13-30.5
Cyanobacteria (cells mL^{-1})	2270-6300

Analyses of water for TP have clearly shown that the water quality of the lake is being degraded by the activities around the lake watershed and sediments (Figure 3). Total P concentration in water samples is used as a primary indicator to predict lake water trophic level. It is considered as a limiting nutrient for aquatic plants growth. However, its excess concentration in water column may cause eutrophication. According to MDDEP trophic status classification, TP concentration between 30-100 µg L^{-1} indicates a eutrophic state of water body (MDDEP, 2012). Total P concentration in the water samples ranged between 10 (S6) and 60 (S4) µg L^{-1}, with an average value of 34 µg L^{-1}, exceeded the Quebec criteria for TP (30 µg L^{-1}). The average concentrations of TP for samples from all sampling stations were equal or above 30 µg L^{-1}. Among stations, the samples from S1 and S4 recorded high

TP content. The lake water near S4 receives the drain from the surrounding forest area. Hence, it is necessary to develop a treatment technique in order to restore the lake to an oligotrophic state (< 10 µg TP L^{-1}).

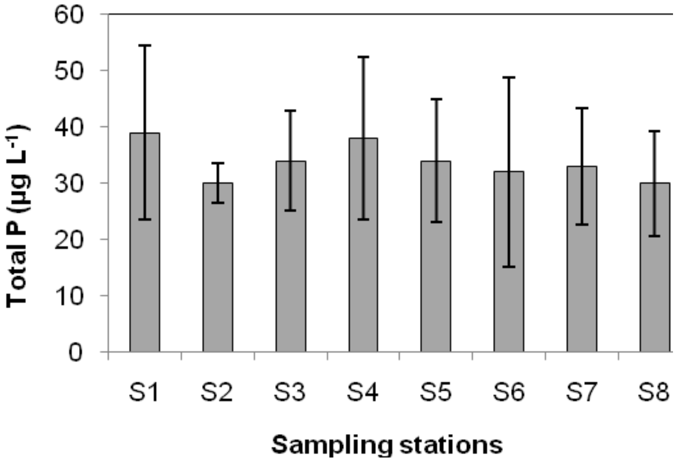

Figure 3: Average concentrations of TP (µg L^{-1}) in the lake water samples collected during June to October, 2013.

3.2 Efficiency of Filter unit with geotextiles

3.2.1 Total P removal

The initial concentration of TP in the lake water was 40 µg L^{-1}. This high TP value indicates the poor water quality and the lake is in a eutrophic state. Irrespective of geotextile filter combinations used, the TP content was decreased to 10 µg L^{-1} due to filtration (Figure 4). This was achieved in 2 to 3 days by TE-GTN350/TE-GTN350, whereas, TE-GTX400/TE-GTN350 took 5 days. TE-GTN350 has smaller AOS (75 µm) compared to TE-GTX400, and this might have retained smaller solid particles than it was done by TE-GTX400. Along with incorporated sediments, these solids might have formed a layer or cake on top of the filter and as the water passed through this newly formed medium the contaminants were removed. Moo-Young and Tucker (2002) indicated that evidence of this phenomenon was the decrease of permeability. At the beginning of the experiment, the hydraulic head obtained was 0.5 cm, whereas it increased to 5 cm within 2 days of run due to the settling of suspended particles in the lake water onto the filters.

According to the MDDEP (2012), TP values above 30 µg L^{-1} represent eutrophic state of lake, between 10 and 30 µg L^{-1} represent mesotrophic and the values below 10 µg L^{-1} are considered as oligotrophic. It is clearly seen from Figure 3 that all geotextile filter combinations along with incorporated sediment improved the trophic state of the lake water from eutrophic to mesotrophic.

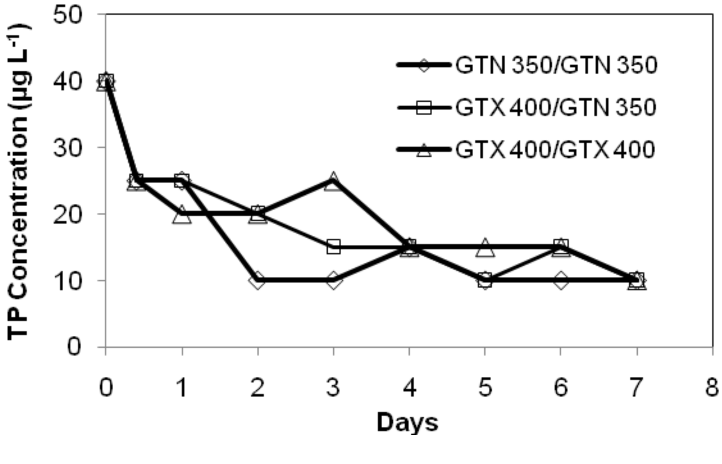

Figure 4. Changes in TP concentration (µg L^{-1}) of lake water during the filtration by geotextile unit

Overall TP removal efficiency by filters was between 62.5 and 75% (Figure 5) and a slightly higher efficiency was observed with TE-GTN350/TE-GTN350. Similar TP removal efficiency by nonwoven geotextile filters was reported by Inoue et al. (2009) and Mulligan and Ramalingaiah (2011).

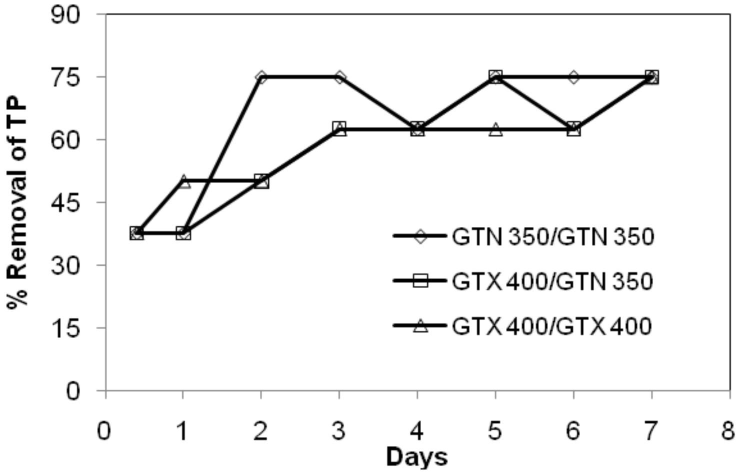

Figure 5. Removal of TP (%) over time by the geotextile filtration unit

3.2.2 Reduction in turbidity

Figure 6 shows the change in turbidity of lake water after filtration. Turbidity provides a measurement of suspended solid (SS) particles in water. The Canadian Council of Ministers of the Environment (CCME) criteria for turbidity in surface water for protection of aquatic life indicates that the maximum concentration of SS in surface water is 2.5 mg L^{-1} (CCME 1999).

The initial turbidity of Lake Caron water was 3.24 NTU. By filtration of this system, the turbidity was reduced and the water became clear. Most of the turbidity removal occurred within the first 6 hours of run, and the turbidity values came down to 1.04-1.06 NTU. These values represent a much improved and acceptable water quality. Between Day 1 and 7, 70 to 79% reduction in turbidity was achieved by both TE-GTN350/TE-GTN350 and TE-GTX400/TE-GTX400, whereas TE-GTX400/TE-GTN350 showed significantly high removal rate (83-85%) (Figure 6). In an experiment with geotextile filter for removal of SS from surface water by Mulligan et al. (2009) showed 93% removal of turbidity. The results obtained in this study indicate that TE-GTX400/TE-GTN350 filters combination is very effective in improving the clarity of water. Despite a high removal rate by filters, the clogging of filters due to retention of solids was not observed during the entire run.

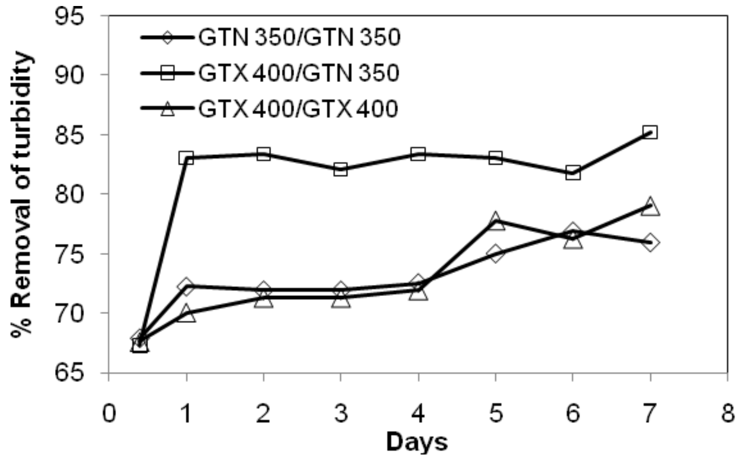

Figure 6. Removal of turbidity (%) over time by the geotextile filtration unit

3.2.3 Total N removal

In general, TN in the lake water is the total of N in the NH_4^+ form, oxidized forms (NO_2^- and NO_3^-), and N bound to suspended particles and soluble organic forms. These forms act as the source of N either directly or indirectly for both plants and animals in the lake. Initially, the water had a concentration of 1.7 mg TN L^{-1}. After passing through the filter, it was found that the TN content reduced slowly and the removal efficiency was in the range of 12 to 52%, 9 to 47% and 19 to 37% for TE-GTN350/TE-GTN350, TE-GTX400/TE-GTN350 and TE-GTX400/TE-GTX400 filters, respectively (Figure 7). According to MDDEP and VDEC (2008), the threshold level of TN for the protection of aquatic life is: < 0.7 mg L^{-1} considered as good and 0.7 – 2 mg L^{-1} considered as moderate. By filtration with TE-GTN350/TE-GTN350 and TE-GTX400/ TE-GTN350, the final concentration of TN in the lake water was as low as 0.7 and 0.8 mg L^{-1}, respectively.

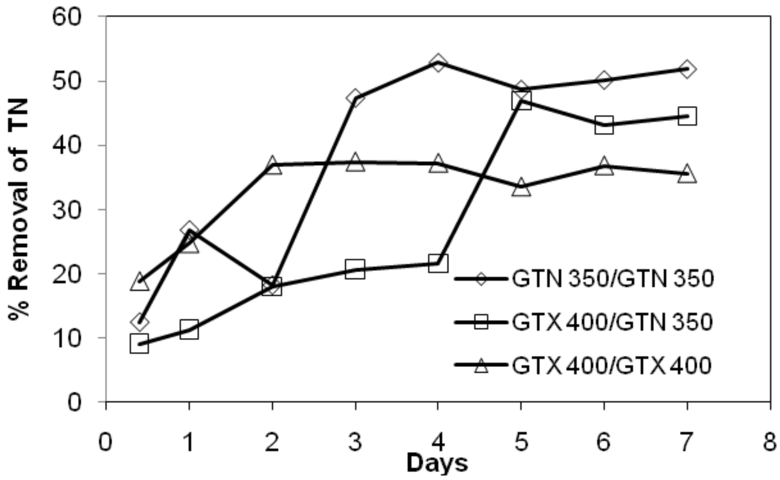

Figure 7. Efficiency of geotextile filters in removal of TN (%) over time

4 CONCLUSIONS

The results of this study showed that the nutrients and turbidity levels of lake water were reduced substantially by filtration technique using geotextiles as filter medium (especially by TE-GTN350/TE-GTN350 and TE-GTX400/ TE-GTN350 combinations). Therefore, it could potentially be used as an alternative remediation technique for improving the water quality of eutrophic shallow lakes without using chemicals or creating any environmental impact. However, the feasibility of this technique must be tested at large scale under *in-situ* conditions where the actual environmental factors will apply.

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