# Improving Surface Water Quality Using a Geotextile Filtration Technique

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# ABSTRACT

## Improving surface water quality using a geotextile filtration technique

**Mina Ghasri**

Different substances are carried from land to water areas such as lakes and ponds by natural or anthropogenic activities. Suspended solids (SS) consisting of organic and inorganic matter are examples of these substances that are discharged into water bodies. Contaminants, such as nutrients, bacteria, and heavy metal, which enter surface waters adsorb onto the surface of these particles and eventually settle on the bottom sediments which then become the largest potential source of contaminants into the overlying water. The presence of these SS in the water causes a decrease in the transparency and also excessive loads of nutrients which lead to eutrophication and rapid growth of algae in the water. Lake Johanne is a shallow mesoeutrophic lake located in the municipality of Saint-Anne-Des-Lacs, Quebec, Canada. The lake was exposed to algal blooms during the hot summer in the past and the water has been found to be turbid since 2008.

The focus of this study was to evaluate the water quality variables of this mesoeutrophic lake, to improve the quality of water using a geotextile filtration technique and thus assess the reliability of the geotextile filters in removing suspended solids and adsorbed nutrients. To accomplish these, lake water quality was monitored for two years (2017-2018). Also, a series of on-site filtration experiments was conducted beside the lake using non-woven geotextiles as filter media. Different combinations of geotextiles, differing in apparent opening sizes and number of layers (5-6), were examined to find the combination showing maximum efficiency in removing SS and associated nutrients. Experiments were classified into four categories with respect to the geotextile combination used as a filter media.

The results obtained from all the experiments conducted with different geotextile combinations were promising for the suspended solids, turbidity, chlorophyll-a, and phosphorus removals. However, combination 3 which included two layers of 100 microns followed by two layers of 90 microns, and two layers of 70 microns showed better results as compared to the other combinations used in this study. The filtration experiments conducted with this combination resulted in 8.3 g $/m^2$-d total suspended solids (TSS), 11.6 mg $/m^2$-d total phosphorus (TP), 9.8 g $/m^2$-d chemical oxygen demand (COD), and 11.1 mg $/m^2$-d chlorophyll-a removal. Overall, the results have indicated the potential of non-woven geotextiles for use as a filter media to improve the quality of surface water by removing SS and algae that impair the water quality. Thus, the geotextile filtration technique can be considered as an effective remediation method for contaminated surface water bodies such as lakes and ponds.

***To Mahsa***

***&***

***My parents***

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# Table of Contents

## List of Figures

# List of Tables

## List of abbreviations

ABVLACS : Agence des Bassin Versants de Sainte-Anne- des-Lacs

AOS : Apparent Opening Size

ASTM : American Society for Testing Materials

BAP : Bioavailable Phosphorus

BGA : Blue-green Algae

CCME: Canadian Council of Ministers of the Environment

Chl-a : Chlorophyll-a

COD : Chemical Oxygen Demand

CRE : Conseil régional de l'environnement

DO : Dissolved Oxygen

DRP : Dissolved Reactive Phosphorus

EC : Electrical conductivity

MDDELCC : Ministère du Développement durable, Environnement et Lutte contre les changements climatiques

MDDEP : Ministry of Sustainable Development, Environment and Parks

MELCC : Ministère de l'Environnement et de la Lutte contre les changements climatiques

MF : Microfiltration

N : Nitrogen

NF : Nanofiltration

ORP : Oxidation-Reduction Potential

P : Phosphorus

PAC : Polyaluminium Chloride

PP : Particulate Phosphorus

PSA : Particle Size Analysis

RO : Reverse Osmosis

ROBVQ : Regroupement des organismes de bassins versants du Québec

RSBF : Red Soil-based Flocculant

SCP : Sodium Carbonate Peroxyhydrate

SRP : Soluble Reactive Phosphorus

SS : Suspended Solids

TDP : Total Dissolved Phosphorus

TN : Total N

TP : Total Phosphorus

TSS : Total Suspended Solids

UF : Ultrafiltration

USEPA : United States Environmental Protection Agency

WHO : World Health Organization

WTRs : Water Treatment Residuals

# 1 INTRODUCTION

## 1.1 The problem

Nowadays, there is an increasing environmental concern about the quality of surface water in the world since the quality of our life is dependent on water as a life source. Despite the abundance of water in Quebec, its quality is decreasing because of urbanization, industrialization, and the intensification of agriculture. Water quality can be affected by point and non-point sources. Wastewater discharge from municipalities and industries, septic tank discharge, and using fertilizers and pesticides are some of the human activities which influence the quality of water. Rain and snowmelt can be responsible for washing materials like sediments and nutrients from the surface into the nearest water body and thereby decreasing water quality. Activities on land like agriculture, mining, and urban improvement can also indirectly affect water quality. Lakes are surface water and as a freshwater source, have become an essential part of people's lives, either for lake residents or the ones who visit lakes for recreational purposes like boating, fishing or swimming. Unfortunately, many lakes in Canada have water quality issues resulting from the input of large amounts of nutrients to lakes and sediments. Blue-green algae blooms and excessive growth of aquatic vegetation can be the result of excess nutrient input (Government of Alberta, 2019; MDDEP, 2019c). Suspended solids which are discharged to enclosed water areas have an important effect on the transport and fate of contaminants. The presence of these particles in the water causes a decrease in transparency. They can also adsorb contaminants such as nutrients and bacteria which can subsequently contaminated sediments and water (Inoue et al., 2009; Mulligan et al., 2009).

## 1.2 Justification

Lake Johanne is one of the lakes located in Quebec, Canada, which is in an advanced intermediate stage of eutrophication (ABVLACS, 2019). The lake was exposed to algal blooms in the past (Municipality of Sainte-Anne-des-Lacs, 2019). Some of the nutrients and organic matter enter the lake from its neighboring wetland which is connected to the lake through a drainage pipe. The quality of lake water is also affected by runoff from its surrounding forest areas, erosion from rocks and land, snowmelt, organic matter degradation, etc.

To date, several management practices have been done to reduce nutrients inputs into aquatic systems. These reduction control strategies limit the external loading of nutrients such as phosphorus into the water (Environment Canada, 2004). However, phosphorus can be released back from sediments into the overlying water and impair its quality by promoting algal growth. In order to control the internal loading of phosphorus, some in-situ techniques have been practiced so far, which include dosing chemicals into the lakes (application of alum, calcite, phoslock, algaecide) (Cooke et al., 1993; Xie et al., 2014), capping with clean sediments, and sediment dredging (Reddy et al., 2007). All of them have their own limitations, thereby restricting the application of these technologies for lake restoration. Some of these limitations are sediment resuspension, toxicity problems, cost factor, lack of disposal sites, etc. (Wang & Jiang, 2016). Therefore, it is important to develop alternative restoration methods which are economical and environmentally friendly, and also follow the principles of ecological engineering and restoration.

Filtration is one the available techniques for removal of suspended solids, contaminants adsorbed on SS, and organic matter from water. The basis of filtration is its separation ability which makes it easy to differentiate particles based on the particle size using various filter media. Geotextiles are permeable fabrics that are widely employed in geotechnical, environmental, and hydraulic applications (Inoue et al., 2009; Palakkeel Veetil et al., 2019). However, there have been very limited studies on the potential feasibility of using geotextiles as a filtration media for surface water remediation. Therefore, filtration using geotextiles as filter media can be an effective method to improve water quality in contaminated surface waters.

## 1.3 Objectives

The main objective of this study was to develop a method to remove suspended solids and associated nutrients from a mesotrophic lake, thereby improving the water quality. According to this objective, some sub-objectives were set which are as follows:

- To evaluate the effectiveness of geotextiles as filter media for improving the lake water quality by removing TSS, turbidity, TP, COD, etc.
- To evaluate different combination of geotextile to determine the best combination showing maximum efficiency in removing suspended solids and nutrients.

To accomplish these goals, a series of on-site filtration tests was performed using different combinations of geotextiles as filter media. Moreover, the relationship between different water quality parameters was also evaluated. Overall, the ultimate objective of this study is to develop an in-situ filtration system which is capable of remediating contaminated surface waters, such as lakes and ponds, without causing any disturbance to the surrounding environment.

## 1.4 Thesis organization

This thesis is presented in 5 chapters. The detail of each chapter is as follows:

- Chapter 1, introduction
  In this chapter, the problem, justification, and objectives for this study have been presented.

- Chapter 2, literature review
  This chapter mainly includes the previous work done related to the study. The main topics discussed in this chapter include an overview of lake water in Quebec, eutrophication, parameters affecting lake water quality, water quality guidelines, surface water treatment, etc. At the end of this chapter, the problem associated with Lake Johanne is explained.

- Chapter 3, methodology

  In this chapter, the morphology and description of the lake are presented, followed by the sample collection and storage, filtration equipment, and analytical measurements, respectively.

- Chapter 4, results and discussion

  In the first part of this chapter, the overall water quality of Lake Johanne is presented, which is followed by all results and discussion from different filtration experiments in the second part.

- Chapter 5, conclusions and recommendations

  Finally, the thesis is concluded with this chapter, including conclusions made based on the on-site filtration tests. Also, recommendations for future work are stated in this chapter.

# 2 LITERATURE REVIEW

## 2.1 Introduction

Clean and safe water is a vital source of life. People are attracted to water as it serves for different purposes like drinking, agriculture, industry, transportation, fishing and recreation (Carpenter et al., 1998). There are various forms of water bodies, and lakes, in particular, play a crucial role in creating a pleasant and healthy environment for humans. They are linked to public health as they are used for a wide range of purposes like drinking, swimming, boating, water sports, etc. Also, lakes have a significant role in the ecosystem as they are habitats for a large number of species of plants and animals. Thus, the health of the lakes is of great importance for sustaining a healthy balance of human and aquatic life (USEPA, 2002).

## 2.2 Overview about Quebec and lake water

Covering 17% of the total Canadian territory, Quebec is the largest Canadian province with a total area of 1667000 km². The province has one of the world's largest reserves of fresh water, occupying 10% of its territory. Quebec includes 430 major watersheds; of which 100 cover a catchment area of greater than 4,000 km². The province is the land of rivers and lakes as it comprises 4500 rivers and more than half a million lakes; 30 of them have an area larger than 250 km². The St. Lawrence River is one of the major hydrographic systems and it covers more than one-third of the Quebec's entire territory, making up for 40% of the renewable fresh water of the province (Gouvernement du Québec, 2002; ROBVQ, 2018).

The abundance of water resources in Quebec is associated with the substantial annual rainfall averaging a total of 750 mm per year. About 80% of this precipitation returns to the ocean through the hydrographic network. However, only 0.5% of the annual gross volume of available water is collected in this province. Municipalities use 49% of the amount collected, and 46% of that is used in the manufacturing sectors. Mining and agricultural sectors account for only 5% of the collected water (MDDEP, 2019c).

Despite the abundance of water, urbanization, industrialization and the intensification of agriculture have resulted in deterioration of water quality in the province. The effect of human activities in deterioration of surface water quality cannot be ignored. For example, the use of fertilizers and pesticides in the agricultural areas results in the nonpoint source pollution which significantly decreases the quality of water (Gouvernement du Québec, 2002; MDDEP, 2019c).

## 2.3 Causes of contamination

Lakes are one of the most treasured resources for life as they provide recreation facilities, enhance amenities, and even contribute to climate change mitigation. Unfortunately, the water quality of many lakes and rivers has deteriorated as a result of increased pollutant inputs in recent decades. Discharge from sewage treatment systems, soil erosion originating from road construction, deforestation, road salt, agricultural practices like manure and synthetic fertilizer management, urban runoff, and septic tank discharge are some of the factors which contribute to lake water pollution. Additionally, the growth of human population coupled with excess demand for recreational access to lakes has resulted in many water quality issues. This increase in pollutant inputs accelerates the aging process of the lakes drastically. The natural aging of a lake occurs very slowly, over thousands of years, but with human influences, this process can take as little as a few decades, and lakes age prematurely in terms of their physical and biological properties (Estalaki et al., 2016; Government of Alberta, 2018).

## 2.4 Eutrophication

Eutrophication is the most common impairment of lakes, rivers, estuaries, and coastal oceans around the world (Smith, 1998). It was reported by the World Health Organization (1999) that 54% of the lakes in the Asia Pacific Region are eutrophic. The proportions for Europe, North America, South America, and Africa are 53%, 48%, 41%, and 28% respectively. Thus, eutrophication is a widespread water quality problem worldwide (Carpenter et al., 1998; Inoue et al., 2009).

The term eutrophic, coming from the Greek language, means rich in food. Einar Naumann first applied this term to lakes containing algal bloom in the early years of the 20th century (Schindler et al., 2016). Eutrophication is described as the enrichment of aquatic systems with nutrients, especially phosphorus and nitrogen, leading to enhanced organic production (Nixon, 1995).

Eutrophication has many harmful effects both on human and aquatic ecosystems. Enhanced growth of algae and aquatic plants is the main consequence of eutrophication which limits the use of water for other purposes such as drinking, agriculture, industry, fisheries, and recreation. Most of the dissolved oxygen in the water is consumed by the decomposition and degradation of the dead algae and results in oxygen depletion and subsequently fish kills (Conley et al., 2009; Jeppesen et al., 1998). Eutrophication contributes to many other problems such as loss of habitats, decreases in transparency, loss of aquatic biodiversity, increases in suspended solids, alteration of food web structure, depletion of dissolved oxygen (DO), decreasing light penetration and toxin release from algal blooms (Carpenter et al., 1998; Chislock et al., 2013; Migliaccio et al., 2007; Ngatia et al., 2019; Schindler, 2006).

Increased growth of algae is among the most harmful effects of eutrophication. These algae are detrimental for humans and other organisms as they produce toxins which can cause food poisoning in humans through the food chain and can increase morbidity and mortality in domestic animals and wildlife. For example, a specific type of algae, called dinoflagellate, produces a very toxic chemical which can damage the nervous system of individuals who come in contact with it. This algae has been identified as a significant reason for finfish mortality on the U.S. Atlantic coast. (Burkholder et al., 1992; Carpenter et al., 1998). There are also some negative economic consequences associated with eutrophication including declines in waterfront property values, reduced tourism incomes, and rising costs for public health (McCrackin et al., 2017).

Eutrophication occurs naturally over the passage of time, but anthropogenic activities accelerate the natural rate of this process by altering nutrient loads in water bodies. Population growth and associated wastewater discharge, increased use of fertilizer in the agriculture area, growing energy demands, and construction of water diversion projects like large dams are some of the causative factors affecting nutrient load in aquatic systems (Glibert, 2017).

Chemical contaminants containing phosphorus and nitrogen compounds accelerate the process of eutrophication. There are two kinds of chemical inputs to surface water, point and nonpoint sources. Point sources such as discharge from municipal sewage treatment plants are easy to measure and can often be controlled by having a treatment at the source. However, it is difficult to measure and regulate nonpoint sources, since these inputs are linked to seasonal agricultural activity and specific circumstances like heavy precipitation or large construction projects. Consequently, controlling this kind of pollution is linked to land management practices and controlling pollutant release to the atmosphere, and may affect people's daily activities (Carpenter et al., 1998). The United States Environmental Protection Agency stated that the main source of water pollution in the United States is nonpoint inputs (USEPA, 1996). Thus, restoration of most eutrophic waters needs the reduction of nonpoint inputs of phosphorus (P) and nitrogen (N) (Carpenter et al., 1998).

Although the existence of organic matter in the water body is essential for ecosystem cycle, the unrestrained growth of it can be considered as pollution. Removal of nutrients from water is a successful method for controlling eutrophication (Moslemizadeh, 2009). Van Der Molen et al. (1998) studied the effect of eutrophication in Lake Veluwe in the Netherlands and found the decrease of eutrophication by using filtration and removing dissolved solids.

## 2.5 Trophic state

The trophic state of a lake is evaluated based on three parameters including phosphorus concentration of the lake, its chlorophyll-a concentration which indicates abundance of algae, and water transparency which is measured by Secchi disk. Figure 2-1 shows the classification of the trophic state of lake water based on these three parameters. According to the diagram, water transparency reduces due to the increased algae production and the concentration of chlorophyll-a increases proportionally with phosphorus concentration. The diagram covers all the potential status for the lakes of Quebec, which are ultra-oligotrophic lakes (very little phosphorus content) to hyper-eutrophic ones (highly enriched with phosphorus). There are five terms used to define classes of trophic state including ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic and hypereutrophic. Oligo-mesotrophic and meso-eutrophic are the terms used for transition zones between the main zones. The terms eutrophic, oligotrophic and mesotrophic are used to define waters having elevated, poor, and intermediate supplies of nutrients respectively (Smith et al., 1998; MDDEP, 2012).

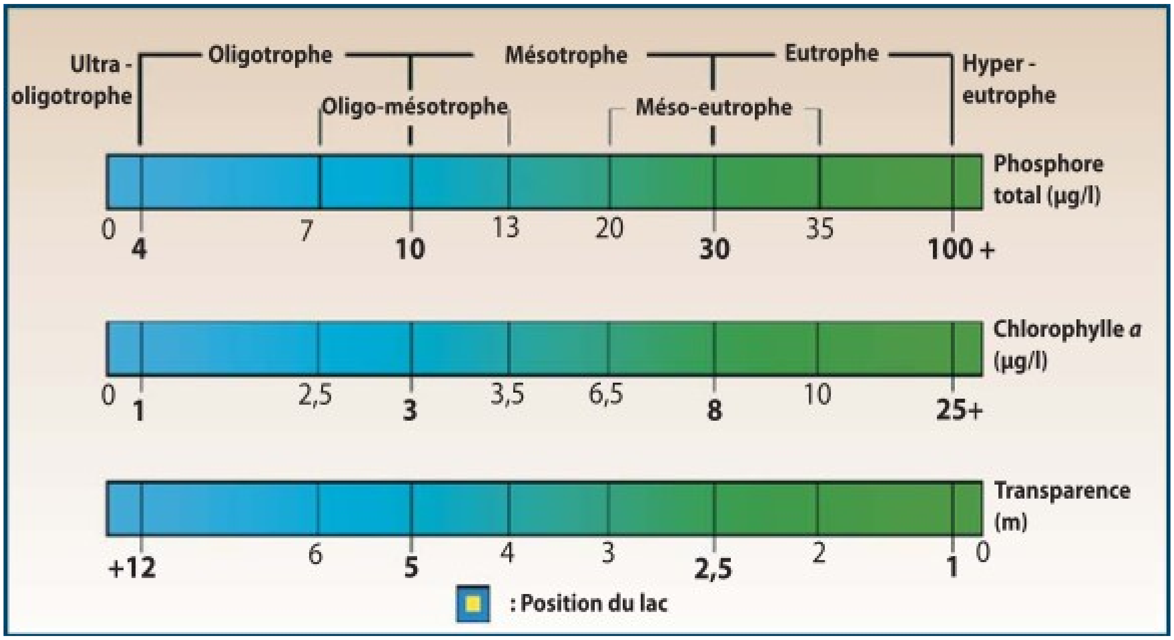

Figure 2-1 Diagram of the trophic level of lakes (MDDEP, 2012)

Figure 2-2 indicates the trophic status of 537 lakes located in Southern Quebec which are monitored through a Voluntary Lake Monitoring programme (RSVL) during the period 2004-2009. According to Figure 2-2, the trophic state of the lakes is reported in six categories. A total of 30 % of the lakes are ultra-oligotrophic and oligotrophic (weekly enriched). 40% of the lakes are oligo-mesotrophic which is a transition between oligotrophic and mesotrophic state. The proportion of mesotrophic and meso-eutrophic states (intermediate enrichment categories) are 15% and 12% respectively. The eutrophic and hyper-eutrophic categories that correspond to highly enriched lakes have been grouped together, and 3% of the lakes are in this condition. All these results were obtained by monitoring the central zone of the lakes and not the littoral area. It should be noted that the level of eutrophication in lakes is dependent not only on human activities but also on physical characteristics of the lake itself. For example, the depth of the lake, its volume and the residence time of the water are the effective factors in occurring natural eutrophication (MDDEP, 2012).

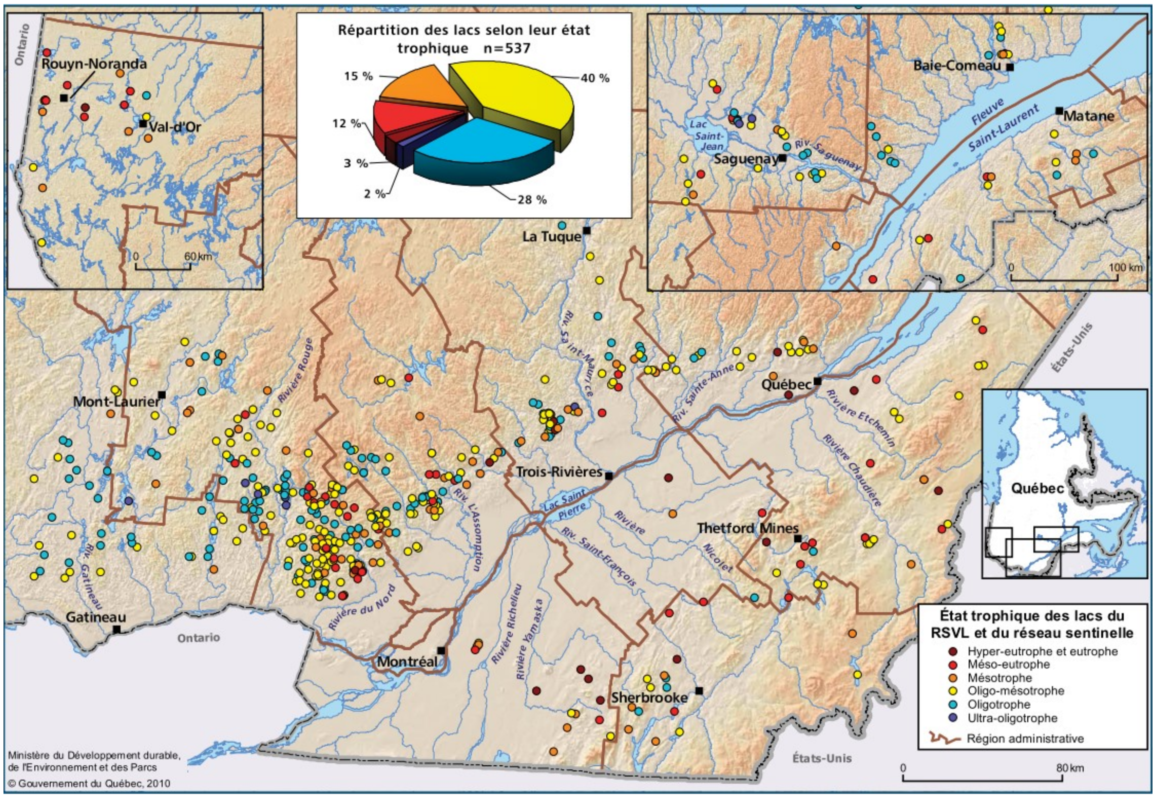

Figure 2-2 Trophic status of Lakes in Southern Quebec monitored from 2004 to 2009 (MDDEP, 2012)

## 2.6 Parameters influencing lake water quality

### 2.6.1 Phosphorus

Phosphorus (P) is an essential element which is used by all living organisms for growth and energy transfers (Correll, 1998; Worsfold et al., 2016). However, excessive quantities of this element can cause excessive growth of algae and aquatic plants in water bodies. This overabundance can lead to oxygen shortage and changes in habitat and communities of aquatic organisms (MDDEP, 2012). The effects of elevated nutrients (phosphorus and nitrogen) on abundance and composition of lake phytoplankton have been studied by the researchers for more than 50 years (Fujimoto et al., 1997; Gerloff & Skoog, 1957; Xie et al., 2003). Phosphorus is often mentioned as a dominant growth-limiting nutrient which can control the phytoplankton biomass and production. Therefore, phosphorus has been targeted for reduction by most lake restoration plans (Galvez-Cloutier et al., 2012; Lewis & Wurtsbaugh, 2008; Wen & Recknagel, 2002). Schindler *et al.* (2008) reported that to decrease eutrophication, management should be focused on reducing phosphorus inputs (Conley et al., 2009).

The sources of phosphorus can be both natural (indigenous soil P and atmospheric deposition) and anthropogenic. However, due to the intensification of agriculture, population growth, and increasing industrialization, the anthropogenic P has been identified as the major source of elevated P inputs to freshwaters (Haygarth et al., 2005; Ngatia et al., 2019; Worsfold et al., 2016).

In lake water, phosphorus exists in total dissolved (TDP) and particulate (PP) phases. Dissolved P is the fraction of phosphorus that passes through a 0.45 µm filter, whereas particulate P is defined as the fraction retained on a 0.45 µm filter. The sum of these two forms of phosphorus represents the total phosphorus concentration. (Gimbert et al., 2007; Bai *et al.*, 2017). TDP can be further divided into organic (dissolved organic phosphorus or DOP) and inorganic components. Dissolved inorganic P is also identified as soluble reactive phosphorus (SRP), dissolved reactive phosphorus (DRP), and orthophosphate (Ortho-P) (Ellison & Brett, 2006). Orthophosphate is considered to be the most bioavailable form of P for aquatic primary producers. (Worsfold et al., 2016; Bai *et al.*, 2017). Bioavailable phosphorus (BAP) is defined as phosphorus that can be utilized by plants and bacteria (Ellison & Brett, 2006).

On the other hand, particulate P is bound to organic matter and soil particles. This fraction is determined by subtracting dissolved phosphorus from total phosphorus. Particulate phosphorus is considered as a long-term water quality concern as it settles to the bottom of water column and can be slowly released to the overlying water. Soil erosion is one of the important drivers of increasing PP in surface runoff, thus reducing soil erosion can be an effective factor in decreasing particulate P loss (Stewart & Howell, 2003).

Although phosphorus exists in different forms in water, aquatic plants need inorganic P, typically in the form of orthophosphate ions ($PO_4^{3-}$) for their nutrition (CCME, 2004). This form of phosphorus can be directly taken up by algae. SRP concentration is measured to check if phosphorus limits the algal growth rate in the lake (Riegman & Mur, 1986). As SRP increases, it indicates that phosphorus is either not required by the algae or is being provided at the rates faster than it can be taken up by the biota. However, many studies indicated that other form of P can be hydrolyzed to the orthophosphate form. Therefore, aquatic scientists measure total P concentration instead of SRP to determine the amount of nutrient that can feed the growth of algae, and the potential for accelerated eutrophication of surface water due to P loading (Minnesota Pollution Control Agency, 2007; Pote & Daniel, 2000).

### 2.6.2 Total Nitrogen

Nitrogen (N) is one of the paramount elements needed for plant and animal growth. It is an essential constituent of all vital processes associated with protein in plants (Leghari et al., 2016). Together with phosphorus, nitrogen is considered as a production-stimulating nutrient in aquatic ecosystems. It works as a catalyst for the process of decomposition of organic material in sediment (Jansson and Andersson, 1994). There are different inorganic and organic forms of nitrogen in the ecosystem including nitrite ($NO_2^-$), nitrate ($NO_3^-$), ammonia ($NH_3$), and organic nitrogen (organic N). Total nitrogen represents the sum of all these nitrogen forms (Mesner and Geiger, 2010).

#### *2.6.2.1 Nitrate*

Nitrate is one of the major forms of inorganic nitrogen that is usually present in surface and groundwaters (Seferlis, 2008). $NO_3^-$ is very soluble in water and high concentration of it can impose a serious threat to the environment and public health. The presence of elevated concentrations of $NO_3^-$ in water bodies stimulates heavy algal growth, thereby promoting eutrophication. The major sources of nitrate contamination include agricultural fertilizer, leakage from septic tanks, animal manure, agricultural and urban runoff, industrial wastewaters, and sanitary landfill leachate (Bhatnagar & Sillanpää, 2011; Minnesota Pollution Control Agency, 2008).

#### *2.6.2.2 Ammonia*

Ammonia is another inorganic form of nitrogen which is formed when bacteria break down organic nitrogen. $NH_3$ is generally less abundant in natural waters except when dissolved oxygen concentration is very low, or when the level of water pollution is too high (Mesner and Geiger, 2010). In surface water, ammonia is mostly found in the form of the ammonium cation ($NH_4^+$) which is formed when ammonia dissolves in water and reacts with it. Phytoplankton can immediately take up nitrogen in the form of nitrate and ammonium (Korppoo et al., 2017). Nitrogen-fertilizer application, sewage infiltration, industrial processes, and livestock operations are some of the major sources that ammonia may originate from (Saskatchewan Ministry of Environment, 2012).

#### *2.6.2.3 Nitrite*

Nitrite ($NO_2^-$) can be formed as a result of nitrate reduction or ammonia oxidation. Generally, the concentration of nitrate is much higher than that of nitrite in water since $NO_2^-$ contains nitrogen in a relatively unstable form of oxidized nitrogen and can be rapidly oxidized to nitrate (Health Canada, 2013). Like ammonia, concentrations of nitrite in lake water are relatively very low unless the level of organic pollution is high. The main sources of nitrite to the water include application of corrosion inhibitors in industrial process water, ammonia or nitrate conversion, runoff from fertilized land, and the breakdown of sewage by bacteria (Government of Saskatchewan, 2008; Hebert & Ontario, 2008).

Although nitrogen is one of the nutrients which supports the growth and nourishment of organisms, the overabundance of it in water can cause a number of health and ecological issues. Excessive amounts of nitrogen along with a sufficient supply of phosphorus in aquatic ecosystems can cause overstimulation of algal growth, which eventually leads to eutrophication. The death and decomposition of algal blooms can reduce severely dissolved oxygen level of water, leading to the death of aquatic organisms like fish. Excess nitrogen not used by growing crops can also be a risk to water quality as it converts to nitrate which is highly mobile in soil and soluble in water. Therefore, nitrate can contaminate groundwater through leaching and surface waters through runoff (Alberta Agriculture and Forestry, 2000; USEPA, 2019).

### 2.6.3 Suspended solids

Generally, the mass (mg) or concentration (mg/L) of organic and inorganic matter, which is found in suspension in the water column of a river, lake or reservoir, is represented by the term suspended solids (SS) (Bilotta & Brazier, 2008). Suspended solids are considered as an important factor in observing water quality. All materials in water are categorized as particulate or dissolved based on their size. Particles that pass through a 0.45 pore size glass fiber are called dissolved, and the rest, which are larger than 0.45 microns, remaining on top of the filter are considered particulate ones. Measuring suspended solids is a method to evaluate the concentration of particulate material in the water.

All streams naturally carry some suspended solids. However, if concentrations are increased by, for example, human activities, this can alter the physical, chemical and biological characteristics of the waterbody (Bilotta & Brazier, 2008; Ryan, 1991). As Kleerekoper (1952) mentioned nutrients contained in the dead plankton organisms and their waste products settle on the bottom of the lakes and make up the bulk of the sedimentation. But human disturbances that leave soil exposed to erosion can trigger the process of sedimentation and consequently pollution of the lakes. Different types of contaminants such as bacteria, heavy metals and pesticides (Kronvang et al., 2003), and nutrients such as phosphorus (Haygarth et al., 2006) can be released from adsorption sites on the sediment into the waterbody. Eisma (1993) noted characteristics of the particulate and dissolved solids are mainly affected by the way that these sediments enter the water and settle in it.

In addition, where SS have a high level of organic content, which is mostly because of runoff from forestry operations, the organic matter undergoes anaerobic breakdown at the bottom of the water body. Further decomposition of these breakdown products can cause critical oxygen depletion in the water, leading to fish deaths under low flow conditions (Ryan, 1991). The effects of high levels of SS on the aquatic ecosystem have been reviewed in several studies in the past. SS can act as a vector of toxic substances such as pesticides and herbicides (Kronvang et al., 2003) and nutrients such as phosphorus (Heathwaite, 1994) from the land to the waterbody. This can indirectly influence the abundance of periphyton, phytoplankton, and macrophytes. Reduced light penetration through the water column is another result of excessive levels of SS in the water that inhibits the photosynthesis of aquatic plants. As photosynthetic processes reduce, less dissolved oxygen is produced, thereby decreasing DO levels in the water column. Also, as previously mentioned, the decay of organic matter by microorganisms can reduce the DO levels even lower. The low levels of dissolved oxygen result in the death of various aquatic biota such as fish and invertebrates (Bilotta & Brazier, 2008; Fondriest Environmental, 2014; Patel et al., 2004).

It is now accepted that suspended solids are one of the main reasons for water quality deterioration which leads to a higher cost for water treatment, decreases in fish resources and aesthetic issues (Verma et al., 2013). Suspended solids have a high potential for adsorbing contaminants such as bacteria, heavy metals, nutrients, and other hazardous materials. These contaminants can be released from the sediments through the decay of the organic matter by microorganisms (Fukue et al., 2006). According to Fukue *et al.* (2006), there is a strong relationship between suspended solids (SS) and chemical oxygen demand (COD) in the water. Therefore, removal of suspended solids is essential for improving water quality in terms of contaminants adsorbed on SS and COD (Mulligan et al., 2009). Filtration is one of the foremost methods via which SS can be removed from the water (Fukue et al., 2006).

### 2.6.4 Blue-green algae

Blue-green algae (BGA), which are also called cyanobacteria, are microscopic organisms that occur naturally in all water bodies in low density. However, if they start to proliferate, they can become problematic for lakes, ponds, and streams. When conditions are favorable, the population of BGA rapidly increase, resulting in forming large mass or scum called algal bloom. Quebec Ministry has established the value of 20,000 cells/ml as a threshold for cyanobacteria, meaning that if the density of cyanobacteria in the water body is equal or greater than this value, it is affected by a BGA bloom. This phenomenon can have negative effects on the ecological balance and aesthetic qualities of the water body. Moreover, algal blooms have the potential to produce toxins that are harmful to human and aquatic biota. This can restrict using water for drinking and swimming purposes (Fleming et al., 2002; Inoue et al., 2009; MDDEP, 2012, 2019a).

#### *2.6.4.1 Factors triggering the growth of BGA*

There are some natural and environmental factors contributing to the growth of blue-green algae. Phosphorus is the predominant factor favoring the development of blue-green algal blooms. It can enter the water through wastewater discharges, agriculture, and leaching from septic tanks, thereby accumulating at the bottom of the water body and acting as a food reserve for BGA. The amount of available nitrogen is also effective in the proliferation of blooms. As the ozone layer becomes thinner, penetration of the ultraviolet rays through water increases. Unlike other algae, BGA can tolerate these rays and use them for photosynthesis. The presence of some agricultural herbicides may also contribute to the blooming of blue-green algae. BGA can tolerate these substances while they can harm other phytoplankton algae. Temperature, brightness, and movements of the water are other physical factors which can influence the growth of algal blooms (Government of Ontario, 2019; MDDEP, 2012, 2019a).

#### *2.6.4.2 Number of water bodies affected in Quebec*

Based on the data which was collected from reports published by MDDEP (2016), the number of water bodies affected by the blue-green algae from 2004 to 2015 is depicted in Figure 2-3. As the chart shows, since 2004, the number of water bodies affected by BGA dramatically increased and reached its maximum value in 2007 (167 water bodies). This rise in the number may be due to increased public reporting as a result of growing public concern. Although there was a slight decline in 2008, the number of affected water bodies again increased after that. It is clearly shown that the number of affected water bodies did not change for the duration of two years (from 2010 to 2011) which were followed by a slight decrease in 2012. The chart indicates that the number started to decrease sharply in 2012 and reached to value of a 46 water bodies in 2014. There was then a slight increase in the annual number of affected water bodies in 2015 (55).

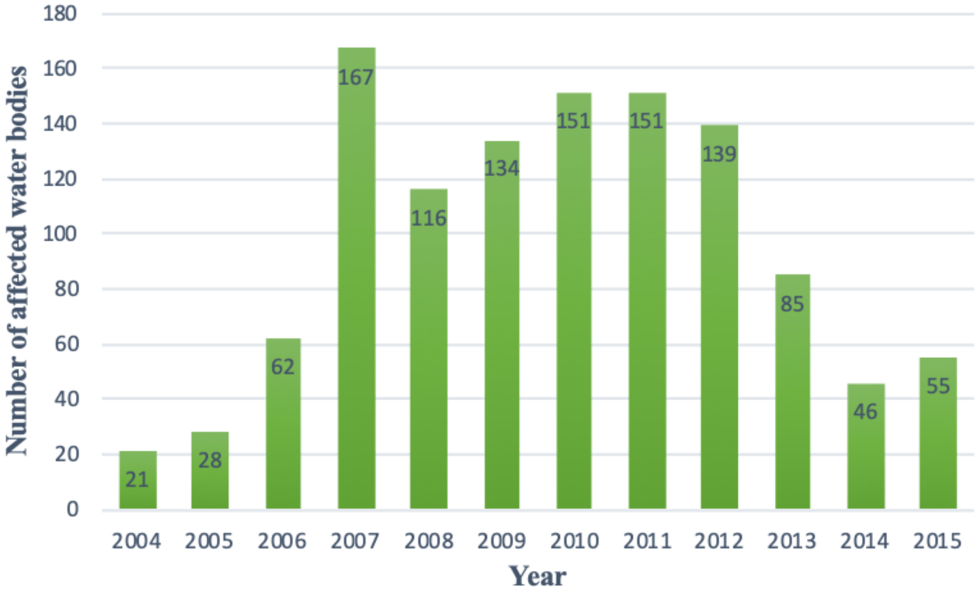

Figure 2-3 Number of waterbodies affected by BGA from 2004 to 2015 (MDDEP, 2012, 2016)

Figure 2-4 represents the number of newly affected water bodies in Quebec from 2007 to 2015. in 2007 116 water bodies were affected by algal blooms that is the highest number affected in the duration of 2007 to 2015. It is clearly shown that, since 2007, the number of newly affected water bodies continuously decreased, except for a two-year period (2010 and 2012). 52 and 48 waterbodies were affected in 2010 and 2012 respectively. The number reached its minimum value in 2015 (17).

Figure 2-4 Number of newly affected water bodies from 2007 to 2015 (MDDEP, 2016)

According to the report published by MDDEP (2016), algal blooms most commonly occur in the three months of July, August, and September (74 % of total algal blooms). 76% of the water bodies visited in 2015 were affected by large algal blooms with the density of equal to or greater than 100,000 cyanobacteria cells per milliliter.

#### *2.6.4.3 Cyanotoxins*

Cyanobacteria blooms consist of large numbers of filaments or cells which can house toxins named cyanotoxins. When these cells rupture or die, cyanotoxins are released into the water as there is no cell wall to prevent their release. These toxins can attack various parts of the body. Neurotoxins and hepatotoxins are known to attack the liver and the nervous system respectively, while dermotoxins can irritate the skin (Environment Canada, 2001). Algal blooms producing these toxic chemicals are known as harmful algal blooms (HABs). The recent increase in HABs has started to demonstrate negative effects on human and animal health, ecology, aquatic ecosystem sustainability, and economic vitality (Dodds et al., 2009; Hudnell, 2010; Landsberg, 2002).

Cyanotoxins can be classified as intracellular or extracellular (dissolved) form. In intracellular form, the cells contain the toxins while in the other form the toxins are released from the cells. Most of the time, the cyanobacterial toxins are found intracellularly and retain in the cyanobacterial cell. In this condition, the toxins are released into the water when the cell dies, and cell membrane breaks down. However, there are species of cyanotoxins, such as cylindrospermopsin, that can be naturally released by the cyanobacterial cells when they are alive. Physical removal like filtration is the most effective method for removing intracellular toxins. However, dissolved cyanotoxins are more difficult to remove as they can adsorb to clays and organic matters in the water. Therefore, additional treatment should be applied to remove extracellular cyanotoxins (USEPA, 2014).

## 2.7 Water quality guidelines

Water quality guidelines are developed to protect freshwater and aquatic life from anthropogenic activities like chemical inputs or alterations in physical parameters such as temperature and pH (CCME, 1999b). These guidelines are based on current knowledge of environmental fate, behavior, and chronic or acute toxicity of a substance (Environment and Climate Change Canada, 2019).

Water quality criteria are numerical limits, or narrative statements that are suggested to protect different water uses including agriculture (livestock watering and irrigation), aquatic life and recreation and aesthetics (Alberta Environment and Parks, 2018). Numeric or quantitative criteria show the exact levels of specific chemicals allowable in a water body. In other words, these criteria indicate specific threshold values for the pollutants in the water. When pollutants are not precisely measurable, numeric criteria are difficult to specify. In this condition, narrative criteria are employed to describe a parameter in a qualitative form (USEPA, 2018).

A complete list of guidelines used by different provinces and territories is provided by Environment and Climate Change Canada (2019). Table 2-1 presents surface water quality criteria used in Quebec. The more often the concentration of a parameter exceeds its guideline, the poorer the quality of water will be.

Table 2-1 Water quality guidelines for surface water used in Quebec

| Parameter | Guideline | Source |
|---|---|---|
| Chlorophyll-a | 8 mg/L | (Environment and Climate Change Canada, 2019; Government of Canada, 2008) |
| Dissolved oxygen | 5.5 mg/L (Lowest acceptable concentration) | (CCME, 1999a) |
| pH | between 6.5 and 9 | (CCME, 2019; Environment and Climate Change Canada, 2019; MDDELCC, 2019a) |
| Total Phosphorus | 0.03 mg/L | (Environment and Climate Change Canada, 2019; MDDELCC, 2019a) |
| Chemical Oxygen Demand | 20 mg/L | (Chapman & Kimstach, 1996) |
| Total Nitrogen | 1.00 mg/L | (Environment Canada, 2014) |
| Nitrate | 2.9 mg $NO_3$-N/L | (CCME, 2019; Environment and Climate Change Canada, 2019; Government of Canada, 2008) |
| Total suspended solids | 25 mg/L | (CCME, 2002) |
| Turbidity | 10 NTU | (Environment and Climate Change Canada, 2019; Government of Canada, 2008) |

For preparing this table, data were collected from different federal and provincial sources such as Canadian Council of Ministers of the Environment (CCME), Environment and Climate Change Canada, Government of Canada, and Ministère du Développement durable, Environnement et Lutte contre les changements climatiques (MDDELCC).

Unlike other parameters, there is no specific guideline recommending the acceptable limits for COD and total nitrogen in surface water in Quebec. However, it is mentioned by Chapman and Kimstach (1996) that, the COD concentrations in surface water vary from 20 mg/L or less in unpolluted water to more than 200 mg/L in waters polluted by effluents. For total nitrogen, Environment Canada (2014) recommended 1 milligram of nitrogen per liter as a guideline to protect surface water in Quebec.

## 2.8 Surface water treatment

Nowadays, increasing population, rapid industrialization, and transition to a modern consumer society have resulted in detrimental surface water pollution. This phenomenon is the cause of increased concern in the public for strict environmental legislation and developing alternative methods for water treatment (Zularisam et al., 2006). The ability to provide a safe source of water has developed dramatically during the last 150 years. Despite these improvements, the environmentally-safe methods for restoration of lakes as a significant portion of surface waters are still limited, and lake eutrophication remains one of the most common water quality problems (Schönach et al., 2018). Chemical addition, capping, and sediment dredging are some of the remediation techniques that have been practiced so far for improving the water quality of many eutrophic lakes.

Sediment dredging is an ex situ technique which has a positive effect in decreasing internal P loading to lakes. Laboratory studies done by Reddy *et al.* (2007) showed that 65% of TP sediment storage could be removed by dredging the top 30 cm of sediment of Lake Okeechobee. However, only diffusive flux from sediment to overlying water column was considered in laboratory experiments, and sediment resuspension and organic material inputs at the sediment-water interface was not included in the tests (Reddy et al., 2007). Although sediment dredging has been adopted in many engineering projects, there are some uncertainties and controversies about this technique. It can result in resuspension of sediment, thereby increasing P loads. Additionally, treatment and disposal of the dredged sediment is a major challenge associated with high costs (Karim et al., 2012; Wang and Jiang, 2016). Overall, the application of sediment dredging is not economically feasible for the small and shallow lakes due to high transportation costs and lack of disposal sites (Palakkeel Veetil et al., 2017).

Addition of adsorbents to lakes with the purpose of reducing P concentration is one of the common methods for lake management especially when the external P load has been previously decreased (Cooke et al., 2005; Deppe & Benndorf, 2002). A wide variety of P adsorbents with various physico-chemical properties are suggested including iron (Fe), aluminum (Al) and calcium (Ca) salts (Hupfer & Hilt, 2008), modified clays (Phoslock® and Aqual- P®) or Fe oxy-hydroxides (CFH-12®) (Álvarez-Manzaneda et al., 2018; Copetti et al., 2016; Gibbs & Özkundakci, 2011; Zamparas et al., 2013).

Xie *et al.* (2014) used magnesium oxide nanoflake-modified diatomite adsorbent (MOD) to test its ability to remove phosphate ($PO_4^{2-}$) from water of a eutrophic lake in China (Chaohu Lake). The concentration of total phosphorus (TP) in lake water before and after adding MOD were 0.158 mg/L and 19.9 µg/L respectively. The results showed that the efficiency of total phosphorus removal was proportional to the dosage of MOD used. 87.2% TP and 75% SRP were reported as removal efficiencies when MOD concentration was 250 mg/L by increasing the MOD concentration to 300 mg/L, 90% TP removal was obtained.

Álvarez-Manzaneda *et al.* (2018) tested two non-magnetic -CFH-12® and Phoslock®- and two magnetic materials -hydrous lanthanum oxide loaded silica-coated magnetite (Fe-Si-La) and commercial zero-valent iron particles (FeHQ)- to remove phosphorus at two different adsorbent dosages. This study showed that the removal efficiency of P is mainly controlled by the type of adsorbent, the adsorbent dosage and color of water which is the indicator of humic substances concentration. The highest P removal efficiency, independently of adsorbent dosage, reported in this study were about 100% for Phoslock®, 85-100% for CFH-12®, 70-100% for Fe-Si-La, and 0-15% for FeHQ. Phoslock® showed the best P uptake regardless of adsorbent dosage and chemical composition of water. Based on this research, non-magnetic materials were more effective in terms of removing P from water compared to the magnetic ones. However, magnetic adsorbents can be reused which makes them more profitable in a long-term duration (Álvarez-Manzaneda et al., 2018). In addition, the effectiveness and treatment longevity of non-magnetic materials are highly dependent on water residence time, water column stability, lake morphology, aging and crystallization of flocs. This is another negative aspect of non-magnetic adsorbents besides being nonreusable (Huser et al., 2016).

It is important to remark that the P removal efficiency of the most P adsorbents is dependent on the potential redox, pH, and/or presence of other dissolved ions (Funes et al., 2017). Ross et al. (2008) found that Phoslock® was very effective in removing P from water at pH values between 5 and 7 and the adsorption capacity declined at the high pH values (above pH 9). Furthermore, adsorbents which settle on the sediments after inactivating phosphorus may ultimately be released into the water column if the physicochemical conditions change or sediment resuspension occurs (Egemose et al., 2009; Funes *et al.*, 2017).

Lürling and Oosterhout (2013) tested the combination of the flocculent polyaluminium chloride (PAC) with the lanthanum-modified bentonite Phoslock® (Flock & Lock) in Lake Rauwbraken (the Netherlands) in April 2008. It was observed that the application of a combined treatment of 2 tons PAC and 18 tons Phoslock® successfully shifted the lake from a eutrophic/hypertrophic state to an oligo/mesotrophic state. The combined treatment significantly decreased the chlorophyll-a concentration in the water column from 19.5 (±36.5) µg/L before application to 3.7 (±4.5) µg/L after treatment. This treatment was also effective in lowering the TP concentration in the lake water. The average TP concentration after treatment was 14 (±15) µg/L, while it was 169 (±126) µg/L prior to this Flock & Lock treatment. Filamentous cyanobacteria were also removed from the lake water by applying this method. Despite the satisfactory results obtained from this study, for large implementations, combined treatment with lanthanum-modified clay is relatively expensive, and cheaper alternatives to solid phase P- sorbents should be tried (Lürling & Oosterhout, 2013).

Galvez-Cloutier *et al.* (2012) carried out an in-situ experiment in Saint-Augustin Lake, Quebec City, Canada. The project aimed to evaluate the effectiveness of alum and/or calcite implementations on water quality and biological community. The results indicated that using alum and calcite together was more efficient compared to alum and calcite only. Alum + calcite greatly reduced the total P concentration (76-95%) in lake water. In addition, by using alum + calcite technique, phytoplankton biomass decreased by 31%, Secchi depth was 106% greater, and chlorophyll-a concentrations were reduced by 19-78%. Although applying alum + calcite was an effective technique for lowering P concentrations and thus improving the water quality of the lake, the TP concentrations were still above the critical limit (20 μg/L) after treatment. (Galvez-Cloutier et al., 2012; Wang & Jiang, 2016). Finally, Galvez-Cloutier *et al.* (2012) concluded that further studies involving this method need to be done in Saint-Augustin Lake to evaluate the TP reduction and the economic feasibility of their method as well.

Drinking water treatment residuals (WTRs), which are inevitable by-products of potable water production, have the capability to adsorb many contaminants such as lead, chromium, mercury, etc. As a result, some researchers have recently attempted to use WTRs to remedy the contamination of these pollutants for natural environment. In lakes, WTRs are employed in the in-situ immobilization technique to control internal P loading originating from lake sediments (Babatunde and Zhao, 2007; Elkhatib et al., 2013; Wang and Jiang, 2016). Wang et al. (2012) investigated the capability of WTRs to immobilize P in the sediments taken from Lake Baiyangdian, and Lake Taihu in China. It was observed that the application of WTRs could stabilize inorganic P in the sediments. Approximately 250 g sediments (dry weight) used in this study. After adding 10% WTRs (proportions of the WTRs in the WTRs/sediment mixtures) to the sediment samples, inorganic P was immobilized within 10 days (Wang et al., 2012). Additionally, Razali et al. (2007) found that WTRs have the potential to adsorb various P species including phosphates and organic P. However, at present, the abilities of WTRs to control lakes internal P loading has only been tested in the short term (limited to 60 days) through laboratory experiments (Wang & Jiang, 2016).

Another approach to mitigate eutrophication in lakes is to use constructed wetlands. Dunne *et al.* (2015) investigated long term P removal by a large-scale constructed wetland named the marsh flow-way located along the northwestern shore of Lake Apopka, Florida. This wetland treated a considerable amount of eutrophic lake water (about 30 m $yr^{-1}$, as hydraulic loading rate). The average rate of phosphorus removal by the marsh flow-way was 0.85 g $m^{-2}$ $yr^{-1}$ (26 metric tons of phosphorus per year). Most of the P removed by this treatment wetland was in the particulate form. It was found that phosphorus removal performance changed according to the season. P removal rates increased during cool periods of the year (September–May) and decreased during the warm summer periods (June–August) while operating costs didn't change. Hydrologic short-circuits, release of dissolve P from wetland during the first few years of operation, and internal nutrient cycling were some of the reported challenges that resulted in a reduction in TP removal performance in this experiment. An earlier pilot-scale treatment wetland project was done by Coveney *et al.* (2002) on the same site. The aim of the project was assessing the removal of suspended solids and particle-bound nutrients from lake water. Lake Apopka water was recirculated for 29 months. The results indicated that more than 90% of particulate matter was removed by the pilot wetland and concentrations of nutrients, especially phosphorus, were low in lake water. According to Coveney *et al.* (2002), the wetland had the potential for removing TSS and TP from lake water with the efficiencies of more than 85% and 30%, respectively. However, further studies are needed to prove the efficiency of wetland treatments for phosphorus removal.

Barley straw has been tested as an alternative to chemical or physical treatment of small shallow lakes for the control of algal blooms (Ball et al., 2001; Ridge & Pillinger, 1996; Welch et al., 1990). An experiment was carried out by Welch *et al.* (1990) to investigate the effect of rotting barley straw on the growth of the filamentous algae in a disused canal. The amount of filamentous algae reduced by the presence of straw while phosphate, nitrate, and ammonium concentrations did not change considerably and nitrite concentrations increased during warm summer periods. Although some studies have indicated that barley straw is capable of inhibiting algal growth (Ball et al., 2001; Welch et al., 1990), no method has shown capacity to completely solve the problem (Inoue et al., 2009). Moreover, using barley straw needs considerable management effort, and the long-term ecological safety of its use is still unknown. The presence of straw bales can restrict using water for angling and can interfere with water traffic (Ball et al., 2001; Welch et al., 1990).

As noted previously, cyanobacteria have the potential for producing cyanotoxins which pose risks to human health and cause various problems for aquatic ecosystems. A large enclosure experiment was done in a tropical mesotrophic reservoir with the purpose of evaluating the effect of red soil-based flocculant (RSBF) on removing cyanobacteria. The flocculant was made up of red soil, chitosan, and $FeCl_3$. The results showed that application of RSBF was very effective in removing cyanobacteria biomass, especially for spherical cell species like *Microcystis spp*. and *Anabaena spp*. However, cyanobacteria slowly recovered according to the dosage of flocculant. This modified flocculant greatly reduced concentrations of nutrients including total nitrogen, nitrate, ammonia, total phosphorus, and orthophosphate. Generally, the red soil-based flocculant was suggested as an effective substance for urgent treatment at local scales in cyanobacteria dominating reservoirs. However, information about the removal capacity of such new modified flocculant and the possible effect on other species is still limited (Peng et al., 2018).

Several studies have shown that hydrogen peroxide ($H_2O_2$) has the potential for controlling cyanobacteria blooms. Matthijs *et al.* (2012) added 2 mg/L $H_2O_2$ to the entire water column of a recreational lake (Lake Koetshuis) using a water harrow which is a special dispersal device. In this experiment, the cyanobacterial population declined by 99% within a few days while zooplankton and macrofauna were not affected by $H_2O_2$ (Matthijs et al., 2012). A recent study indicated that $H_2O_2$ released by sodium carbonate peroxyhydrate (SCP) reduced phycocyanin concentrations and cell densities but did not have a significant effect on chlorophyll-a concentrations. Phycocyanin is an algal pigment presents in cyanobacteria and concentration of phycocyanin has been generally used to represent the cyanobacteria biomass in the field (Geer et al., 2017). Yang *et al.* (2018) tested $H_2O_2$ in a hyper- eutrophic aquaculture pond dominated by toxic cyanobacterial blooms. Results of this study demonstrated that $H_2O_2$ doses >1.3 mg/L effectively reduced cyanobacteria. However, the higher dosage of $H_2O_2$ (20 mg/L) exerted negative effects on zooplankton which were non-target organisms. Thus, research concluded that small scale studies need to be done to test different $H_2O_2$ concentrations before whole system treatments (Yang et al., 2018).

### 2.8.1 Filtration

Filtration is a physicomechanical technique used for separating solids from fluids by a porous medium or screen that allows the liquid to pass while retaining the solids (Taulbee & Maroto-Valer, 2000). It is one of the most reliable techniques widely used in water treatment to remove suspended solids (Fukue et al., 2006). Most surface waters contain a wide variety of particles such as algae, clay, sediment, and other organic and inorganic particles. However, filtration can eliminate these particles resulting in improvement of the water clarity. In addition, through the combined effect of chemical disinfection and filtration, microorganisms in surface waters can be removed. For these reasons, filtration is used in almost all surface water treatment facilities (Crittenden et al., 2012). In a conventional water treatment plant, filtration is the most significant process which has been developed over the years in order to produce water that meets higher water quality standards. Filtration usually follows coagulation, flocculation, and sedimentation in the process of treatment of water for drinking purposes. Granular filtration, using sand or other granular materials, was known as the only filtration method in the past. Nowadays, increasing attention is paid to nongranular filtrations, and they are becoming more popular (Binnie & Kimber, 2009; Spellman, 2009).

#### *2.8.1.1 Filtration methodology*

Filtration is defined as any process for the removal of two or more components from a suspension based on size differences (Cheryan, 1998). This process consists of passing water through a filter media which retains all particles bigger than its openings size while allowing the water to pass through its pores. (Binnie & Kimber, 2009). The four driving forces which help this process include gravitational, vacuum, pressure, and centrifugal (Perlmutter, 2015; Sahai, 2000). There are several key factors that can affect the filtration process. They are chemical properties of the particles and water, filter pore size, grain size and shape, and filtration velocity. According to research carried out by Ives (1967; 1971), the main mechanisms of removing particles in filtration are gravity (or sedimentation), interception, hydrodynamic diffusion, attraction and repulsion. The contribution of each mechanism to filtration is dependent on the nature of water and its chemical characteristics (Brandt et al., 2017). Clogging is one of the main problems that can occur during filtration, leading to a decline in filtration flux. Generally, particles block inside or on the top of the filter when more than a few percent of solids is present in the fluid. The main four mechanistic models used to describe fouling are as follows (Grenier et al., 2008; Sarma, 2016):

- Complete blocking: pore entrances are completely sealed, thereby preventing any flow through them.
- Intermediate blocking: a fraction of particles sealed pore entrances and the rest are deposited on top of them.
- Cake filtration: solid particles accumulate at the surface in a permeable cake of cumulative thickness that adds a hydraulic resistance to filtration.
- Standard blocking: particles accumulate inside the membrane on the pore walls, thereby reducing the membrane permeability.

#### *2.8.1.2 Filtration type*

The main two types of filtration are depth filtration and surface filtration.

- **Depth filtration**

In depth filtration, the particle removal from its carrying fluid is achieved by passing the fluid through a packed granular bed or fibrous filter media. As the stream flows through the filter bed, captured particles are transported to the surface of filter material, where they are then removed by different mechanisms such as straining by mechanical contact, flocculation, adhesion, aggregation, sedimentation, and diffusion. The attachment of particles to the media can occur due to the interactions between particles and inner filter surface. However, some particles still can remain in the fluid due to the detachment from filter surface and/or previously retained particles. The two main types of depth filtration media are ''slow'' and ''rapid'' granular media, such as anthracite, sand, diatomaceous earth, etc., which can effectively remove many particles from water and wastewater (Gao et al., 2012; Gitis et al., 2010; Zamani & Maini, 2009).

- **Surface filtration**

In surface filtration, particles, whose diameter are greater than the opening size of the filter, deposit on to the filter surface. The pore size of the filters is represented by the term AOS which is an abbreviation for apparent opening size. Efficiency of this method is highly dependent on

AOS and the particle size in the water body. Although deposited particles on the surface of the filter can clog and block it, they can form a layer of substrate with lower AOS than the filter itself, thereby facilitating filtering. This layer of substrate, called filter cake, can improve the function of many surface filters (Chapman, 2010). Materials that can be used as filter media in this type of filtration include cloth fabrics of different weaves, woven metal fabrics, and a variety of synthetic materials (Spellman, 2009).

Moreover, membrane filtration is applied as an advance separation technology when there is the necessity of producing water free of all substances such as bacteria, microorganisms, particulates, and natural organic material. Membrane processes are increasingly used in a wide variety of applications such as water purification, desalination, ion separation, pharmaceutical and medical purposes, chemical processing, food processing, and material recovery. This method is the only filtration technology which can separate dissolved solutes in liquid streams or gas mixtures (Cheryan, 1998). In all types of membrane filtration methods, a driving force is needed to help the flow to circulate in the system (USEPA, 2005).

Membrane filtration consists of a semi-permeable membrane which allows water and potentially a part of the dissolved or suspended material to pass. Based on the membrane pore size, filtration mechanism, and size of particles removed, membrane filtration can be classified to microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) (Figure 2-5). Specifically, particles with the size of 0.0007–0.005, 0.005–0.5, and 0.5–5 μm can be filtered out by NF, UF, and MF, respectively. RO can eliminate almost all pollutants larger than a water molecule (Brandt et al., 2017; Hoslett et al., 2018). Membranes can be made of a wide variety of materials including woven fibers (Chollom et al., 2017), metallic or polymeric materials (Waszak & Gryta, 2016), and ceramics (Mouiya et al., 2018). MF/UF can be used as a pretreatment prior to NF/RO to decrease the possibility of fouling in these following steps. In addition, MF and UF are very effective in eliminating bacteria from water. The performance of these membranes can be enhanced by some modification with different materials such as titanium dioxide ($TiO_2$) nanoparticles or polyvinylpyrrolidone. NF shows high potential for removing specific contaminants such as pharmaceutically active compounds and ionic compounds. RO is needed for desalination of saltwater in places where seawater is used for drinking purposes. However, NF and RO are expensive treatment options as they need pretreatment of the influent and a high level of expertise for operation and maintenance. Thus MF/UF can be applied instead of NF/RO in areas where production of drinking water is the main priority (Brandt et al., 2017; Hoslett et al., 2018).

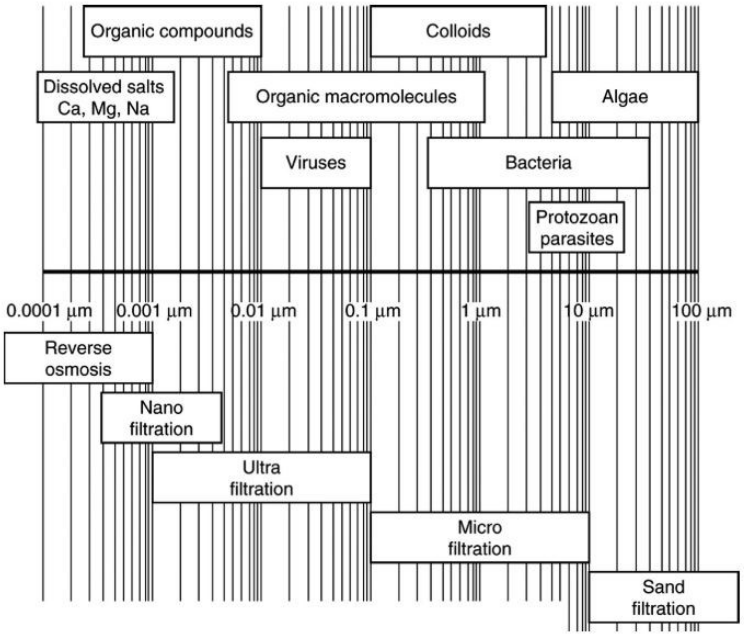

Figure 2-5 Comparison of membranes and their removal ability with particle size (Brandt et al., 2017)

Using chemicals to remove contaminants and organisms from water is very common in water treatment works. However, there are always concerns about the side effects of the chemicals in the treated water. For example, using chemicals in disinfection processes can lead to the formation of by-products which are undesired because of their potential to turn the water toxic, and chronic exposure to these by-products through ingestion, inhalation or dermal contact may pose risks to human health (Hu et al., 2018; Von Gunten et al., 2001). The use of alum as a coagulant is another example of the chemical application in the water treatment industry. This can increase aluminum concentration and therefore increase the toxicity of water (Cooke et al., 1993). Also, residual aluminum salt that remains in the treated water can lead to Alzheimer disease. The reaction of alum with natural alkalinity in the water is another problem which results in pH reduction and low efficiency of coagulation in cold water (Liew et al., 2006).

Results of an experiment conducted by Rybak et al. (2017) also indicated that using coagulants for the purpose of lake restoration can lower pH and deteriorate light conditions, thereby posing a threat to lake ecosystems. Considering all the above discussed problems associated with chemical application, researchers have recently focused on developing technologies, capable of treating the water without using any chemicals.

Fukue *et al.* (2004) carried out an experiment in Kasaoka Bay in Japan by using filter units installed on a barge to purify polluted sea water. In this manner, the filtering system can be simply moved to any area where water is contaminated and treatment is required. This ability makes the technique potentially cost effective. In Kasaoka Bay, the filtration system consisted of a purification vessel which contained 38 sand filter units with a total area of 205 $m^2$. The results indicated that the SS were decreased from 30 mg/L to 2 mg/L. However, if the water is highly turbid, sand filters can clog frequently and thus require extensive cleaning. This can result in increased operational costs. Therefore, materials other than sand need to be evaluated as filter media (Fukue et al., 2004).

Dr. Mulligan and her research team performed a laboratory scale filtration test for removing contaminated suspended solids from surface water. In this study, the filtration efficiencies of two nonwoven geotextiles, a woven geotextile, and a sand filter were compared. Among the four filters evaluated, the nonwoven geotextile with the highest permeability was the most effective media in terms of removing the total suspended solids from the water samples taken from Saint-Lawrence River in Montreal, Canada. The overall removal efficiency by this filter was for turbidity 93-98%, for SS up to 98.9%, and for COD 65-71% for three selected sites with initial turbidity of 70, 20, and 120 NTU, respectively. According to Mulligan et al. (2009), this treatment is potentially economically efficient technology as it can be employed only as needed. Moreover, the development of this method can protect not only the public from dangerous pollutants but also the river and marine animals which can absorb these contaminants (Mulligan et al., 2009).

Suspended solids (SS) can adsorb contaminants such as nutrients, bacteria, organic compounds, and heavy metals, which were released into water bodies. Phosphorus (P) is known as the major controlling factor in the propagation of algal blooms and eutrophication in surface waters. In order to control the growth of algal blooms, it is necessary to remove phosphorus (P) along with SS. Another experiment was conducted by Mulligan et al. (2011) to remove SS and P through a pilot scale on-site filtration unit using a nonwoven geotextile as the filter media.

The results obtained indicated that a nonwoven geotextile with the thickness of 0.3 cm and apparent opening size (AOS) of 150 μm was effective in eliminating 61% of suspended solids as well as 41% of phosphorus, thereby supporting the potential of this technique for improving surface water quality in terms of SS and P removal.

Lac Caron is a shallow, artificial, eutrophic lake located in Saint-Anne-des-Lacs, Quebec, Canada. As part of the restoration plan for this lake, Saminathan *et al.* (2014) performed a laboratory study with the aim of assessing the effectiveness of nonwoven geotextiles in reducing nutrients level as well as improving the lake water quality. In this study, two geotextiles with different apparent opening sizes were tested. Since clean sediments can act as adsorbent materials for nutrient, they were incorporated onto the filters to improve the efficiency of treatment. According to the results obtained, the total P (TP) concentration was decreased from 40 μg/L to 10 μg/L, due to filtration. The overall TP, turbidity, and total N (TN) removal efficiencies of 62.5-75%, 77-85%, and 37-52% were achieved, respectively. In another study, Sarma (2016) carried out a small scale field experiment on the lake water with initial turbidity ranging from 9 to higher than 14 NTU. Custom-made geotextiles with different pore sizes were used as filter media to reduce contaminants in the lake water. The results of this study were promising for the SS, turbidity, TP, COD, and Chl-a removal. According to Sarma (2016), this filtration technique could be a potential alternative remediation method for improving the water quality of eutrophic lakes without using any chemicals in the process of treatment.

#### ***2.8.1.3 Geotextiles***

Geosynthetics are permeable and flexible material sheets which are mostly used in geotechnical and geo-environmental applications. They are manufactured mainly from three types of thermoplastic polymers: polypropylene, polyester, and polyethylene (Heibaum, 2016; Prambauer et al., 2019). Among all geosynthetics, geotextiles are the most important category and they have been widely used over the past 45 years as drainage and filter materials in geotechnical engineering works. Nowadays, demand for geotextiles on the market has risen sharply and over 1400 million square meters of geotextiles are used in various applications every year (Palmeira & Gardoni, 2002; Prambauer et al., 2019). Geotextile filters have been successfully used as the substitute for graded granular filters in most of the drainage applications. The main reasons which make geotextiles successful over the conventional graded granular filters include their comparable performance, consistent properties, improved economy, and ease of placement. Moreover, this replacement can be justified due to the cost advantages from using less drainage aggregate, reduced excavation, eliminating collector pipes, using smaller sized drains and less wasted materials (Fischer, 1992).

Polypropylene (PP), polyethylene terephthalate (PET), and polyethylene (PE) are the most frequently used material in the production of geotextiles. Moreover, different polyamides and chlorinated polymers make a small contribution to geotextile production (Prambauer et al., 2019). Geotextiles are usually subdivided into three types including woven, nonwoven and knitted. Woven and knitted geotextiles are used when high tensile strength is needed. However, nonwovens are employed when porosity, robustness, and deformation capability are required (Heibaum, 2016). Nonwovens fabrics, which constitute the biggest share of geotextiles, exhibit better filtration and separation properties than woven geotextiles. This is due to the 3-dimensional structure of nonwoven fabrics that results in high porosity and permeability with different pore opening sizes. In contrast, woven fiber sheets are characterized by their superior mechanical properties, and therefore they are employed in the field of soil reinforcement and stabilization. In terms of price, woven geotextiles are usually cheaper than non-woven types of the same strength (Li et al., 2016; Prambauer et al., 2019; Scholz, 2013).

The five main categories for typical functions of geotextiles are separation, filtration, protection, drainage, and reinforcement.

- Separation: to prevent two foundations with different properties from mixing with each other, as it is commonly needed in road and railway construction
- Filtration: where water passes through the filter while retaining particles
- Protection: where protection is required against mechanical damage
- Drainage: where superfluous water should be collected from structures

- Reinforcement: geotextiles are an ideal reinforcement solution for an unstable or highly exposed environment (Prambauer et al., 2019; Scholz, 2013).

Filtration performance of geotextiles primarily depends on the pore size and the permeability of the textiles. Generally, the pore opening size of the fabrics should be lower than the particles to capture them and the textile should be permeable enough to allow the fluid to pass through it (Luettich et al., 1992; Aydilek et al., 2005). As previously mentioned, non-woven geotextiles are usually made from very permeable and compressible materials. It should be noted that, by reducing the thickness of the geotextile under stress, its permeability coefficient and pore dimensions also decrease (Palmeira & Gardoni, 2002). Clogging happens when the geotextile's permeability reduces to the point that flow through it results in the hydraulic system's non-performance (Miszkowska et al., 2017). Luettich et al. (1992) suggested the following criteria to minimize the risk of filter clogging:

- Using the largest pore opening size which can satisfy the retention criteria
- The largest porosity available should be used for nonwoven geotextiles, but not less than 30%
- The largest percent open area available should be used for woven geotextile, but not less than 4%.

## 2.9 Problem of Lake Johanne

Lake Johanne is a shallow lake located in the municipality of Saint-Anne-des-Lacs, Quebec, Canada. Since 2008, the government of Quebec has been analyzing the water quality of 22 lakes located in the watersheds of Sainte-Anne-des-Lacs through the Quebec Voluntary Lake Monitoring Network (RSVL) program in order to establish the trophic level of lakes and evaluate the changes in the lake's water quality (ABVLACS, 2019). Based on the results obtained, Lake Johanne, as one of these lakes, is in an advanced intermediate stage of eutrophication due to the poor transparency and elevated concentration of nutrients (phosphorus) and chlorophyll-a. The lake was exposed to algal blooms in the past years (2004-2012), which could advance degradation of the lake and prevent further usage of the water for different purposes such as recreational activities. (Lapierre, 2012; MDDELCC, 2019b; Municipality of Sainte-Anne-des-Lacs, 2019). Thus, Lake Johanne is selected for this study.

## 2.10 Summary

There are several different methods which have been suggested and tested in many eutrophic lakes to remediate them. However, most of these techniques are not economically feasible to implement for small shallow lakes due to the large operations and construction designs that would be involved. Also, the existing treatments may not follow the principles of ecological restoration. As previously discussed, suspended solids are a significant cause of water quality deterioration as most of the pollutants present in the water can be adsorbed onto the surface of suspended solids and then released to the overlying water under certain condition. These pollutants which contain nutrients promote the growth of algae, leading to a variety of issues such as oxygen depletion and release of toxins in the water. Therefore, the removal of suspended solids is essential for improving water quality as well as reducing the risk of algal blooms and eutrophication associated with the elevated level of phosphorus in the water. In-situ filtration is a recent technology which seems to be the easiest, low-cost, and reliable water treatment technique through SS reduction without using any chemicals. Thus, more studies on this method were undertaken in this thesis.

# 3 MATERIALS AND METHODS

## 3.1 Lake description and morphology

Lake Johanne is a shallow lake located in the municipality of Sainte-Anne-des Lacs, Quebec, about 75 km north of downtown Montreal in the Laurentian Mountains. The geographical coordinates of the site are 74°08'19" W and 45°50'23" N. The maximum and the average depth of the lake are 3.1 and 1.7m, respectively. The lake has a surface area of 0.04491 km$^2$ and the volume of the lake is approximately 76,300 m$^3$. The watershed area, including the lake, is 0.254 km$^2$ (ABVLACS, 2019; Quebec Commission of Toponymy, 2019). According to CRE Laurentides (2019), the altitude of the lake is 301 m and the renewal time and drainage ratio of the lake are 0.47 years and 6.14 respectively.

The lake is surrounded by wild trees and there are some privately owned houses with lawns around the lake shore. Some of the owners use their properties all-year round, while others use their houses just in the summer. The primary sources of water in the lake can be highlighted as natural precipitation, snow melt, surface runoff and an outflow from its adjacent, small wetland which is connected to the lake via a drainage pipe. This pipe carries some of the nutrients and organic matter to the lake from the wetland, and from the forest area around it (Veetil et al., 2018). The photo and map of lake Johanne are depicted in Figure 3-1 and Figure 3-2 respectively.

Figure 3-1 Photo of Lake Johanne

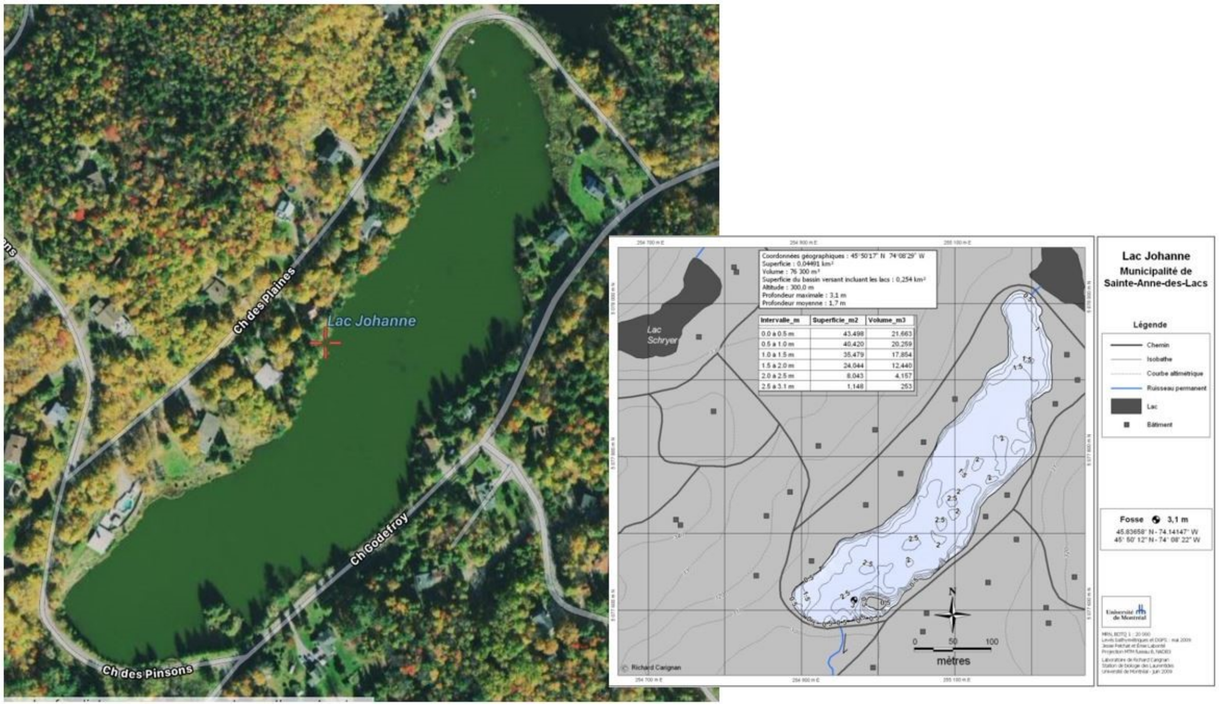

Figure 3-2 Map of Lake Johanne (ABVLACS, 2019)

## 3.2 Sample collection and storage

Water samples were collected during the summer and fall of 2017 and 2018. Usually during July to September of each year, the lake water shows its worst condition in terms of water quality and the amounts of blue-green algae blooms. As it is indicated in Figure 3-3, Lake Johanne was divided into 15 stations spanning the whole lake, which helps to monitor and analyze the water quality throughout the lake. Water samples were obtained from these stations using 50 ml glass tubes for chemical tests, as well as 1L amber color bottles for measuring the total suspended solids and for particle size analysis. It should be noted that all glass tubes and amber bottles were initially washed three times with the lake water, then they were used for sampling. Some in-situ measurements of variables such as turbidity, water pH, water temperature, dissolved oxygen, etc. were taken at the time of sampling. Furthermore, a setup was installed beside the lake for the filtration experiment using geotextiles. Figure 3-3 shows the location of the filtration experiment.

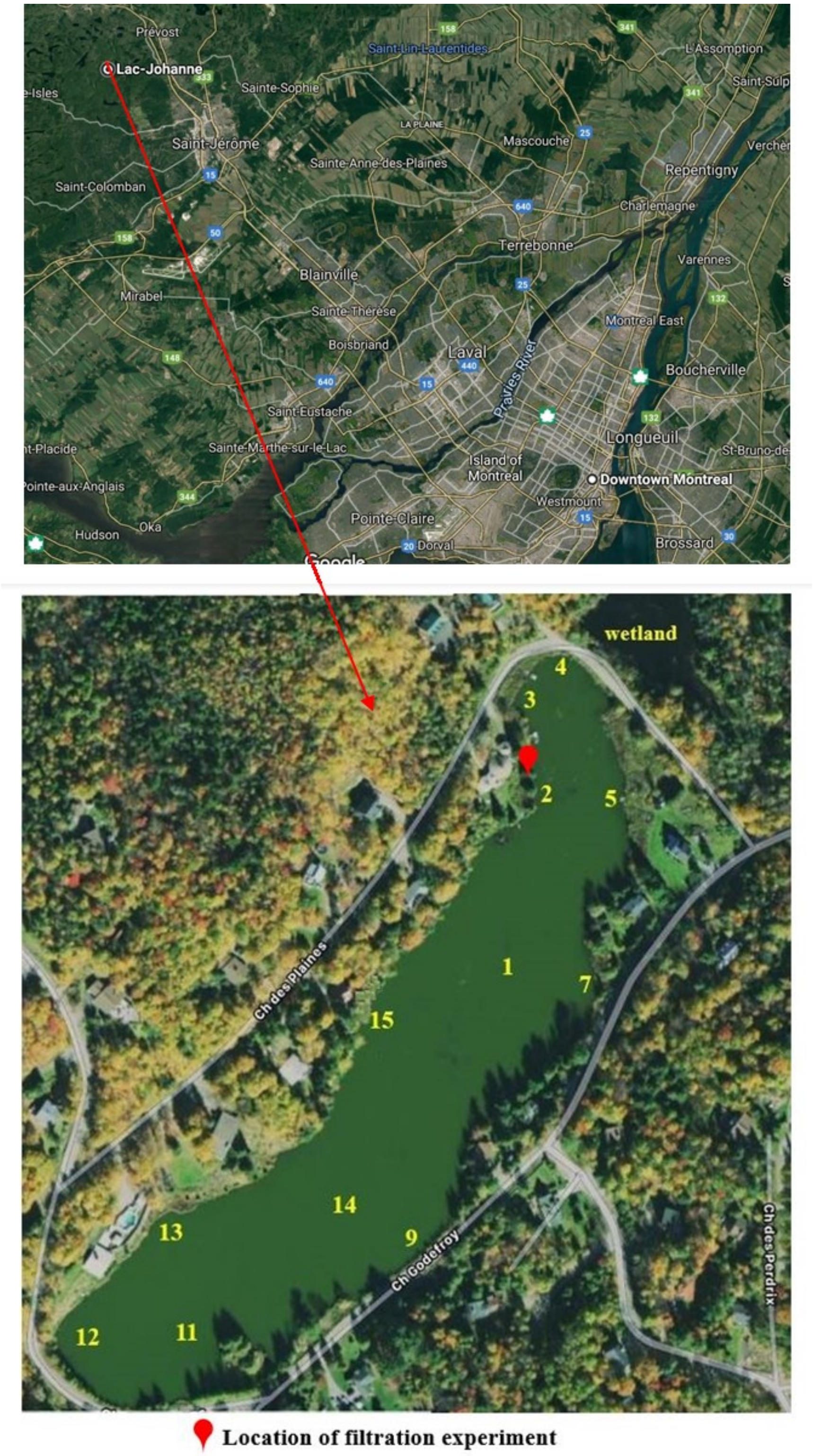

Figure 3-3 Location and map of Lake Johanne showing sampling stations and the location of filtration experiments (Google Maps, 2019; Satellite map of Lac-Johanne, 2019)

Samples taken from the sampling stations were labeled according to the station number along with the date and time of sampling. With regards to the filtration experiment, samples were taken and labeled before running the filtration, during the period of filtration, and at the end of the filtration for each experiment. All the collected samples were kept in a dark cooler to control their temperature and prevent any physical, chemical, and biochemical reactions. Then, the samples were transported to Concordia University laboratory, where they were stored in an incubator at a temperature of 4°C prior to further use.

## 3.3 Filtration equipment

### 3.3.1 Filtration unit

To achieve the goal of this study, which is to improve the lake water quality in terms of nutrients, total suspended solids, and turbidity, a series of small-scale field experiments using geotextiles as filter media were performed onsite by means of a laboratory scale filtration unit. The schematic diagram of this unit is indicated in Figure 3-4.

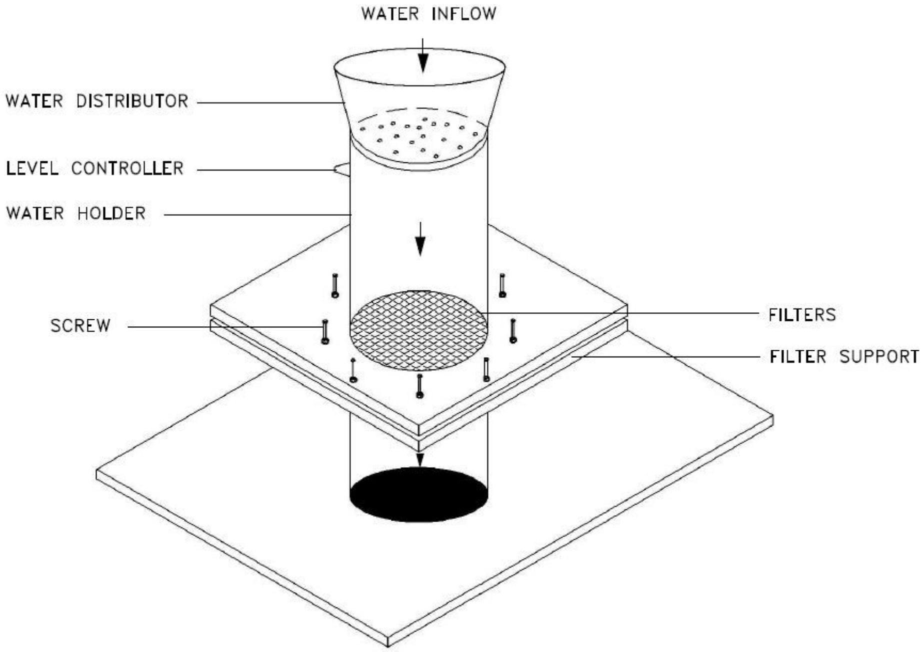

Figure 3-4 Schematic diagram of geotextile filtration unit

The filtration unit comprises a cylindrical column, made of plexiglass, with an internal diameter and a height of 20 cm and 25 cm respectively, as well as a square-shaped base, as filter support, with a circular hole at its center with the same inner diameter of the cylinder. The filtration column was placed on top of the base to hold water and support a hydraulic head of 18 cm above the geotextile filters. The filtration column and the square-shaped base were fixed and tightened together using screws and a water pump was used to pump the water into the top of the filtration column. To prevent water overflow, a level controller, which is able to turn on and off the pump automatically, was installed at a height of 18 cm. Whenever the water head reaches 18 cm, the water level controller would stop the pump. Figure 3-5 illustrates the photo of the filtration unit.

Figure 3-5 Photo of the filtration unit

### 3.3.2 Field filtration setup

Filtration tests were performed in a square-shape tank with a 35.6 cm height, a 97.8 cm width, and a capacity of 543 L. This tank was placed in a suitable location beside the lake, then it was filled with 300 L of the lake water by means of a submersible pump. After this, the filtration unit was placed on a piece of foam with the aim of floating the whole unit on the surface of tank water. The foam which was made of polystyrene had a circular hole at its center with the exact diameter of the filtration column (20 cm) to pass the filtered water into the tank again. Ultimately, the filtration unit, with selected geotextile filters, along with the polystyrene foam were placed on the water to float in the tank. In order to filter all the water inside the tank, water was continuously circulated with the aid of four submersible pumps in the tank. The power of these pumps was supplied from the private property located near to the experiment setup. The flow rate of the pump that was used for supplying water through the filtration unit was 8 L/min. an EXO2 multiparameter sonde (YSI, 2019) was kept inside the tank to measure the physical and biological parameters of the lake water during the experiments. Long-term deployment of the probes provided an almost continuous record of alterations in the parameters monitored in the tests. The whole filtration setup was covered by a tarpaulin with the aim of protecting the setup from rain and other external damage. The schematic diagram and photo of the field experiment setup are illustrated in Figure 3-6 and Figure 3-7.

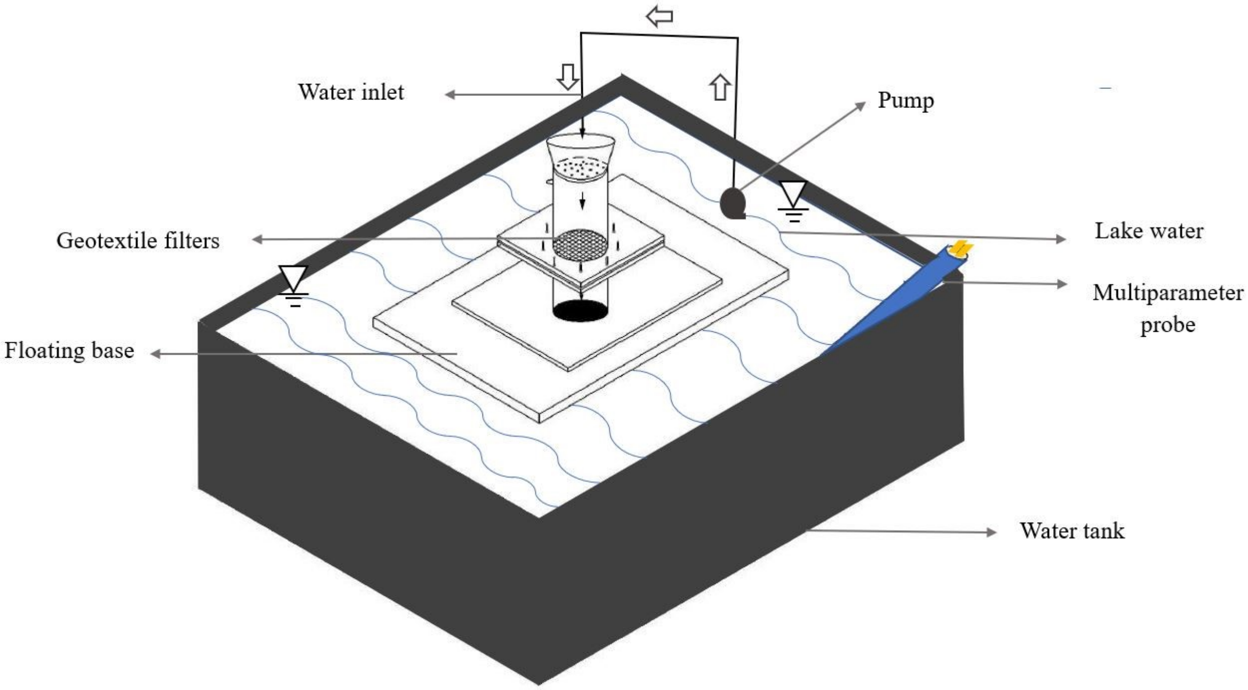

Figure 3-6 Schematic diagram of field experiment setup

Figure 3-7 Photo of field experiment setup

Before running an experiment, water samples were taken and turbidity of the water was measured using an Oakton turbidity meter. The water was then pumped into the top of the filtration column and passed through a set of a selected combination of geotextiles of distinct apparent opening sizes, and then returned to the tank for subsequent refiltration. The average duration of each experiment was eight days and treated water samples were collected during this period. As the suspended solids were captured by geotextile filters, the hydraulic head slowly increased and the water permeability through the filters gradually decreased. However, the unit could filter the water smoothly and there was no need for changing the geotextile filters.

### 3.3.3 Filter media

In this study, non-woven geotextiles of different apparent opening sizes, which were supplied by Titan Environmental Containment Inc., were used as filter media. Different combinations of these geotextiles, with varying numbers of layers (5 or 6 layers), were tested during the field experiments. The geotextile filters, made of polyester and polypropylene, were cut in circular shape with a diameter of 22 cm prior to placing them on the filter support. In each test, a stack of 5 or 6 filters was used in a way that the filter with high AOS was placed on the top, followed by other filters with reducing AOS. Some of the characteristics of selected geotextile filters tested in this study are given in Table 3-1.

Table 3-1 Characteristics of the geotextiles used in this study

| Filters | Material | Apparent Opening Size (AOS) (μm) | Mass Per Unit Area (g/m$^2$) |
|---|---|---|---|
| TE-GTX300 | polyester (PET) | 110 | 300 |
| TE-GTT100-100 | polypropylene (PP) | 100 | 150 |
| TE-GTT120-90 | polypropylene (PP) | 90 | 120 |
| TE-GTT200-70 | polypropylene (PP) | 70 | 200 |
| TE-GTN350 A | polypropylene (PP) | 75 | 350 |
| TE-GTN350 B | polypropylene (PP) | 65 | 350 |

A total of sixteen experiments with different combinations of geotextiles were performed during the summer and fall of 2017 and 2018 with the aim of determining the best combination which provides maximum efficiency in eliminating suspended solids and nutrients. In order to improve the filtration efficiency, water that passed through the filter media and returned to the tank was again pumped to the filtration unit and this process was continued throughout the experiment duration. As the water passed through the filter media, smaller particles that were captured by filters filled the pores, thereby decreasing the pore sizes. This process increased the efficiency of filter media in terms of removing the smaller sized particles from the water and hence improved the lake water quality.

### 3.3.4 Sampling during field experiments

In this study, sixteen experiments with different combinations of geotextiles were conducted beside Lake Johanne from June to October of 2017 and 2018. Each experiment was performed for an average of eight days. To find out the initial condition of water, before starting each experiment, turbidity was measured and water samples were collected for chemical analyses, measuring total suspended solids, and particle size analyses. Furthermore, some other parameters such as pH, temperature, dissolved oxygen, redox potential, and chlorophyll-a were measured using a YSI multi-probe meters for experiments carried out in 2017. During the period of each experiment, these parameters were measured hourly by deploying the sonde in the tank. After running each experiment, the turbidity of the water was measured, and water samples were collected to measure total suspended solids, particle size, total phosphorus, COD, total nitrogen and nitrate. Collected samples were placed in a cooler to preserve properly and prevent any changes in them and were then transported to the Concordia University laboratory, where they were stored in an incubator at a temperature of 4°C prior to further use.

## 3.4 Analytical measurements

### 3.4.1 Total suspended solids (TSS)

The standard procedure of ASTM method (D5907-13) was used to measure total suspended solids in the water. According to this method, glass fiber filters with pore size of 0.45 µm and diameter of 47 mm, were washed with three successive volumes of deionized water by means of a vacuum pump (Figure 3-8). The suction was continued until all traces of water were removed. Then, the filters were dried in an oven at 103ºC to 105 ºC for at least one hour. After that, filters were cooled in a desiccator and weighed using a digital balance with the detection limit of 0.001g. Following the same procedure, a water sample was then filtered through one of the prepared filters. The dissolved material passed through the filter while the particulate material retained on it. The filter was dried in the oven at the same temperature (103ºC to 105 ºC) for one hour, cooled in the desiccator, and then weighed. Finally, the total suspended solids (TSS) was calculated using the following equation.

$$Total\ suspended\ solids\ (TSS),\ in\ mg/L = \frac{(mg\ of\ residue + filter) - (mg\ of\ filter)}{mL\ of\ sample\ filtered/1000} \qquad \text{Equation 3-1}$$

Figure 3-8 Separation of suspended solids using vacuum filtration system

### 3.4.2 Phosphorus

In this study, water samples were analyzed for total phosphorus (TP) and dissolved phosphorus (DP). All the analyses were performed using HACH TNT plus 843 test kits (Figure 3-9) according to the ascorbic acid method (method 10209/10210). Unfiltered samples were analyzed for TP while filtered samples were required for measuring DP. Therefore, water samples were first filtered through a syringe filter with a pore size of 0.45 µm, and then the same ascorbic acid method was followed to measure the dissolved phosphorus in the filtrate.

Figure 3-9 HACH test kit and spectrophotometer used for analyzing TP and DP

### 3.4.3 Chemical oxygen demand

The chemical oxygen demand (COD) test was performed to measure the amount of oxygen consumed to chemically oxidize organic matter in a water sample. In this study, COD analyses were done using HACH TNT plus 820 test kits following the USEPA reactor digestion method (method 10211). This method, which is able to measure COD in the range of 1-60 mg/L, is usually employed for wastewater, water, and surface water quality monitoring.

### 3.4.4 Total nitrogen

As previously mentioned, nitrogen is found in different forms in water bodies. Total nitrogen represents all forms of nitrogen present in a water sample, and therefore it is the most common form of nitrogen which is determined. In this study, measurement of total nitrogen was done using HACH TNT plus 826 test kits according to the persulfate digestion method (method 10208) published in the HACH water analysis book. This test kit is able to measure total nitrogen in the range of 1-16 mg/L.

### 3.4.5 Nitrate

Nitrate is one of the major forms of nitrogen that is usually present in surface and groundwaters. Phytoplankton can immediately take up this form of nitrogen. Elevated concentration of $NO_3^-$ in water can pose a serious threat to the environment and public health. The presence of high concentration of nitrate along with phosphorus in water bodies stimulates heavy algal growth, thereby promoting eutrophication. The amount of nitrate in the collected water samples was measured by following the dimethylphenol method (method 10206) as specified in HACH water analysis book. HACH TNT plus 835 test kits, which are able to measure nitrate in the range of 0.23-13.5 mg/L $NO_3^-$–N, were used for nitrate analyses in this study.

### 3.4.6 Particle size distribution

The particle size distribution for the water samples was determined using the Laser Scattering analyzer (HORIBA, LA-950V2) as indicated in Figure 3-10. This instrument is capable of measuring the particle size of wet or dry samples within a range of 0.01 - 3000 µm. Basically, to determine particle size with laser scattering method, the correlation between the intensity and the angle of light scattered from a particle is detected by the instrument which then calculates the particle size according to a specific theory (Mie-scattering theory). For the samples containing particles with different sizes, a pattern of scattered light defined by density and angle are produced (HORIBA, 2019). In this study, measurements were done for each sample and the distribution of the particles sizes was generated using Excel Microsoft Office by plotting the accumulated percentage finer to the particle diameter on a semi-log scale.

Figure 3-10 Laser Diffraction Particle Size Analyzer (HORIBA LA 950-V2)

### 3.4.7 Water parameters

A YSI EXO2 multiparameter (Hoskin) sonde with corresponding probes (YSI, 2019) was employed in-situ to measure physical and biological water quality parameters such as temperature, pH, turbidity, dissolved oxygen (DO), oxidation-reduction potential (ORP), chlorophyll-a and blue-green algae-phycocyanin (BGA-PC) for experiments done in 2017. The probes were calibrated under field conditions and temperature as described in its instruction manual.

# 4 RESULTS AND DISCUSSION

## 4.1 Introduction

As outlined earlier, the main goal of this study was to remove suspended solids from lake water in order to alleviate the problems associated with suspended solids loading in water bodies. To achieve this goal, filtration tests were performed using non-woven geotextiles as filter medium. In this chapter, the overall water quality of Lake Johanne and the results of filtration experiments are discussed.

## 4.2 Lake water quality

In this study, the changes in water quality parameters were monitored in lake Johanne during summer and fall of 2017 and 2018. Six samplings were performed in 2017 and eight samplings were done in 2018 on this lake using a pedal boat. Table 4-1 shows the number of samplings conducted in each month. In each sampling, water samples were collected from different stations shown in Figure 3-3 to measure total phosphorus, total suspended solids, chemical oxygen demand, total nitrogen and nitrate levels. Turbidity of lake water was measured onsite using a portable turbidimeter (Oakton). Also, in-situ measurements were performed for various variables such as temperature, pH, dissolved oxygen (DO), redox potential (ORP), electrical conductivity, and chlorophyll-a using a YSI sonde for samplings done in 2017.

Table 4-1 Number of samplings conducted in each month

| year | Number of samplings | | | | |
|---|---|---|---|---|---|
| | June | July | August | September | October |
| 2017 | 1 | 2 | 2 | 1 | - |
| 2018 | 2 | 1 | 3 | 1 | 1 |

For each sampling, the values of water quality parameters of different stations were averaged to better demonstrate the overall lake water quality. The average results of the measurements are presented in the following sections and also in Table 4-2.

Table 4-2 Overall water quality of lake Johanne (Jul.-Sept. 2017)

| **Parameter** | **Value** |
|---|---|
| Temperature (ºC) | 22.2 ± 3.9 |
| pH | 8.0 ± 0.3 |
| Dissolved oxygen (mg/L) | 9.0 ± 0.6 |
| Oxidation-Reduction Potential (mV) | 176.5 ± 62.6 |
| Electrical conductivity (µS/cm) | 164.2 ± 10.6 |
| Chlorophyll-a (µg/L) | 14.5 ± 6.1 |

### 4.2.1 Temperature

Temperature is one of the main factors that affects lake water quality. Water temperature may exert effects on many physical, chemical and biological properties of lake water and has defining influence on the amount of dissolved oxygen in the water. Water temperature changes seasonally and is normally higher in the summertime. In general, as water temperature increases in summer, biological activity also increases in water as well. Temperature of Lake Johanne water varied in the range of 23.5ºC to 25.3ºC during the summer, whereas in the fall, it dropped to around 17ºC. Table 4-3 shows the average temperature of Lake Johanne from July to September of 2017.

Table 4-3 Temperature of Lake Johanne from July to September of 2017

| Parameter | ºValues (ºC) | | |
|---|---|---|---|
| Temperature | July | August | September |
| | 25.3 ± 0.7 | 23.5 ± 1.7 | 17.9 ± 0.3 |

### 4.2.2 pH

According to the CCME (2019), the pH range for the protection of aquatic life in the surface water is 6.5-9. As pH level moves away from this range, regardless of moving up or down, it can influence the quality of water through releasing nutrients (especially phosphorus) from sediments, thereby making them more accessible for plant growth. The pH levels of Lake Johanne ranged between neutral to slightly alkaline (7.9-8.4) with the average value of about 8 ± 0.3, which is within the recommended limit for the Quebec surface water criteria. Table 4-2 indicates the average pH value of the lake water during the summer and fall of 2017.

### 4.2.3 Dissolved oxygen (DO)

Dissolved oxygen is an important parameter in determining water quality in a body of water. This parameter has a significant effect on the health of the aquatic system and the higher the DO level in the water, the healthier the aquatic life is. According to CCME (1999), the lowest acceptable dissolved oxygen concentration in fresh water for the protection of aquatic life is 5.5-6.0 mg/L in warm water as well as 6.5-9.5 mg/L in cold water (CCME, 1999a). The average dissolved oxygen concentration in Lake Johanne water samples during the summer and fall of 2017 was about 9 ± 0.6 mg/L, which is above the acceptable limit to support aquatic life. Table 4-2 shows the average dissolved oxygen level during the monitored months in 2017.

### 4.2.4 Oxidation-Reduction Potential (ORP)

Oxidation-reduction potential is measured to determine the oxidized or reduced state of water bodies. This parameter represents the ability of a lake or a river to cleanse itself through breaking down the pollutants and dead plants and animals by oxidation. The higher the ORP value, the more likely a water body is to cleanse itself and thus, the healthier it is. In general, for better quality of surface water, ORP value must be in the range of 300 to 500 mV (Chapman & Kimstach, 1996; Environment and Natural Resources, 2019b). Also, the ORP value of less than 200 mV designates a high amount of contaminants in the water and reduced state of water bodies

(ERD, 2012). The oxidation-reduction potentials of Lake Johanne water samples were in the range of 108.9 mV to 232.4 mV during July to September 2017. The average value of ORP was 176.5 ± 62.6, which indicates the poor quality of the lake water.

### 4.2.5 Electrical conductivity (EC)

Conductivity indicates the ability of water to conduct an electrical current and it is directly related to the concentration of dissolved salts in the water. Salts are introduced through surface runoff and weathering processes; therefore, conductivity is influenced mainly by the types of rock and soil of the area surrounding water bodies. Lake Johanne falls within the Canadian shield and as the Canadian shield is predominantly made up of hard rocks which do not break down easily and are difficult to erode, it causes the lake to have a lower conductivity due to lower soil content. Pristine water bodies are characterized by a range of conductivity values between 0 µS/cm to 200 µS/cm (Environment and Natural Resources, 2019a) and the electrical conductivity of Lake Johanne water samples ranged between 152.1 µS/cm and 171.5 µS/cm during the summer and fall of 2017. The conductivity value decreased from summer to fall, which could be as a result of the decrease in water temperature. Table 4-2 shows the average conductivity value of the lake water during the monitored months in 2017.

### 4.2.6 Chlorophyll-a

Chlorophyll-a is the photosynthetic pigment that gives algae and plants their green color. This parameter is measured to estimate the algal concentration or lake productivity, as the concentration of chlorophyll-a is directly related to the amount of algae present in the water. The concentration of chlorophyll-a in the water column is one of the key parameters which help to estimate the trophic level of lake water (Figure 4-1). For Lake Johanne, the chlorophyll-a concentrations of water samples varied between 9.4 and 20.2 µg/L during the summer and fall of 2017. The maximum value of chlorophyll-a concentration was found in August (20.2 µg/L) which was followed by a decrease in September (9.4 µg/L). The average concentration of chlorophyll-a was 14.5 ± 6.1 µg/L, which places the trophic state of the lake in the eutrophic class (Figure 4-1).

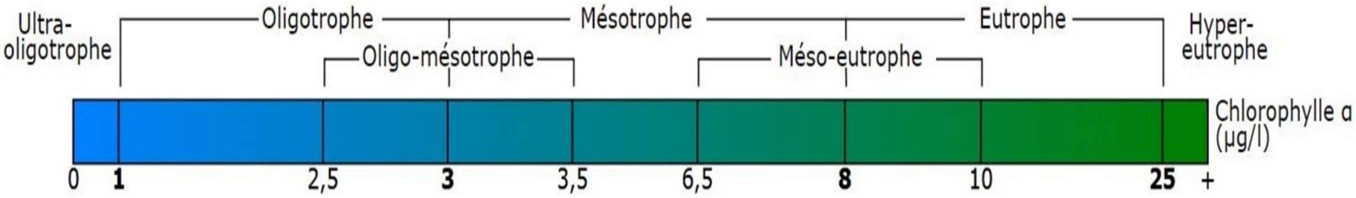

Figure 4-1 Concentration of chlorophyll-a vs trophic classification diagram (MDDEP)

### 4.2.7 Total suspended solids (TSS)

Excess concentration of suspended solids in water can pose many problems for the health of aquatic ecosystems as well as water quality. Figure 4-2 indicates the concentrations of total suspended solids in Lake Johanne water samples collected during different months of summer and fall of 2017 and 2018.

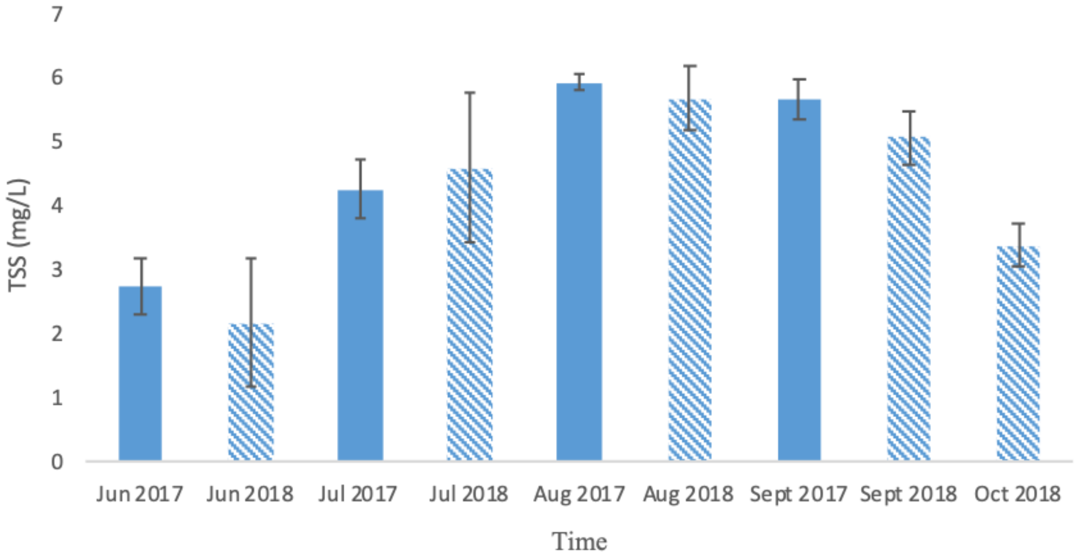

Figure 4-2 Concentration of total suspended solids of Lake Johanne water during 2017 and 2018

From Figure 4-2, the concentration of total suspended solids was below the criterion recommended by MELCC (2019) for TSS in clean water (25 mg/L) during 2017 and 2018. In both years, the average concentration of total suspended solids increased from June to August and then decreased during the following months. Also, a comparison of the year 2017 and 2018 showed that the TSS values were almost the same for the same months from June to September. The maximum and minimum concentrations of total suspended solids for Lake Johanne water were found in August and June with the values of 5.9 and 2.7 mg/L in 2017 as well as 5.7 and 2.1 mg/L in 2018, respectively.

### 4.2.8 Turbidity

Turbidity, which is a key test of water quality, is a measure of the lack of transparency or clarity of water due to the presence of suspended solids and dissolved colored material. The higher the concentration of these particles in water, the more turbid the water becomes (CCME, 2002). According to water quality guidelines used in Quebec (Environment and Climate Change Canada, 2019), the maximum acceptable turbidity value in the surface water is 10 NTU.

Figure 4-3 shows the turbidity values of Lake Johanne during different months of summer and fall of 2017 and 2018.

Like TSS concentration, in both years, the turbidity value of lake water was maximum in August with the value of 4.2 NTU and 4 NTU in 2017 and 2018, respectively. The average turbidity values for all the different months were below the allowable limit recommended by Environment and Climate Change Canada (2019). Since June 2017, the average turbidity value continuously increased and reached its maximum value in August (4.2) which was followed by a decrease to its minimum value (2.9) in September of the same year. In 2018, the turbidity value of the lake water decreased from 4 NTU in August to 2.7 NTU in October. The turbidity values were almost the same in 2017 and 2018 in August.

Figure 4-3 Turbidity values of Lake Johanne during 2017 and 2018

### 4.2.9 Total phosphorus (TP)

The average total phosphorus concentration of the lake water during different months of summer and fall of 2017 and 2018 are depicted in Figure 4-5. To plot this chart, the total phosphorus concentrations of all the stations were averaged for each sampling and the final value was calculated by averaging the values of all the samplings for the months in which more than one sampling was performed. For reproducibility of the data, each sample was tested in duplicate and the average was reported. According to the trophic status classification (MDDEP, 2012), if the concentration of total phosphorus in a water body exceeds 30 µg/L, it indicates that the water body is in the eutrophic condition (Figure 4-4).

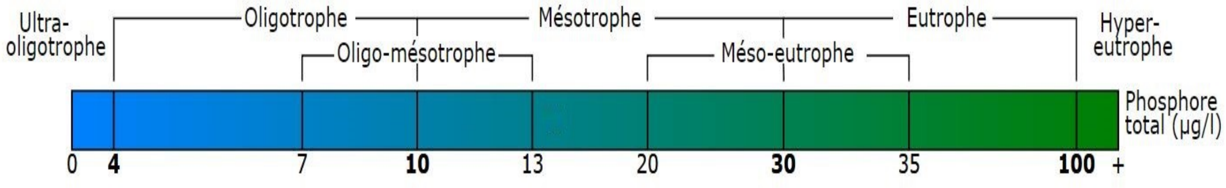

Figure 4-4 TP concentration vs trophic classification (MDDEP)

Figure 4-5 shows the average concentration of TP during the monitored months in summer and fall of 2017 and 2018. The concentration of total phosphorus varied in the range of 13.9 µg/L to 17.1 µg/L during June to September of 2017 as well as 8.9 µg/L to 14.4 µg/L from June to October of 2018. The average concentration of total phosphorus in the lake water was 15.7 µg/L in 2017 and 11.5 µg/L in 2018, which indicated that the water was enriched by nutrients and it was in the mesotrophic condition (Figure 4-4). In both years, the maximum concentration of TP was found in the month of June, which was followed by a decrease in July.

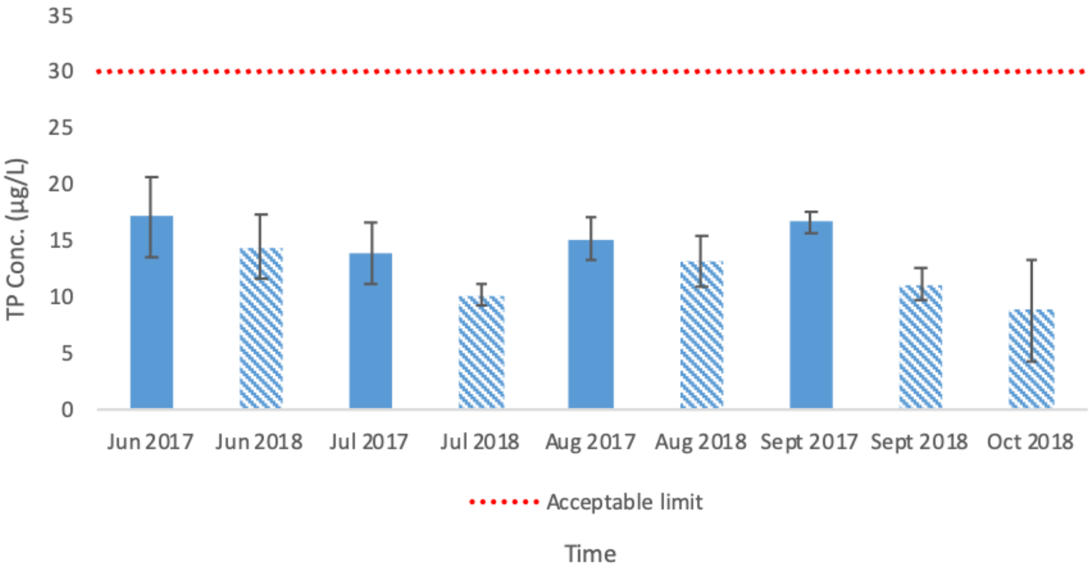

Figure 4-5 Total phosphorus concentration of Lake Johanne water during 2017 and 2018

### 4.2.10 Chemical Oxygen Demand (COD)

Figure 4-6 presents the average concentration of chemical oxygen demand in the lake water during various months in summer and fall of 2017 and 2018. There is no specific guideline recommending the COD threshold value for the protection of aquatic life in surface water in Quebec. However, World Health Organization (WHO) mentioned that the COD concentrations in surface waters vary from 20 mg/L or less in unpolluted waters to greater than 200 mg/L in waters polluted by effluents (Chapman & Kimstach, 1996). Figure 4-6 indicates that the average concentration of COD was above the limit (20 mg/L) in all monitored months except in June 2017 and 2018, even though the maximum value was higher than 20 mg/L in June 2018. The average COD concentration varied in almost the same range in both years; 15.8 mg/L to 29.7 mg/L in 2017 as well as 15.9 mg/L to 27 mg/L in 2018. It also showed the same increasing trend from June to August of both monitored years. However, the average concentration gradually decreased from August to October of 2018 as compared to that in 2017 which slightly increased from August to September. 24.6 mg/L and 23.1 mg/L were the average COD concentration of the lake water in 2017 and 2018, respectively.

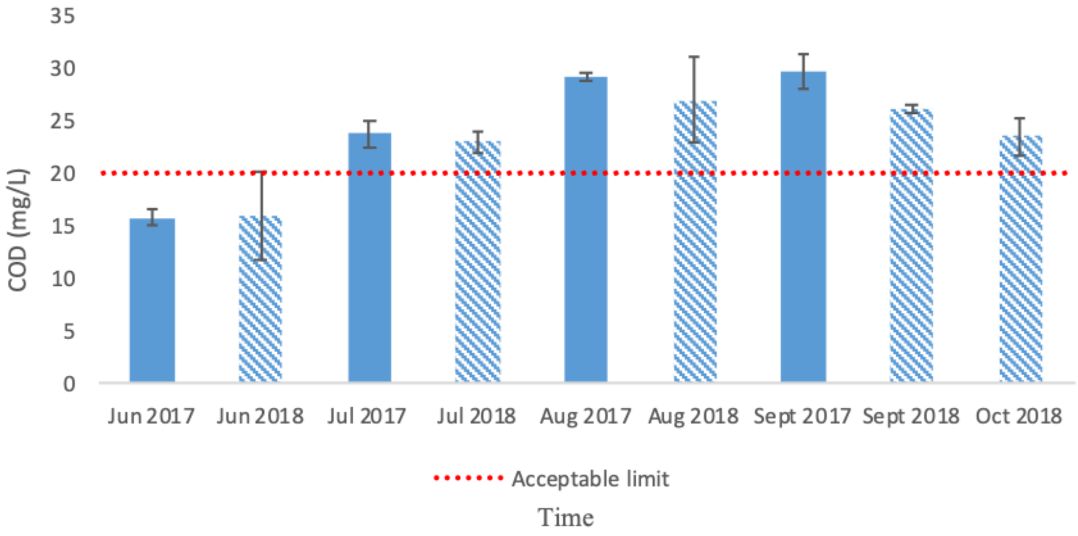

Figure 4-6 COD concentration of Lake Johanne water during 2017 and 2018

### 4.2.11 Total nitrogen (TN)

Like phosphorus, nitrogen is also an essential nutrient for aquatic plant growth, but elevated concentration of it in water can lead to overstimulation of growth of algae and eutrophication. Figure 4-7 presents the average concentration of total nitrogen in the lake water samples collected during different months of summer and fall of 2017 and 2018. Like COD, there is no specific guideline for total nitrogen concentration for the protection of surface water quality in Quebec. However, Environment Canada (2014) has recommended 1 milligram of nitrogen per liter as a guideline value to protect surface water in Quebec. According to Figure 4-7, the average concentration of TN was below 1 mg/L during all the monitored months. However, the maximum concentration of total nitrogen during August 2018 was very slightly above the acceptable limit (1.04 mg/L). In both years, the average total nitrogen concentration showed almost the same trend from June to September. In 2017, the concentration of total nitrogen ranged between 0.23 mg/L and 0.7 mg/L, with an average concentration of 0.52 mg/L, while in 2018, it varied in the range of 0.74 mg/L to 0.99 mg/L, with an average concentration of 0.85 mg/L. The maximum and minimum concentrations of TN were found in August and June of both years.

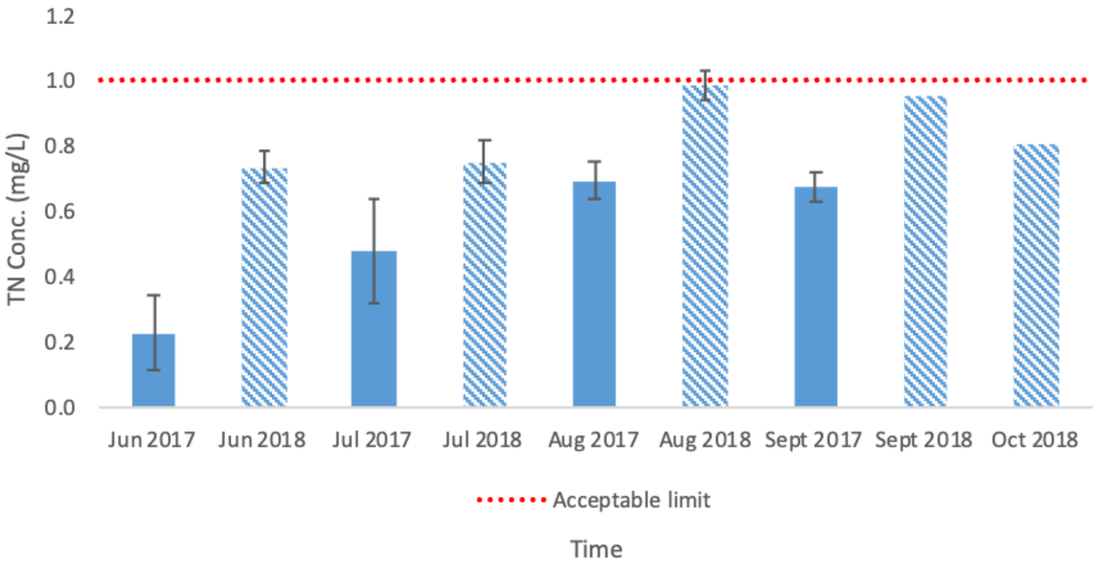

Figure 4-7 TN concentration of Lake Johanne water during 2017 and 2018

### 4.2.12 Nitrate ($NO_3^-$)

Nitrate is one of the nitrogen forms that can be taken up by algae and aquatic plants. However, the overabundance of $NO_3^-$ in water can cause eutrophication and its associated problems such as oxygen depletion. The average concentration of nitrate in Lake Johanne water samples is given in Figure 4-8. The Government of Canada (2008) has recommended that the nitrate concentration should be lower than 2.9 mg $NO_3^-$-N/L for the protection of surface water quality in Quebec. As clearly shown in Figure 4-8, the average $NO_3^-$ concentrations during various months of summer and fall of 2017 and 2018 were sufficiently below the guideline value. The concentration of nitrate gradually decreased from June to September 2017, whereas in 2018, the nitrate concentration increased from June to August, and then decreased during the following months. The average concentration of nitrate during all the monitored months was found as low as 0.09 mg/L in 2017 and 0.12 mg/L in 2018.

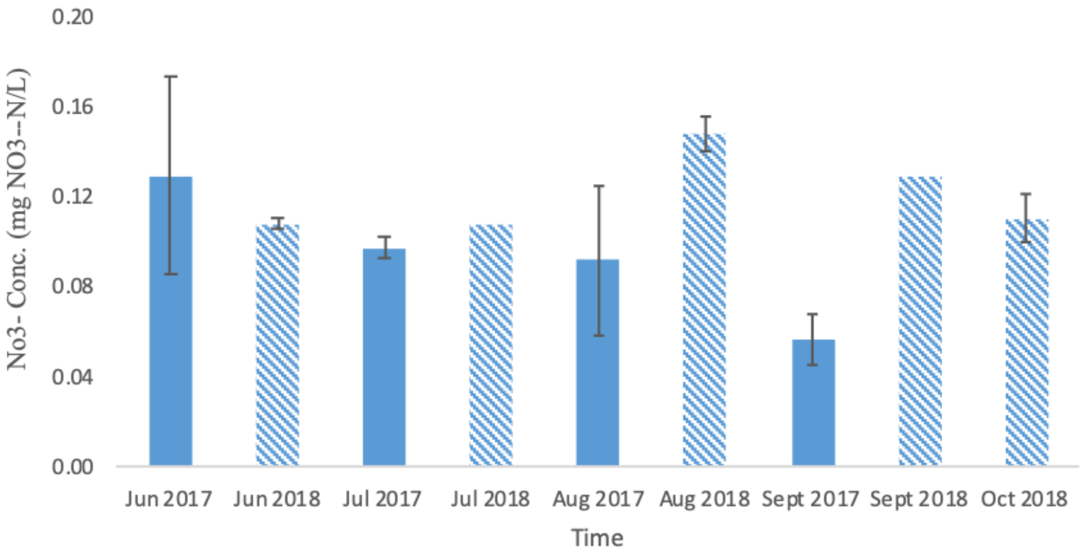

Figure 4-8 Nitrate concentration of Lake Johanne water during 2017 and 2018

### 4.2.13 Particle size distribution (PSA)

The particle size distribution of water samples collected during different months of summer and fall of 2017 and 2018 is shown in Figure 4-9. The graph is shown on a semi-logarithmic scale with particle diameter (µm) in x-axis as well as cumulative frequency (%) in y-axis. For each sampling, the values of different stations were averaged. Also, for the months in which more than one sampling was performed, the final values were calculated by averaging the values of all the samplings conducted. Particles within a range of 0.01 to 1 µm are known as colloids, 1 to 4 µm as clay, 4 to 60.5 as silt, and 60.5 to 2000 µm as sand. As it is clearly shown in Figure 4-9, most of the particles in Lake Johanne water samples collected in 2017 and 2018 were silt. d50 and d90 describe the diameter where fifty and ninety percent of the distribution has a smaller particle size, respectively. d50 ranged from 7.3 µm to 33.1 µm and d90 varied from 43 µm to 70 µm during the monitored months in 2018. For the water samples collected in 2017, d50 and d90 values were in a range of 8.1 µm to 34.2 µm and 51.5 to 88.5, respectively.

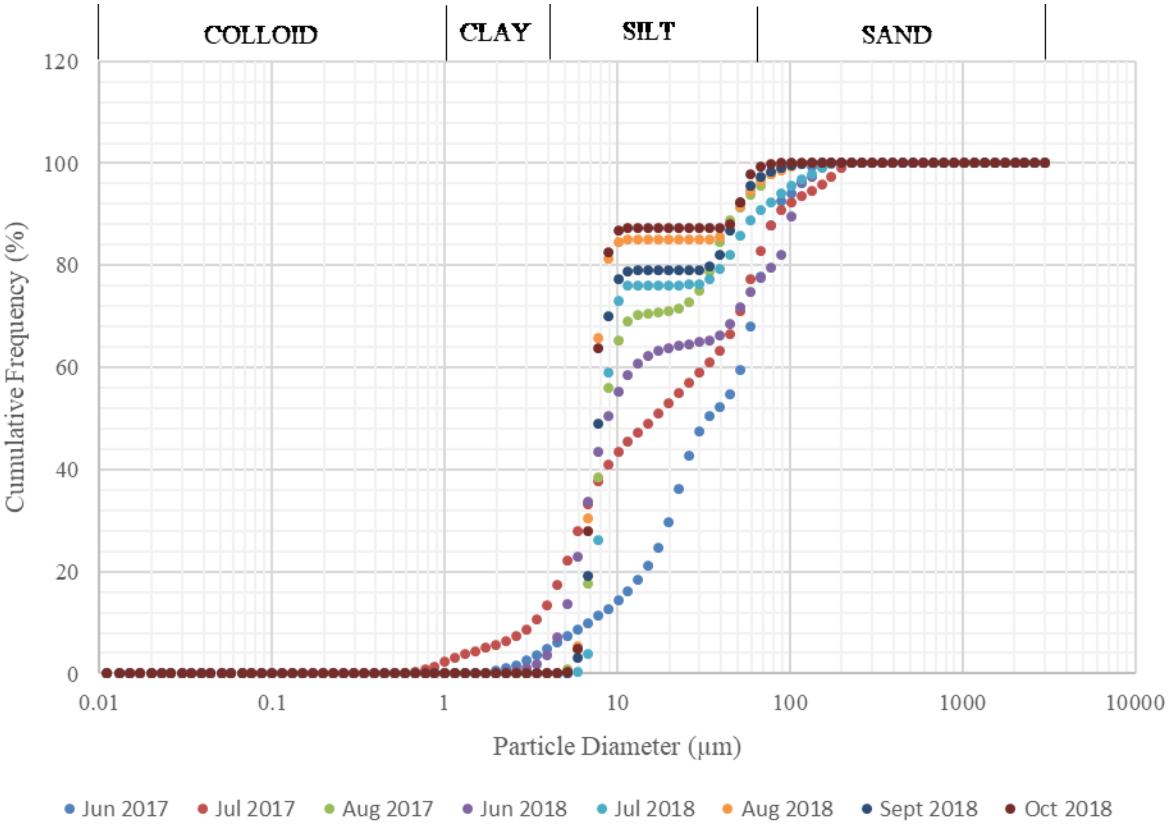

Figure 4-9 Particle size distribution of water samples in 2017 and 2018

## 4.3 Filtration experiment results

In this study, a total of sixteen experiments using a filtration technique were executed besides the lake with the aim of evaluating the effectiveness of non-woven geotextiles in reducing suspended solids and nutrient concentrations and therefore improving the overall water quality. To accomplish this goal, customized non-woven geotextiles with different apparent opening sizes ranging from 65 µm to 110 µm were used as filter media during the filtration process. Different combinations of these geotextiles were tested to determine the best combination which provides maximum efficiency in eliminating suspended solids and nutrients to the allowable limits. In each experiment, a set of 5 or 6 filters was used in a way that the filter with the highest AOS was placed on the top to capture larger suspended solids. Table 4-4 shows the combinations of filters used in each experiment.

Table 4-4 Geotextile combination of each experiment

| **Experiment No.** | **Geotextile Combination** |
|---|---|
| 1 | 2*110 + 2*90 + 1*75 µm |
| 2 | 2*110 + 2*90 + 1*75 µm |
| 3 | 2*110 + 2*90 + 1*75 µm |
| 4 | 2*110 + 1*90 + 1*75 + 1*65 µm |
| 5 | 2*110 + 1*90 + 1*75 + 1*65 µm |
| 6 | 2*100 + 2*90 + 2*70 µm |
| 7 | 2*100 + 2*90 + 2*70 µm |
| 8 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 9 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 10 | 2*110 + 1*90 + 1*75 + 1*65 µm |
| 11 | 2*110 + 2*90 + 1*75 µm |
| 12 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 13 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 14 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 15 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 16 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |
| 110 µm: GTX300, 100 µm: GTT100-100, 90 µm: GTT120-90, 75 µm: GTN350 A 70 µm: GTT200-70, 65 µm: GTN350 B | |

As indicated in Table 4-4, each combination of geotextile filters was tested numerous times to ensure the reproducibility of the results. According to the combination of geotextiles used, experiments were categorized into four different groups as shown in Table 4-5 .

Table 4-5 Classification of the experiments based on geotextile combination

| **Category** | **Geotextile Combination** | **Experiment No.** |
|---|---|---|

|  |  |  |
|---|---|---|
| 1 | 2*110 + 2*90 + 1*75 µm | 1,2,3,11 (2017) |
| 2 | 2*110 + 1*90 + 1*75 + 1*65 µm | 4,5,10 (2017) |
| 3 | 2*100 + 2*90 + 2*70 µm | 6,7 (2017) |
| 4 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm | 8,9 (2017)<br>12,13,14,15,16 (2018) |

As previously mentioned, the excess amounts of suspended solids and nutrients in the water can overstimulate the growth of algae and impair the water quality. This may pose a serious threat to the health of aquatic life and eventually, human health through the food chain. The more the water is affected by contamination, the more likely it is to influence the food chain. Therefore, in this study, the best results were selected based on the decrease in the concentrations of water quality parameters such as total suspended solids, turbidity, phosphorus, chlorophyll-a, etc. In the following sections, discussion has been made independently for each contaminant with respect to each filter combination and the percentage removal was calculated using the initial and final values over the experimental period.

### 4.3.1 Filter combination: 2*110 + 2*90 + 1*75 µm (category 1)

Four experiments were conducted using this geotextile combination as filter media. They were experiment numbers 1, 2, 3, and 11. In these tests, two layers with the AOS of 110 microns were placed on the top, followed by two layers with AOS of 90 microns and one layer with the AOS of 75 microns, respectively. Table 4-6 shows the initial concentrations of different water quality parameters. For all the experiments in this category, the initial concentrations of turbidity, total suspended solids, total phosphorus, total nitrogen, and nitrate were below the acceptable limits while the initial concentrations of COD were above the acceptable level (20 mg/L).

Table 4-6 Initial water condition of each experiment of category No. 1

| Experiment | Initial water condition |
|---|---|

| No. | Turbidity (NTU) | Total suspended solids (mg/L) | Total phosphorus (µg/L) | Chemical oxygen demand (mg/L) | Total nitrogen (mg/L) | Nitrate (mg/L) |
|---|---|---|---|---|---|---|
| 1 | 4.47 | 5.00 | 16.5 | 23.90 | 0.422 | 0.091 |
| 2 | 3.43 | 1.57 | 15.0 | 24.60 | 0.805 | 0.152 |
| 3 | 3.90 | 4.87 | 15.0 | 26.75 | 0.785 | 0.097 |
| 11 | 3.04 | 2.80 | 18.0 | 29.65 | 0.930 | 0.053 |

The removal trend of total phosphorus for experiments 1, 2, 3, and 11 are depicted in Figure 4-10. According to Table 4-6, the initial total phosphorus concentrations were in the range of 15 to 18 µg/L, which indicated that the lake was in the mesotrophic condition. The experiments were run for 7 to 10 days continuously and the TP content decreased to 7-11 µg/L due to the filtration. It is clearly seen in Figure 4-10 that this combination improved the trophic state of the lake water from mesotrophic to oligotrophic. The overall total phosphorus removal efficiency by filters was between 33.3% (Exp 1) and 61.1% (Exp 11).

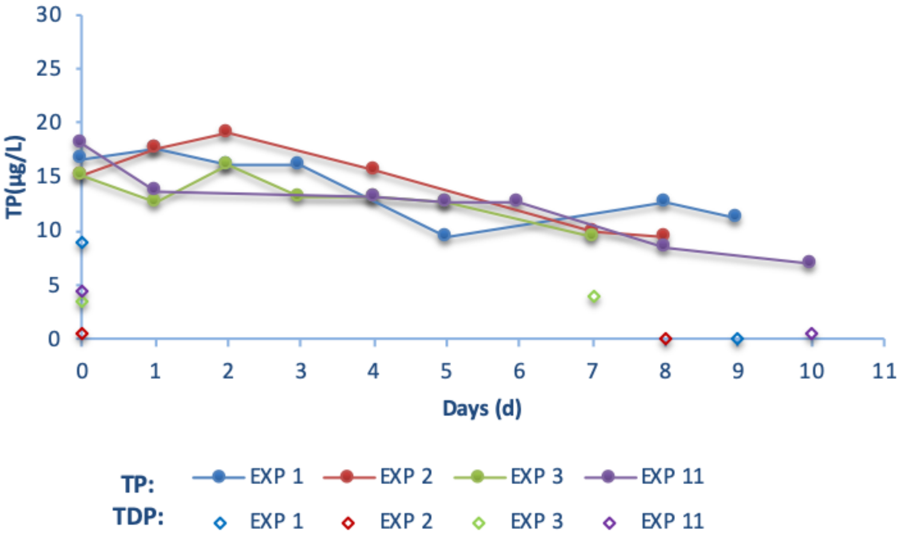

Figure 4-10 Removal trends of total phosphorus for the experiments in category No. 1

The removal patterns of COD for experiments 1, 2, 3, and 11 are shown in Figure 4-11. As previously mentioned, the COD concentration is 20 mg/L or less in unpolluted water. The initial COD concentration for all experiments was above 20 mg/L, ranging from 23.9 mg/L in experiment 1 to 29.6 mg/L in experiment 11. For experiments 1 and 2, COD concentration was reduced to 20 mg/L in three days after running the experiments, while for experiment 3, it took five days to reduce to the acceptable limit. Experiment 11 was the only experiment in which the COD concentration remained above 20 mg/L at the end of the experiment (24.7 mg/L). The overall COD removal efficiency by filters varied from 22% to 30.1% for experiments 1, 2, and 3, while it was 16.5% for experiment 11. As it is shown in Figure 4-11, most of the COD (78-84%) was in the dissolved form, which is why the filtration test was not very effective for COD removal. However, due to the removal of algal biomass and suspended organic matter, the concentrations of COD slightly decreased during the experiments.

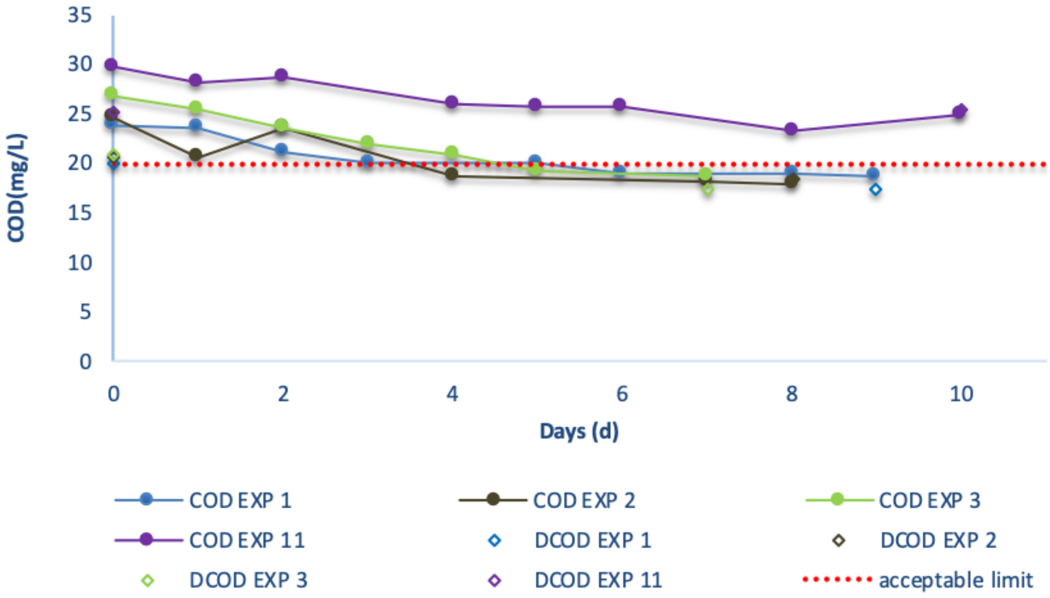

Figure 4-11 Removal trends of COD for the experiments in category No. 1

Figure 4-12 andFigure 4-13 show the total nitrogen and nitrate concentrations in the filtered water for experiments 1, 2, 3, and 11 over the experimental periods. In general, total nitrogen in the lake water is the sum of the different forms of N, including $NH_4^+$, oxidized forms ($NO_2^-$ and $NO_3^-$), and nitrogen bound to suspended solids and soluble organic forms. As can be seen in Figure 4-12, the initial total nitrogen concentration for all experiments was below 1 mg/L which is the acceptable limit recommended by Environment Canada (2014). The overall TN removal efficiency of 10% (Exp. 1) to 42% (Exp. 11) was obtained at the end of these experiments. Considering that like COD and TP, only particulate form of nitrogen can be removed by filtration and the majority of TN was in the dissolved form (83%), only a small fraction of particulate N was removed in this filtration and thus low removal efficiency was obtained. Similar to TN, nitrate concentration was below the allowable limit (2.9 mg $NO_3$-N/L) throughout all experiments. No significant removal was observed for nitrate as almost all the nitrate was in the soluble form in the lake water. In general, nitrogen in the forms of nitrate and nitrite (anionic forms) does not bind as strongly to negatively charged materials as phosphorus does. This is why it is difficult to remove the dissolved forms of nitrogen (Inoue et al., 2009; Yong et al., 2014).

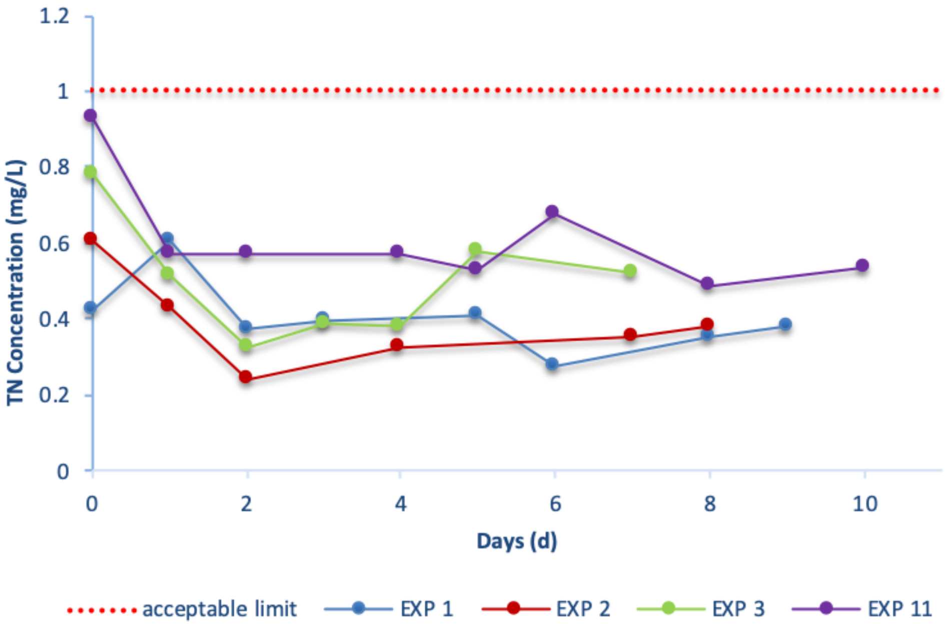

Figure 4-12 Removal trends of TN for the experiments in category No. 1

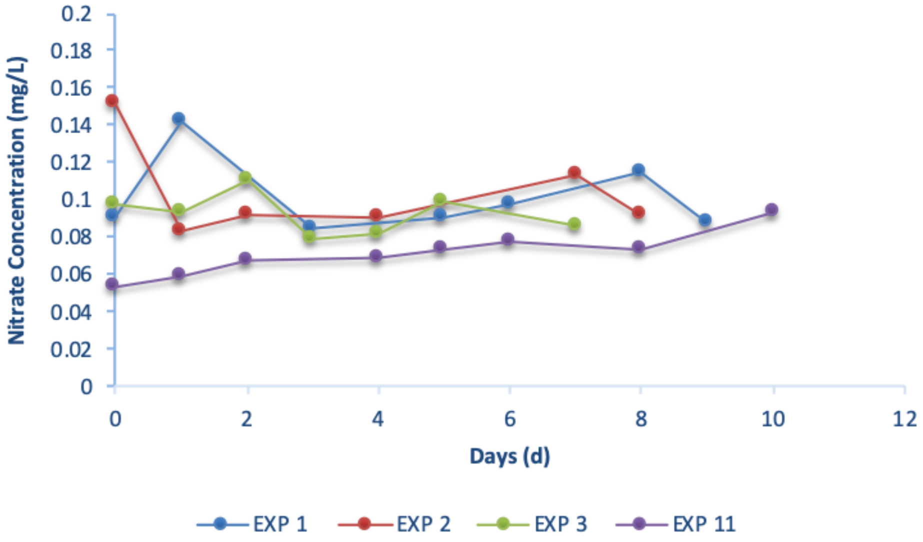

Figure 4-13 Removal trends of nitrate for the experiments in category No. 1

The removal pattern of total suspended solids and turbidity of the lake water for experiments 1, 2, 3, and 11 are presented in Figure 4-14 and Figure 4-15, respectively. As can be seen in Figure 4-14, the initial concentration of total suspended solids was below the acceptable limit (25 mg/L) for all the experiments (CCME, 2002). By filtration of this system, the initial TSS concentration reduced significantly, and the removal efficiency was in the range of 68 to 92%. Like TSS, a significant removal was observed for turbidity and the water became clear. The initial turbidity of water was in the range of 3-4.5 NTU which decreased to 0.06-0.67 NTU at the end of the experiments. 45-65 % of the turbidity was removed within the first three days of run, and overall 82-98% reduction in turbidity was achieved by using this geotextile combination as a filter media. Despite the high removal efficiency, the clogging of filters was not observed during the entire run of the experiments and there was no need to change the filters.

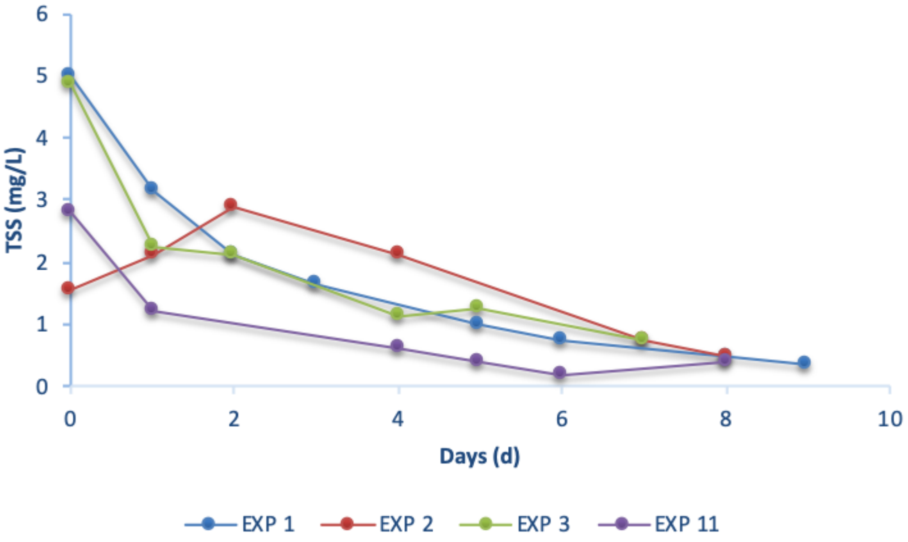

Figure 4-14 Removal trends of suspended solids for the experiments in category No. 1

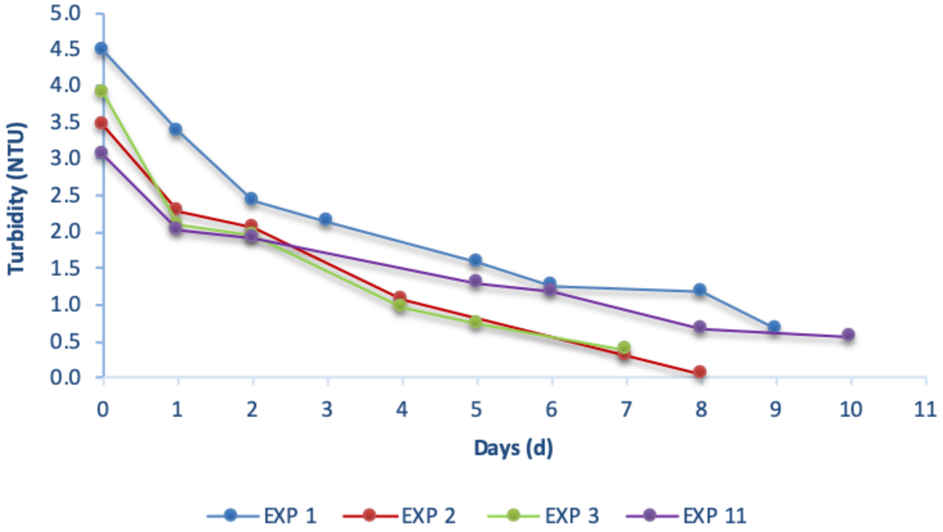

Figure 4-15 Removal trends of turbidity for the experiments in category No. 1

Figure 4-16 indicates the size distribution of suspended solids in the water samples taken during experiments 1, 2, 3, and 11. Before the filtration, about 90 % (d90) of the particles were below 116 microns for the sample taken in experiment 1, 58 microns in experiment 11, 23 microns in experiment 3, as well as 27 microns for the samples taken in experiment 2. As it is clearly shown in Figure 4-16, at the end of the experiments, all samples analyzed had a very similar particle size distribution and 90 % (d90) of particles were under 9 microns. This indicates the efficiency of geotextile filters to capture suspended solids of larger size. Also, as the minimum pore size of geotextile filters used in the experiments in category 1 was 75 µm, these filters could remove the particles higher than 75 microns and at the end of the experiments, no particles larger than 75 microns were observed. At the end of all four experiments, the sizes of particles were reduced to less than 17.4 microns.

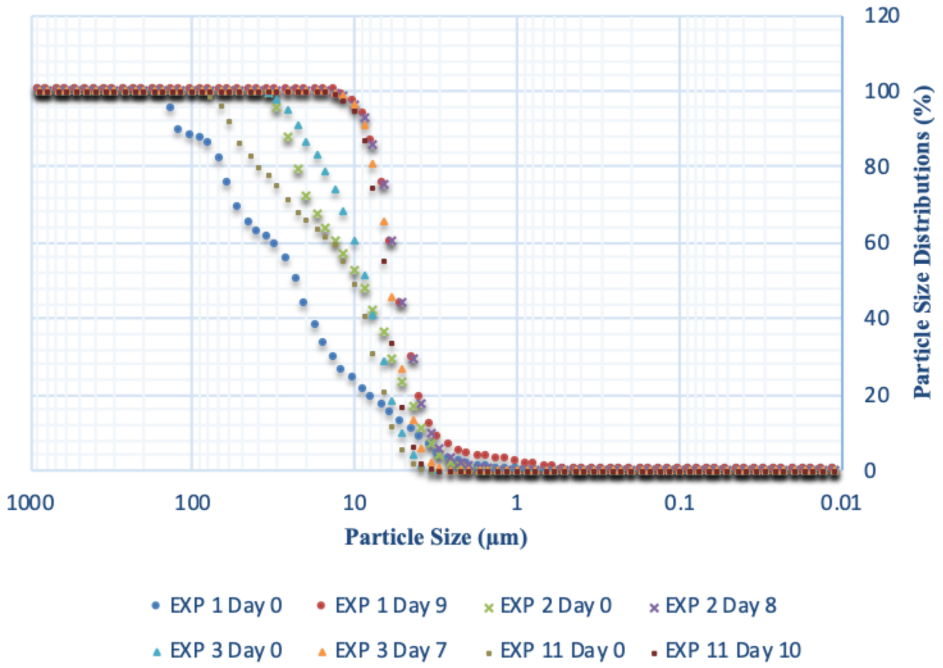

Figure 4-16 Grain size distribution of SS in the lake water for the experiments in category No. 1

As mentioned in chapter three, some of the parameters such as temperature, pH, DO, ORP, chlorophyll-a, and BGA were measured hourly using a YSI sonde during the experiments. The hourly data for experiment 2, as one of the experiments in category one, captured by the sonde is presented here. The change in turbidity in the contained lake water during this experiment is given in Figure 4-17. This graph is plotted using the hourly data obtained from the sonde over the filtration test in experiment 2. As can be seen in Figure 4-17, a significant reduction was observed in turbidity due to the filtration process. Initially, the turbidity value was 2.2 NTU, which was reduced to 0.02 NTU at the end of the experiment.

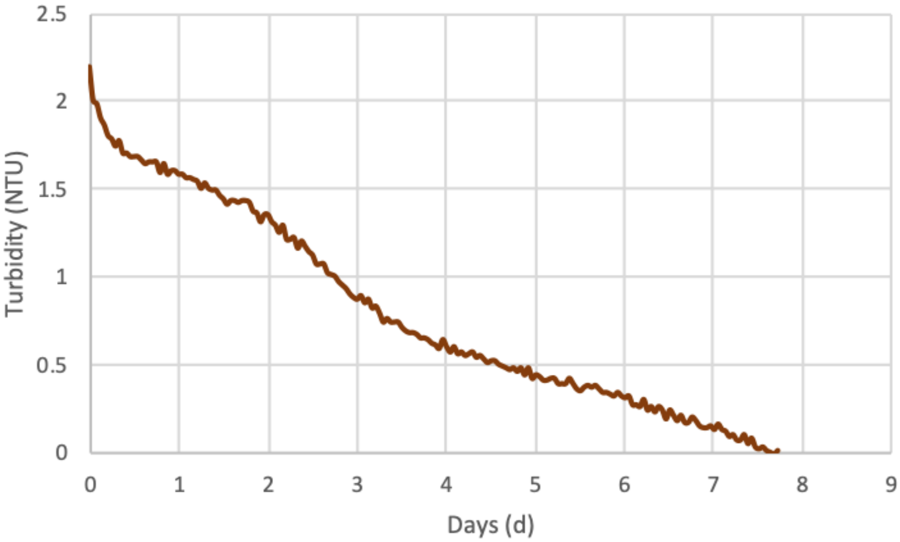

Figure 4-17 Removal trend of turbidity for experiment 2

Figure 4-18 indicates the decreasing trend of chlorophyll-a during the experiment. Initially, the concentration of chlorophyll-a was 7.7 µg/L which reduced to 1.8 µg/L at the end of the experiment. Considering that chlorophyll-a is an indicator of algal abundance, the amount of living algae was drastically lowered during this experiment. The average concentration of chlorophyll-a present in the water was 4.7 µg/L.

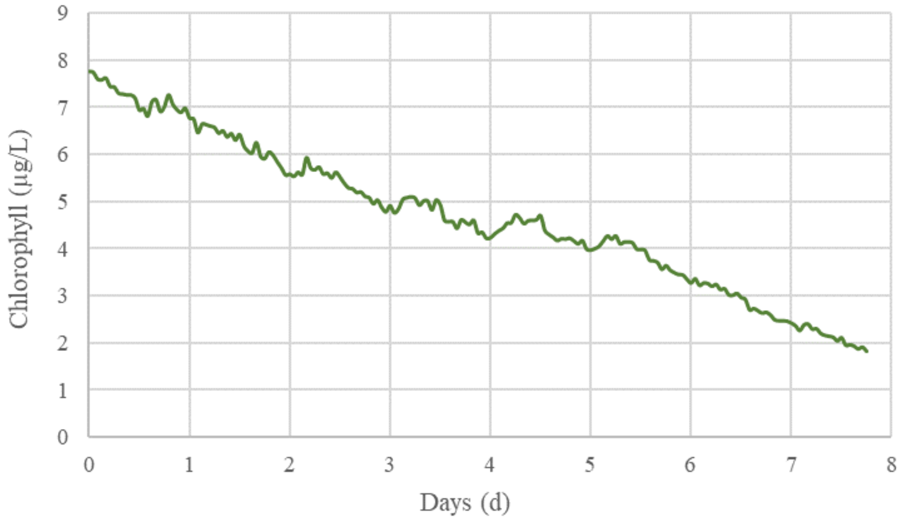

Figure 4-18 Removal trend of chlorophyll-a for experiment 2

As stated earlier, blue-green algae (BGA) occur naturally in all water bodies in low density, but if they start to perfoliate, they can become problematic for the health of humans and animals. The growth of BGA is directly proportional to the amount of available nutrients in the water. Figure 4-19 illustrates the decreasing trend of BGA in the water during experiment 2. The initial concentration of BGA was 0.42 µg/L which came down to 0.14 µg/L at the end of the experiment. From Figure 4-19, it was found that the BGA concentration remained above 0.4 µg/L for the maximum time of the first three days of the experiment and then started to reduce to 0.14 µg/L during the remaining days. The average concentration of blue-green algae was 0.3 µg/L in this experiment.

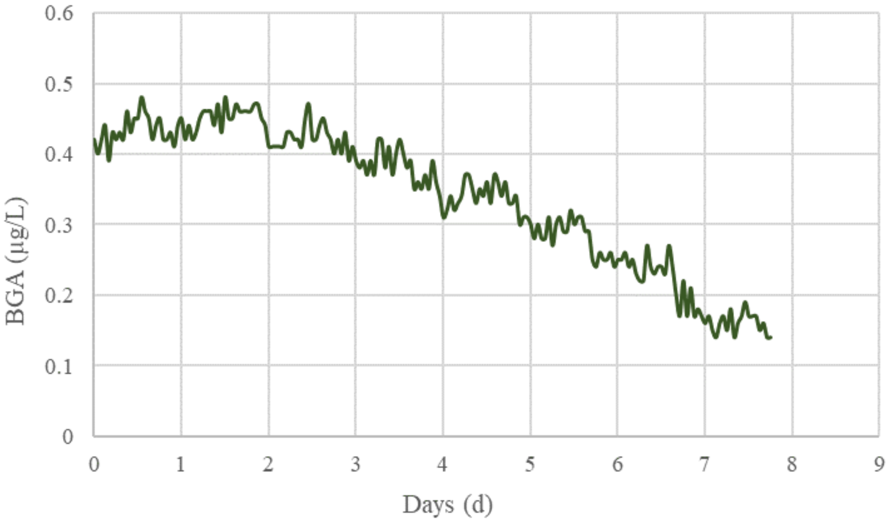

Figure 4-19 Removal trend of BGA for experiment 2

The changes in the temperature and pH of the water over the filtration test are given in Figure 4-20 andFigure 4-21, respectively. During the experiment, the temperature varied in the range of 21.3 ºC and 24.4 ºC with an average value of 22.7 ºC. pH was almost the same throughout the experiment, with an average value of 7.8.

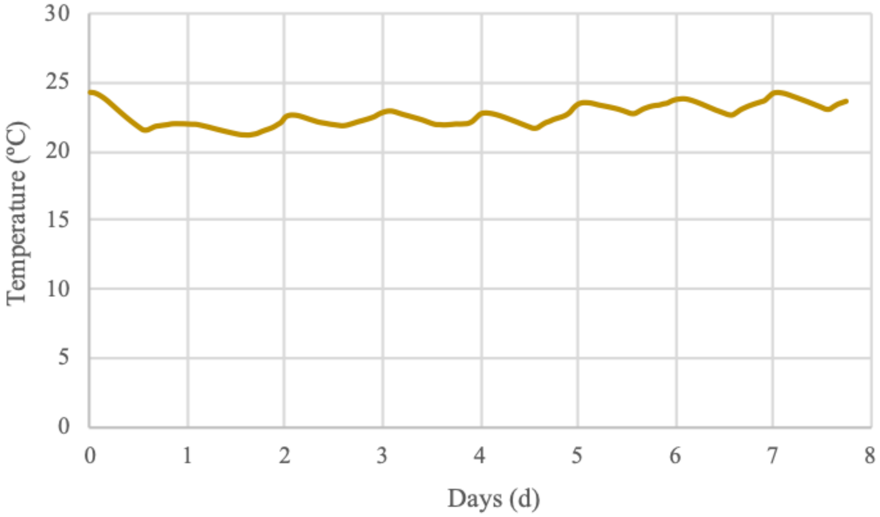

Figure 4-20 Probe data for temperature during experiment 2

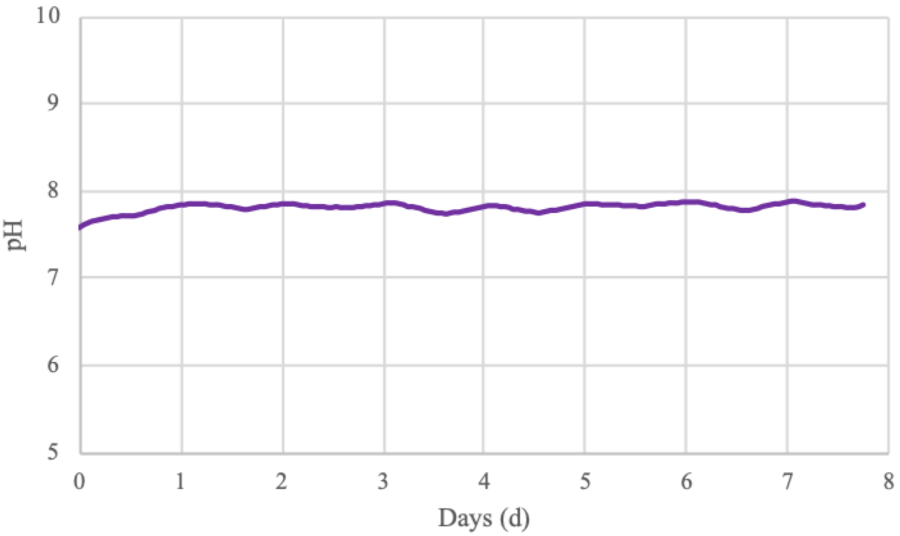

Figure 4-21 Probe data for pH during experiment 2

As discussed earlier, the ORP value represents the water ability to break down contaminants. Figure 4-22 indicates the increasing trend of oxidation-reduction potential over the filtration test. The ORP value for experiment 2 varied from 120 mV to 143 mV, with an average value of 130.1 mV. Figure 4-23 presents the amount of oxygen dissolved in the water during experiment 2. As can be seen, the concentration of DO slightly changed in the range of 8 to 8.5 mg/L, with an average value of 8.3 mg/L throughout the experiment.

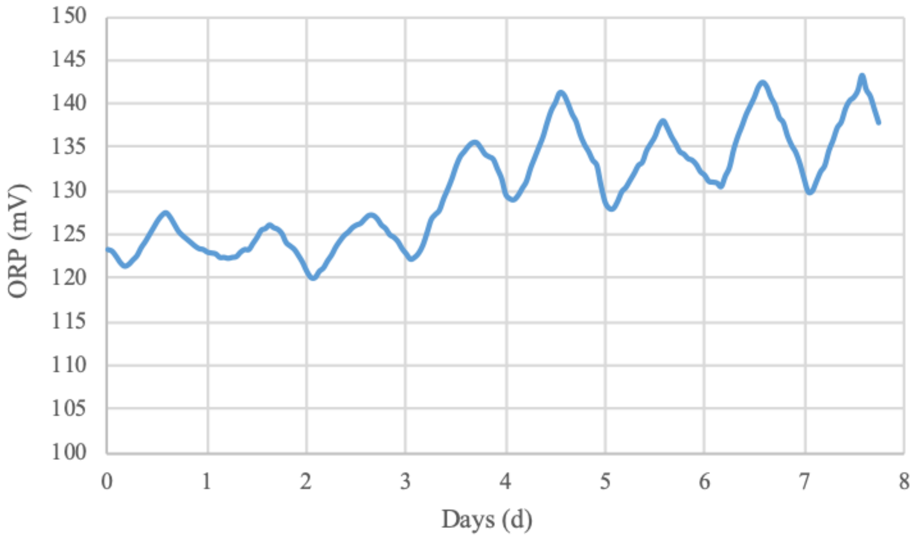

Figure 4-22 Probe data for ORP during experiment 2

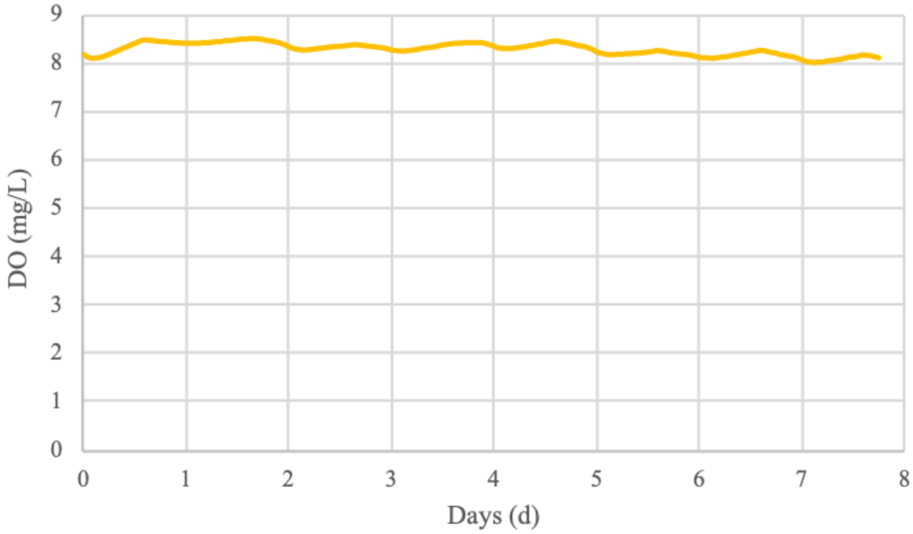

Figure 4-23 Probe data for DO during experiment 2

The overall percent removal obtained for TSS, turbidity, TP, COD, and chlorophyll-a using the geotextile combination of two layers of 110 microns, two layers of 90 microns, and one layer of 75 microns are presented in Table 4-7. The results of total nitrogen and nitrate experiments are not included in this table as they exist mostly in their dissolved forms in the lake water and the filters are not effective for removing them.

Table 4-7 Overall percent removal obtained for different parameters for experiments in category 1

| | **TSS** | **Turbidity** | **TP** | **COD** | **Chlorophyll (exp 2)** |
|---|---|---|---|---|---|
| Removal efficiency (%) | 82.8±10.3 | 88.8±7.3 | 41.9±12.9 | 24.1±6.1 | 76.6 |

As the experimental period was not the same for all experiments, in addition to removal efficiency, the removal rate was also calculated since it's more appropriate to be used for comparison of the combinations. Table 4-8 shows the removal rates obtained for different parameters for experiments in category 1. The following equation was used to calculate the removal rate for TSS:

$$Removal\ rate\ = \frac{the\ total\ volume\ of\ filtered\ water\ *\ removal\ of\ SS\ concentration}{filter\ area\ *\ duration\ of\ experiments} \qquad \text{Equation 4-1}$$

The same steps were followed to calculate the removal rates for the other parameters.

Table 4-8 Removal rates obtained for different parameters for experiments in category 1

| | **TSS** (g /m$^2$-d) | **TP** (mg /m$^2$-d) | **COD** (g /m$^2$-d) | **Chlorophyll (exp 2)** (mg /m$^2$-d) |
|---|---|---|---|---|
| Removal rate | 3.5±2.1 | 7.6±2.1 | 7.4±2.8 | 7.1 |

### 4.3.2 Filter combination: 2*110 + 1*90 + 1*75 + 1*65 µm (category 2)

Experiments 4, 5, and 10 were carried out using the combination of two layers of 110 µm, followed by one layer of 90 µm, one layer of 70 µm, and one layer of 65 µm. Compared with the combination used in the experiments of category 1, one layer of 90 μm was removed and one layer with smaller AOS (65 μm) was added to the combination. As the PSA results obtained from experiments in category one showed the presence of small sized particles in the water samples, a smaller pore sized geotextile was replaced to capture them. The initial concentrations of different water quality parameters are given in Table 4-9. Similar to category 1, for all experiments of this category, the initial concentrations of turbidity, total suspended solids, total phosphorus, total nitrogen, and nitrate were below the acceptable limits while the initial concentrations of COD were above the threshold value which is 20 mg/L.

Table 4-9 Initial water condition of each experiment in category No. 2

| Experiment No. | Initial water condition | | | | | |
|---|---|---|---|---|---|---|
| | Turbidity (NTU) | Total suspended solids (mg/L) | Total phosphorus (μg/L) | Chemical oxygen demand (mg/L) | Total nitrogen (mg/L) | Nitrate (mg/L) |
| 4 | 4.6 | 7.75 | 18.0 | 25.45 | 0.525 | 0.100 |
| 5 | 3.7 | 6.87 | 16.5 | 29.35 | 0.850 | 0.108 |
| 10 | 2.9 | 5.00 | 18.0 | 29.65 | 0.721 | 0.043 |

Figure 4-24 indicates the removal trends of total phosphorus over the experimental periods for experiment 4, 5, and 10. The initial total phosphorus concentration varied in the range of 16.5 to 18 μg/L, which indicated that the water was enriched by nutrients and the lake was in the mesotrophic condition. For experiments 4 and 10, the initial TP concentrations were the same (18 μg/L) while the experimental periods were different. Experiment 4 was run for 7 days, whereas experiment 10 was run for 14 days. However, no removal was observed after day 7 in experiment 10. As it is shown in Figure 4-24, the filtration system could successfully lower the TP content to 9.5-12 μg/L, which is close to the recommended TP level in surface water needed for aquatic organisms (MDDEP, 2019b). The overall total phosphorus removal efficiency by filters was between 24.2% and 47.2%. No dissolved phosphorus had been found in the water samples taken in these experiments.

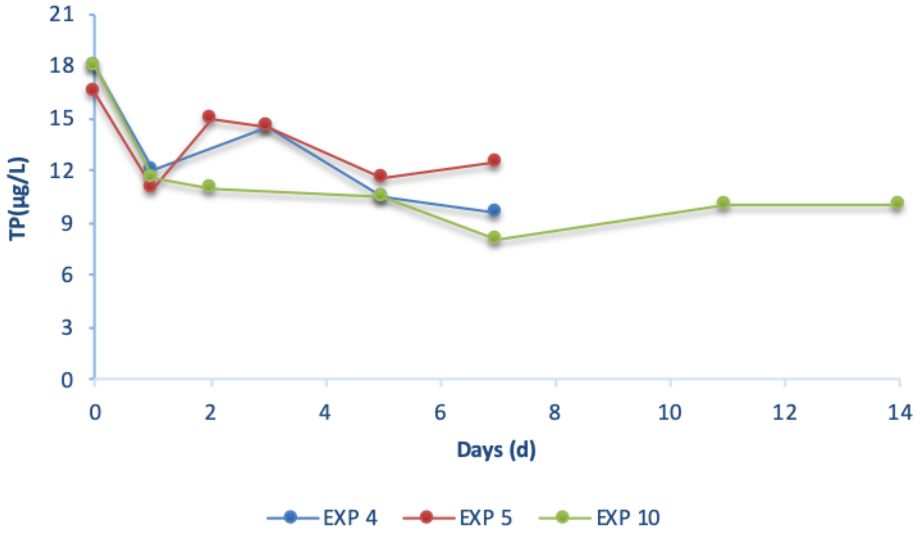

Figure 4-24 Removal trends of total phosphorus for the experiments in category No. 2

Figure 4-25 shows the decreasing trends of COD concentration over time for experiments 4,5, and 10. For all experiments, the initial COD concentration exceeded the acceptable limit, ranging from 25.45 to 29.65 mg/L. Similar to the experiments of category 1, COD was mostly in the dissolved form (80%) and as a result, no high removal efficiency was observed (21-31%). Although the removal efficiencies of the experiments were found to be very close to each other, experiment 4 was the only experiment in which the COD concentration reduced to less than the acceptable limit. This might be due to the lower initial COD concentration for experiment 4 than for experiments 5 and 10.

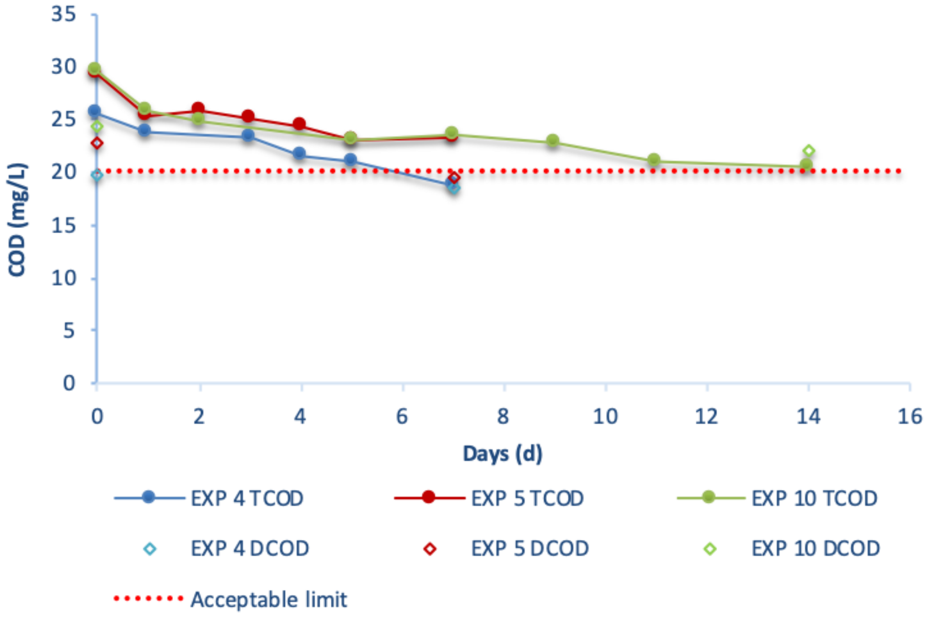

Figure 4-25 Removal trends of COD for the experiments in category No. 2

As stated earlier, the filters are not very effective for removing nitrogen as it mostly exists in its dissolved forms in the lake water. Therefore, for the rest of the experiments, just the initial and final concentrations of total nitrogen and nitrate are presented to show the change in their concentrations.

Table 4-10 Concentration of TN and $NO_3^-$ before and after filtration for the experiments in category No. 2

| | Total nitrogen (mg/L) | | Nitrate (mg/L) | |
|---|---|---|---|---|
| | Initial | Final | Initial | Final |
| Exp 4 | 0.525 | 0.391 | 0.100 | 0.145 |
| Exp 5 | 0.850 | 0.829 | 0.108 | 0.103 |
| Exp 10 | 0.721 | 0.653 | 0.043 | 0.071 |

The initial and final concentrations of total nitrogen and nitrate for all experiments were below the acceptable limits. Like previous experiments, most of the total nitrogen and nitrate were in their dissolved forms (80% and 92%, respectively), and thus no considerable removal was observed. Besides, a very slight increase in nitrate concentration was observed for experiment 4 and 10, which might be due to the oxidation of other reduced nitrogen species such as nitrite and ammonium in the water (Palakkeel Veetil et al., 2017).

The change in total suspended solids and turbidity during the filtration test for experiments 4,5, and 10 are given in Figure 4-26 andFigure 4-27, respectively. In experiments 4 and 5, the initial TSS concentration was 7.7 and 6.9 mg/L, which decreased to 1.4 and 3.1 mg/L after 7 days, respectively. Experiment 10 was run for 14 days and most of the suspended solids were removed in this test. At the end of this experiment, the concentration of TSS was reduced to 0.2 mg/L from 5 mg/L. Overall, 54.5-96% TSS removal was obtained for the experiments in this category. The initial turbidity value was in the range of 2.9 to 4.6 NTU, which was below the allowable limit for surface water (10 NTU). Similar to TSS, a significant turbidity removal (97%) was achieved for experiment 10. The initial turbidity value was 2.9 NTU, which came down to 0.09 NTU over the 14 days experimental period. This value represents a much-improved water clarity. 85.5% and 70.6 % reduction in turbidity were obtained for experiments 4 and 5, respectively.

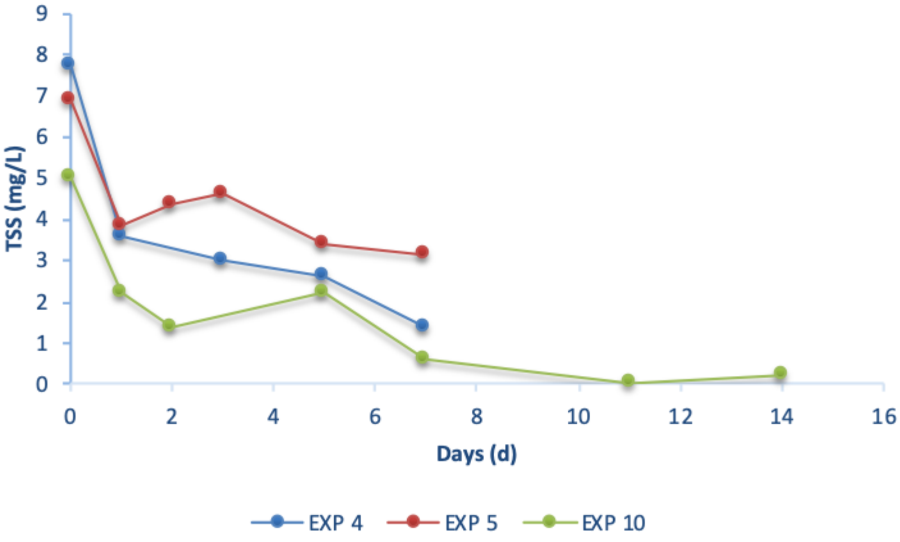

Figure 4-26 Removal trends of total suspended solids for the experiments in category No. 2

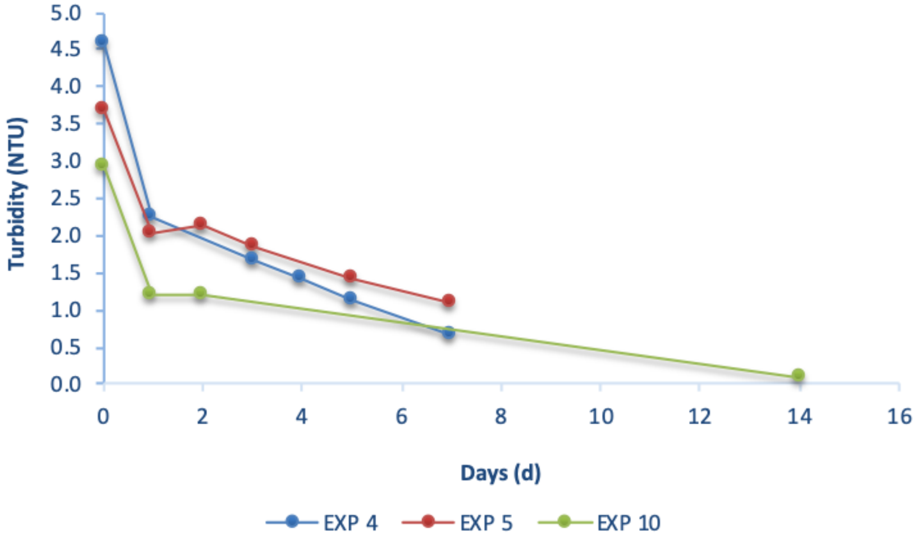

Figure 4-27 Removal trends of turbidity for the experiments in category No. 2

Figure 4-28 indicates the grain size distribution curve of suspended solids at the beginning and end of the filtration for the experiments in category 2. Before the filtration, around 90% of the particles were under 88.5, 67.5, and 39.2 microns for the samples taken in experiments 4, 5, and 10, respectively. As can be seen in Figure 4-28, filtration was able to remove large and fine suspended solids and resulted in around 90% of the particles under 5.9, 34.2, and 8.8 microns on the final day of experiments 4, 5, and 10, respectively. Analysis of the lake water samples before starting the experiments showed that all particles were in the size of silt and sand and there was no clay particle in the samples. However, at the end of the experiments, it was found that all particles were clay and silt sizes. Also, as expected, no particles larger than 65 microns were found in the final samples as the minimum pore size of the geotextiles used in the tests was 65 microns.

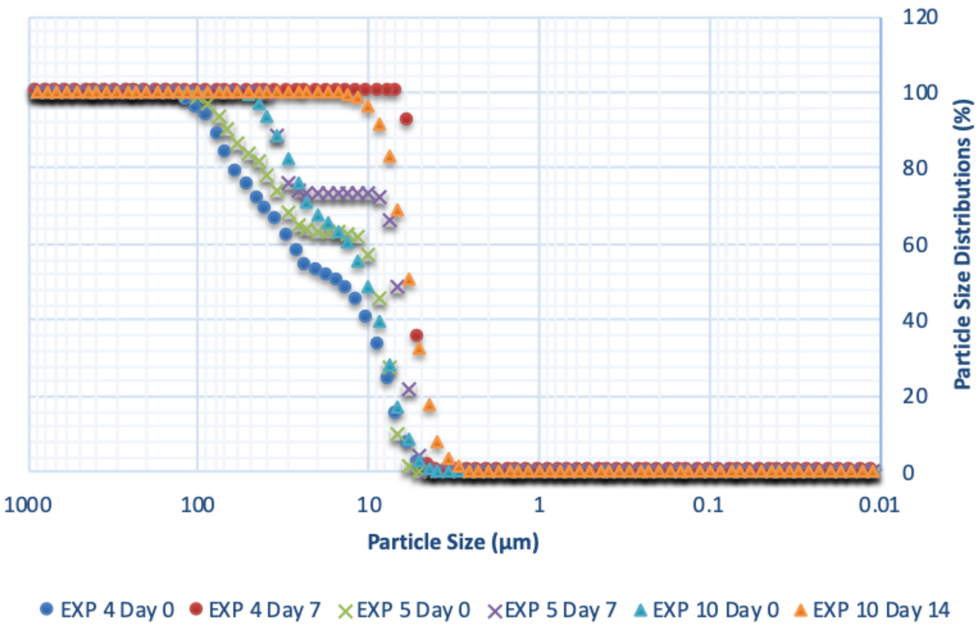

Figure 4-28 Grain size distribution of SS in the lake water for the experiments in category No. 2

The hourly data for experiment 4 measured with the help of the YSI probes are presented here. Figure 4-29 shows the decreasing trend of turbidity during experiment 4. As it is clearly shown in Figure 4-29, more than 50 % of the turbidity removal occurred within the first day of the run, and overall 86.2% of the initial turbidity was removed at the end of the experiment.

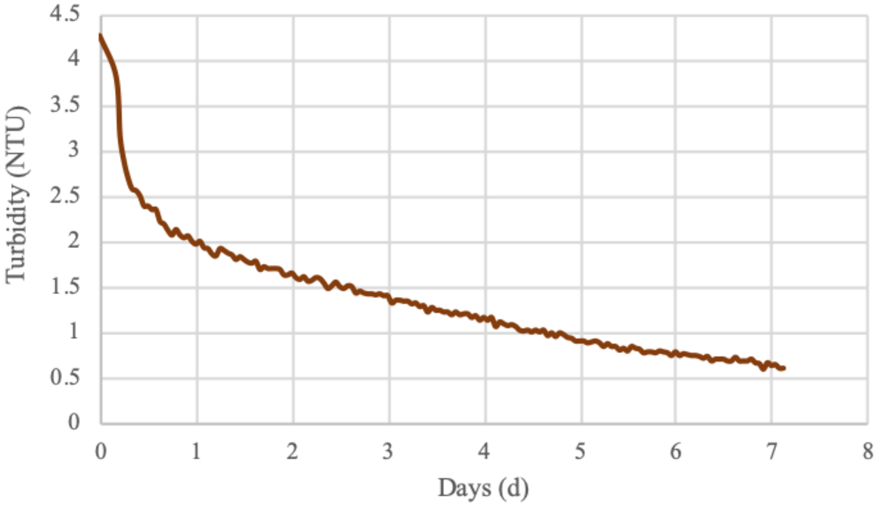

Figure 4-29 Removal trend of turbidity for experiment 4

Figure 4-30 andFigure 4-31 illustrate the change in the chlorophyll-a and BGA concentrations throughout experiment 4. Both chlorophyll-a and BGA concentrations were found to decrease, gradually. Initially, the concentration of chlorophyll-a was 21 µg/L, which revealed a medium in which the microscopic algae in suspension was significantly high. At the end of the experiment, the chlorophyll-a concentration decreased to 8.7 µg/L, indicating less living algae in the water. The initial concentration of BGA was 1.04 µg/L which reduced to 0.48 µg/L at the end of the filtration test. The average concentration of BGA was 0.8 µg/L. About 58.8% chlorophyll-a and 53.8% BGA removal were achieved within the 7 days of this experiment.

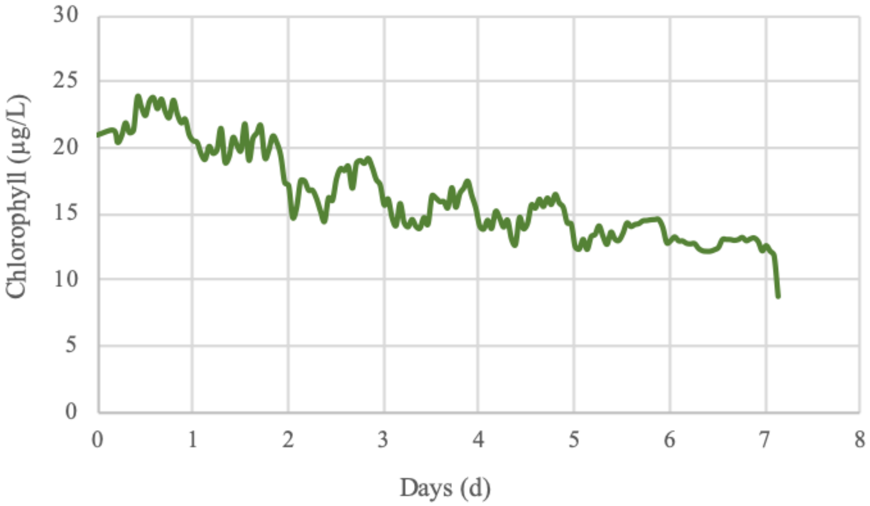

Figure 4-30 Removal trend of chlorophyll-a for experiment 4

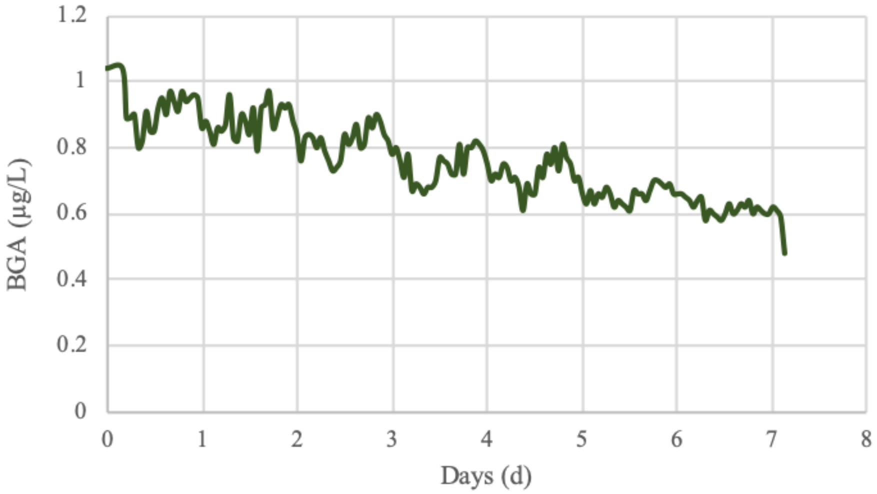

Figure 4-31 Removal trend of BGA for experiment 4

Figure 4-32 andFigure 4-33 show the hourly temperature and pH values measured by the sonde during experiment 4. As can be seen in the figures, these two variables didn't change considerably over the experimental period. The temperature ranged from 19.7 ºC to 24 ºC, with an average value of 22.2 ºC and the pH varied between 7.7 and 8, with an average value of 7.9.

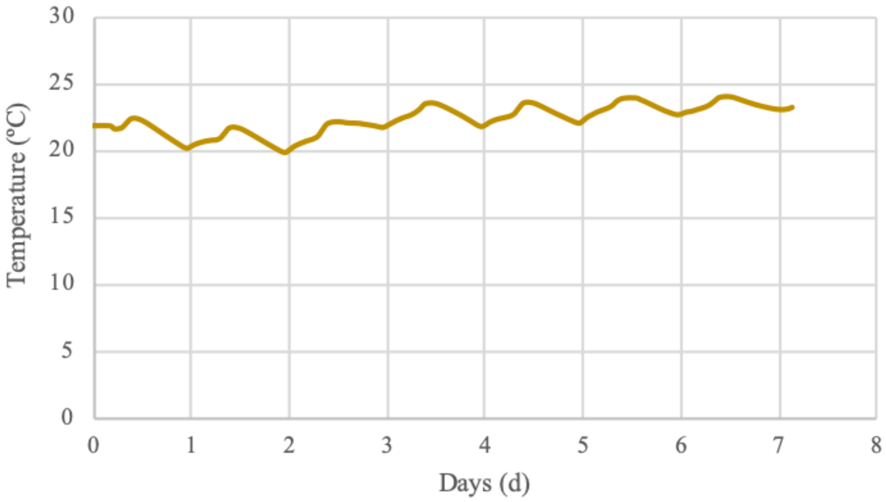

Figure 4-32 Probe data for temperature during experiment 4

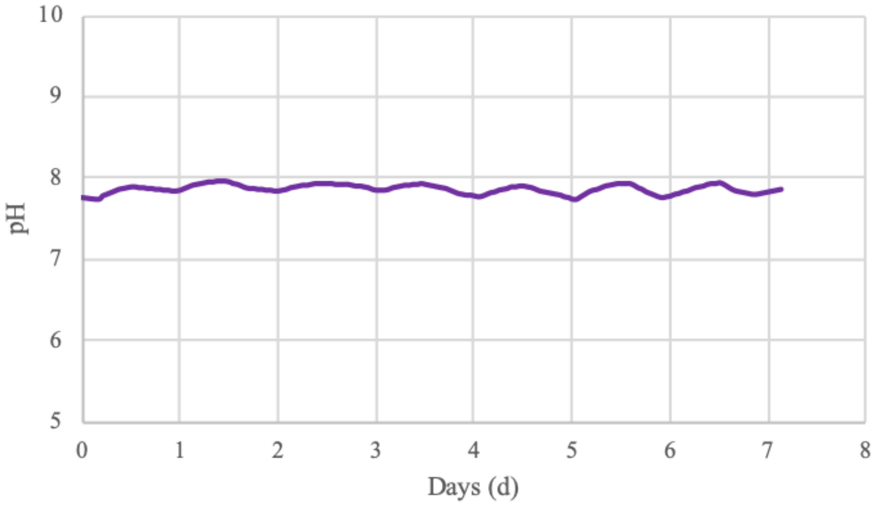

Figure 4-33 Probe data for pH during experiment 4

The changes in oxidation-reduction potential and dissolved oxygen values during experiment 4 are presented in Figure 4-34 andFigure 4-35, respectively. The ORP increased from 237.4 mV to 309.5 mV with an average value of 326 mV. DO varied from 8.1 mg/L to 8.8 mg/L with an average value of 8.3 mg/L during the experiment (Figure 4-35).

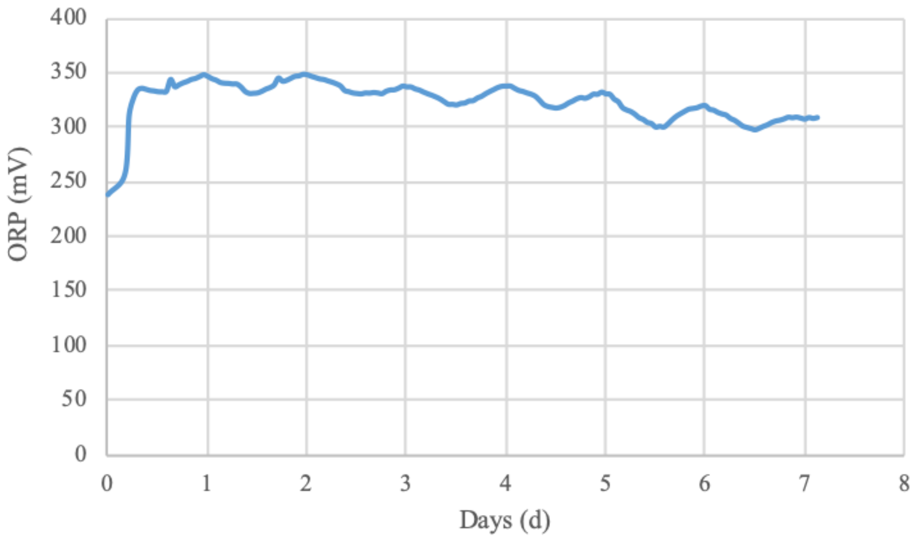

Figure 4-34 Probe data for ORP during experiment 4

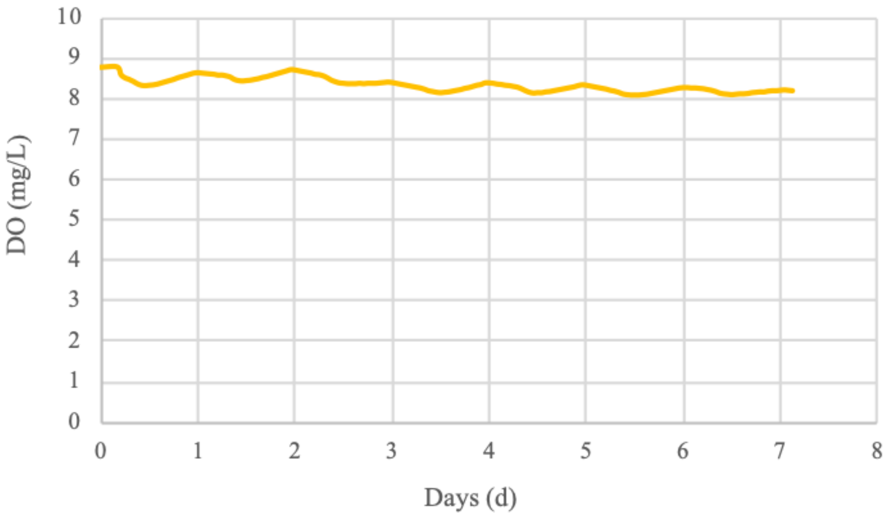

Figure 4-35 Probe data for DO during experiment 4

Table 4-11 indicates the overall percent removal obtained for TSS, turbidity, TP, COD, and chlorophyll-a using the geotextile combination of two layers of 110 microns followed by one layer of 90 microns, one layer of 75 microns, and one layer of 65 microns. As stated earlier, the results of total nitrogen and nitrate experiments are not included in Table 4-11 as they are mostly in their dissolved forms, and the filters are not effective for removing them. Table 4-12 shows the removal rates obtained for different parameters for experiments in this category.

Table 4-11 Overall percent removal obtained for different parameters for experiments in category 2

| | **TSS** | **Turbidity** | **TP** | **COD** | **Chlorophyll (exp 4)** |
|---|---|---|---|---|---|
| Removal efficiency (%) | 77.6±21.1 | 84.3±13.2 | 38.6±12.5 | 26.2±5.1 | 58.8 |

Table 4-12 Removal rates obtained for different parameters for experiments in category 2

| | **TSS** (g /m$^2$-d) | **TP** (mg /m$^2$-d) | **COD** (g /m$^2$-d) | **Chlorophyll (exp 4)** (mg /m$^2$-d) |
|---|---|---|---|---|
| Removal rate | 5.7±2.8 | 6.3±5 | 8±1.5 | 16.8 |

### 4.3.3 Filter combination: 2*100 + 2*90 + 2*70 µm (category 3)

Experiments 6 and 7 were performed using the filter combination of two layers of 100 microns followed by two layers of 90 microns, and two layers of 70 microns, respectively. Table 4-13 indicates the initial water quality for these two experiments. Similar to the previous experiments, the initial COD concentrations were above the acceptable level (20 mg/L) for both experiments of this category. The initial concentrations of turbidity, total suspended solids, total phosphorus, and nitrate lied within the allowable range for both experiments whereas, only in experiment 6, the initial concentration of total nitrogen was equal to the threshold value (1 mg/L).

Table 4-13 Initial water condition of each experiment of category No. 3

| Experiment No. | Initial water condition | | | | | |
|---|---|---|---|---|---|---|
| | Turbidity (NTU) | Total suspended solids (mg/L) | Total phosphorus (µg/L) | Chemical oxygen demand (mg/L) | Total nitrogen (mg/L) | Nitrate (mg/L) |
| 6 | 5.72 | 8.67 | 15 | 32.95 | 1 | 0.099 |
| 7 | 4.85 | 7.52 | 16.5 | 33.95 | 0.826 | 0.051 |

Figure 4-36 shows the removal trends of total phosphorus during experiments 6 and 7. At the beginning of the filtration, the TP concentrations were 15 µg/L in experiment 6 as well as 16.5 µg/L in experiment 7, respectively. After 7 days of run, TP was removed to 6 µg/L in experiment 6 and 8.5 µg/L in experiment 7 due to the filtration. These variables indicated that this filter combination could successfully change the trophic state of the lake water from mesotrophic to oligotrophic class in terms of phosphorus concentration (MDDEP, 2012). The results showed that about 60% of TP in experiment 6 and 48.5% of TP in experiment 7 were removed over the experimental periods. No dissolved phosphorus had been observed in the water samples taken in experiment 6, which showed that all phosphorus was contained in the suspended particles. In experiment 7, TDP slightly increased at the end of the experiment. This might be due to an incident that happened during the experiment, which resulted in the resuspension of the particles and release of phosphorus through the filter.

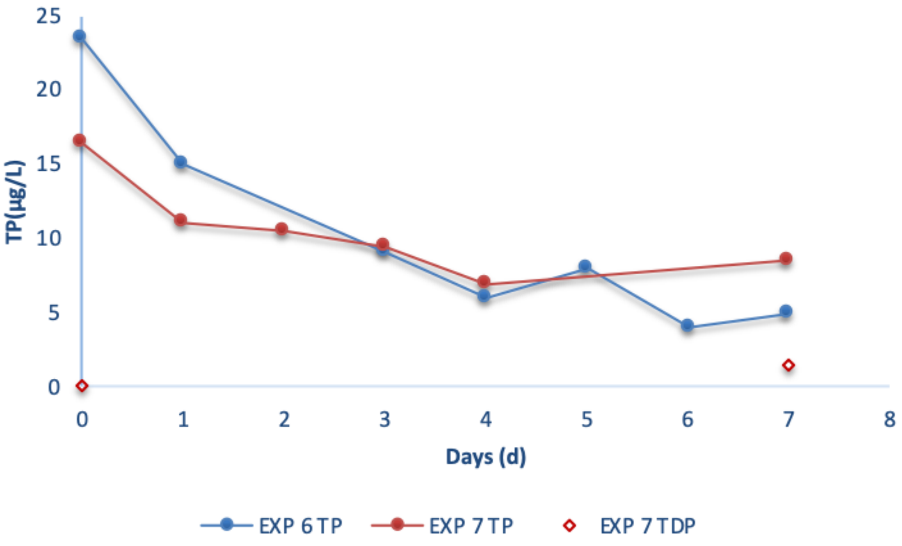

Figure 4-36 Removal trends of total phosphorus for the experiments in category No. 3

Figure 4-37 indicates the COD concentration in the filtered water during experiments 6 and 7. Similar to the experiments in category 1 and 2, the initial COD concentration for the experiments in this category was above 20 mg/L which is the acceptable level for unpolluted surface water. As shown in Figure 4-37, COD was mainly in its dissolved form (69-72%) which is difficult to remove by filtration. Therefore, no significant COD removal was obtained (19.3-23.5%), and the final COD concentration weren't reduced to the acceptable level. This is because filtration can remove the particulate COD which was a small fraction of total COD in these experiments. The concentrations of dissolved COD remained almost the same or changed slightly during the experiments. This indicates that dissolved forms of COD and phosphorus cannot be removed by filters alone.

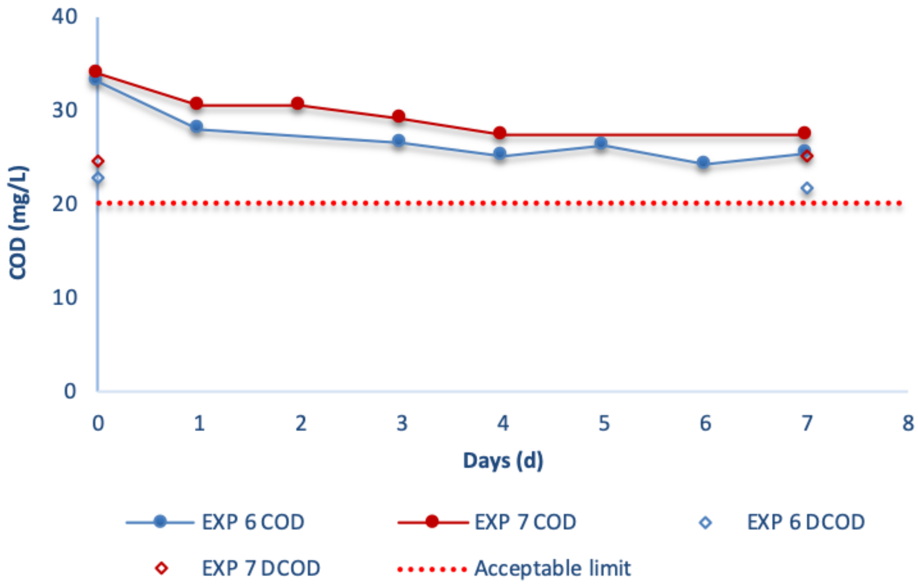

Figure 4-37 Removal trends of COD for the experiments in category No. 3

The initial and final concentrations of total nitrogen and nitrate for experiments 6 and 7 are given in Table 4-14. As stated earlier, 1 mg/L nitrogen is considered as a water quality guideline for total nitrogen by Environment Canada (2014). In this category, the initial total nitrogen concentration in experiment 6 was equal to the allowable limit which was reduced to 0.576 mg/L on the final day of filtration. For experiment 7, the initial total nitrogen concentration was within the acceptable level. At the end of the filtration tests, TN concentration decreased by 42.7% and 20.4% for experiment 6 and 7, respectively. The concentration of nitrate in both experiments was within the guideline for protection of aquatic life (CCME, 2019).

Table 4-14 Concentrations of TN and $NO_3^-$ before and after filtration for the experiments in category No. 3

| | Total nitrogen (mg/L) | | Nitrate (mg/L) | |
|---|---|---|---|---|
| | Initial | Final | Initial | Final |
| Exp 6 | 1.000 | 0.576 | 0.099 | 0.037 |
| Exp 7 | 0.826 | 0.657 | 0.051 | 0.109 |

Figure 4-38 andFigure 4-39 illustrate the removal pattern of TSS and turbidity during experiments 6 and 7. After 7 days of filtration, the TSS concentration was removed to 1.75 mg/L from 8.7 mg/L in experiment 6 as well as 2.25 mg/L from 7.5 mg/L in experiment 7. As can be seen in Figure 4-38, this filter combination removed about 80% of TSS for experiment 6, 60% of that was removed within the first day of the run. For experiment 7, the TSS removal efficiency was around 70% within the first four days of filtration. In the case of turbidity, the initial values for experiment 6 and 7 were 5.7 and 4.8 NTU, respectively (Figure 4-39). Considering the initial and final values for turbidity, this filter combination showed the performance of 64.2 to 70.2% with respect to turbidity removal.

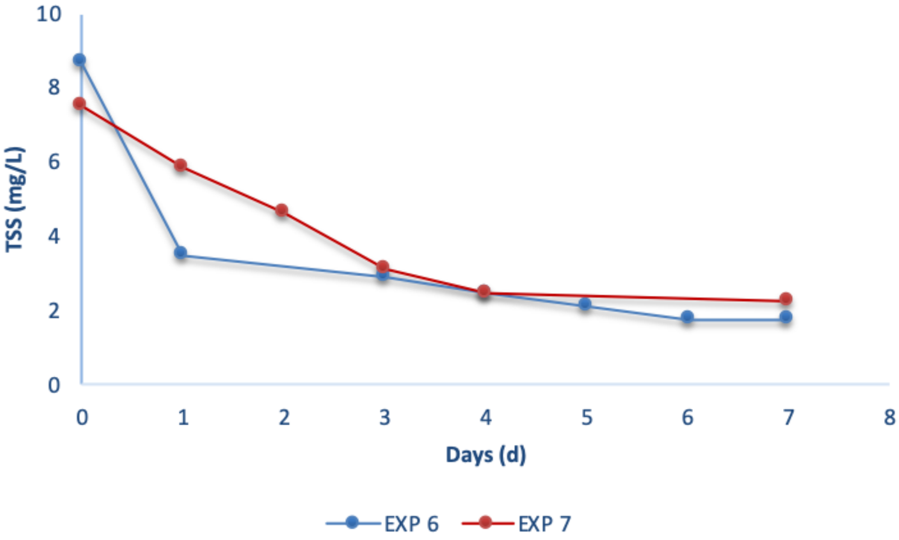

Figure 4-38 Removal trends of total suspended solids for the experiments in category No. 3

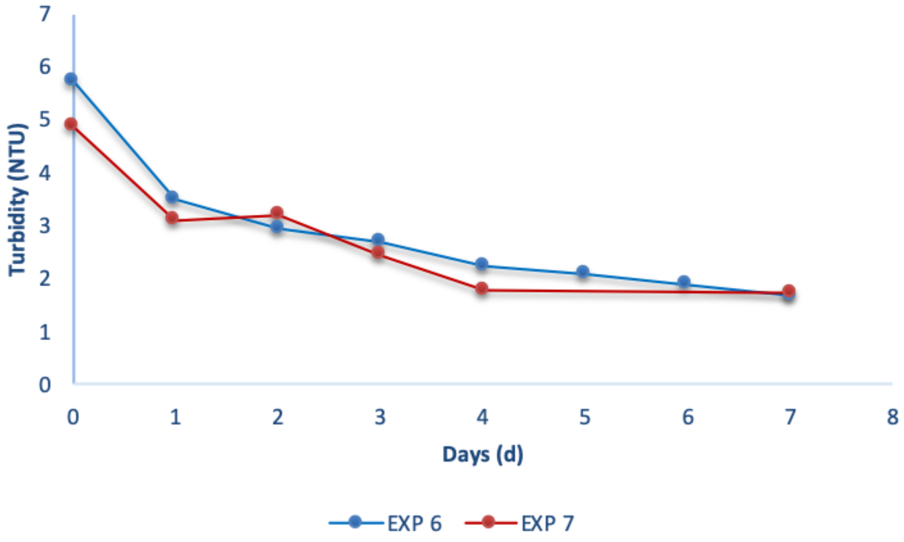

Figure 4-39 Removal trends of turbidity for the experiments in category No. 3

The particle size distribution of SS in the water samples collected at the beginning and end of experiments 6 and 7 is given in Figure 4-40. Initially, about 90 % of the particles were under 133 µm in experiment 6, whereas for experiment 7, 90 % of the particles were under 67.5 µm. As it is clearly seen in Figure 4-40, the filtration could successfully remove large particles in the water and thus resulted in around 90% of the SS below 39 and 11 µm on the final day of experiment 6 and 7, respectively. In both experiments, initially the particles were in the size of silt and sand, but at the end, it was found that all particles were silt size. The minimum pore size of the geotextiles used in this combination was 70 microns and, as expected, there were no particles higher than this size in the water at the end of the experiments.

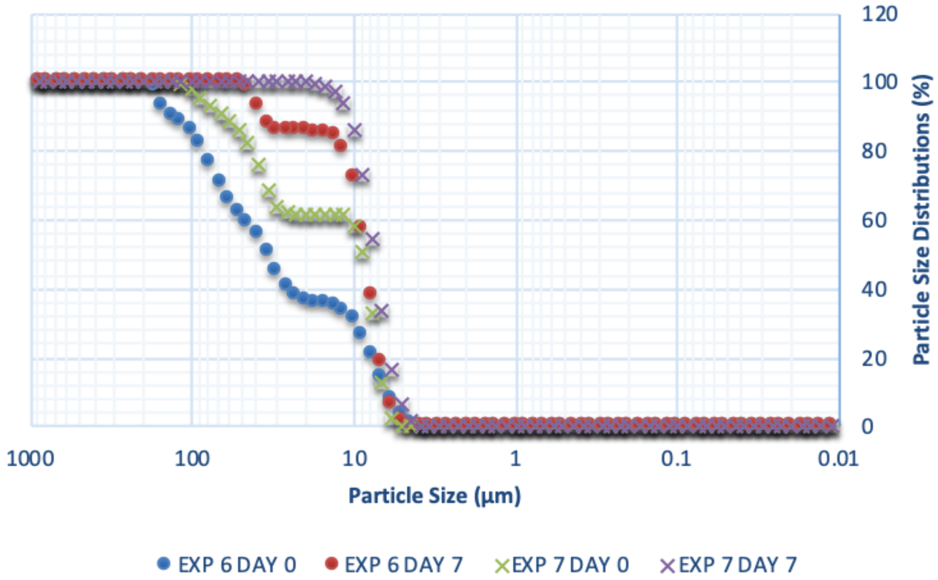

Figure 4-40 Grain size distribution of SS in the lake water for the experiments in category No. 3

The results for experiment 6 obtained from the YSI sonde are discussed here. Figure 4-41 indicates the turbidity of the water, which was monitored hourly by the sonde during experiment 6. These values were compared with those obtained by the handheld turbidity meter to validate them. As seen in Figure 4-41, the turbidity in the water was reduced, from 3.4 to 1.21 NTU within seven days of filtration. These values show the effectiveness of the filters in improving the clarity of the water.

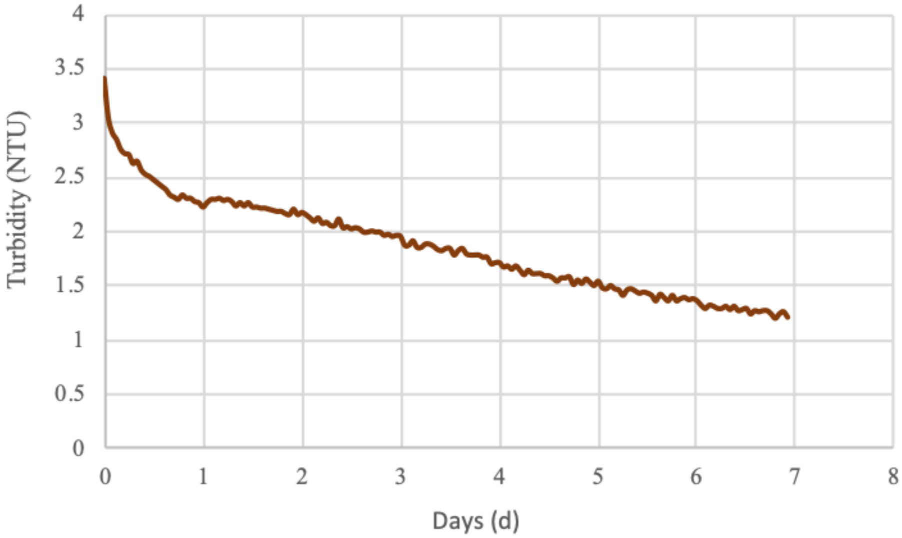

Figure 4-41 Removal trend of turbidity for experiment 6

The changes in chlorophyll-a and BGA concentrations in the water for experiment 6 are shown in Figure 4-42 andFigure 4-43, respectively. These graphs were plotted with the hourly data measured by the sonde over the filtration test. At the beginning of the experiment, the concentration of chlorophyll-a was 26.2 µg/L. As it is shown in Figure 4-42, a slight increase in Chl-a concentration was observed during the first days, which might be due to the increase in water temperature. While the filtration continues, the chlorophyll-a concentration in the water was decreased gradually, yielding about 31 % removal. The average concentration of chlorophyll-a was 24.9 µg/L. The concentration of BGA varied slightly, from 1.2 to 0.7 µg/L, with an average value of 0.9 µg/L. As seen in Figure 4-43, a small reduction (7%) in BGA concentration was observed over the experimental period.

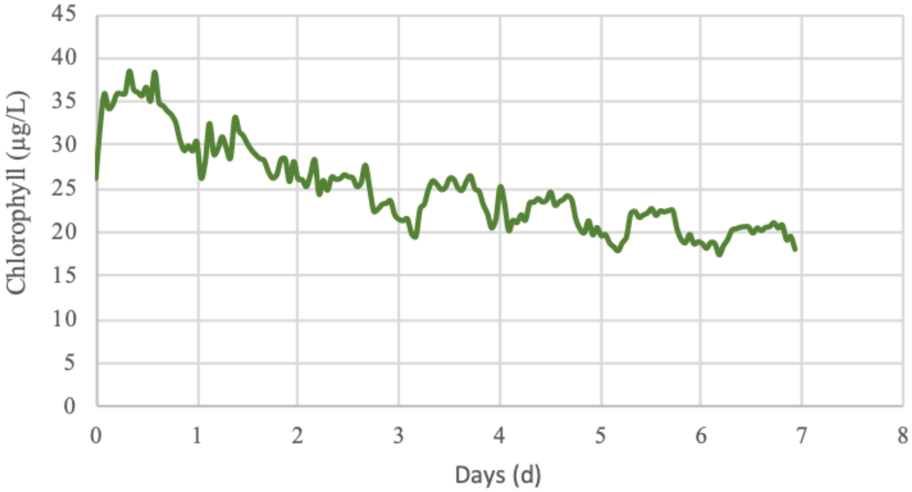

Figure 4-42 Removal trend of chlorophyll-a for experiment 6

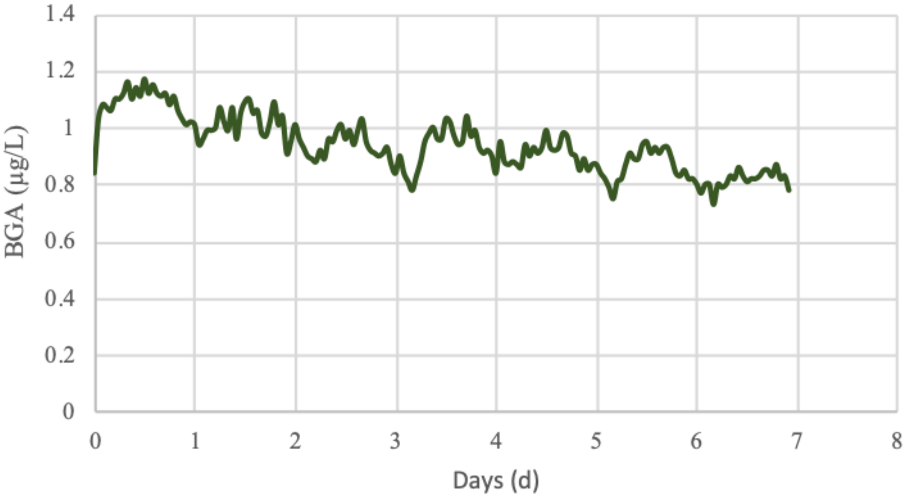

Figure 4-43 Removal trend of BGA for experiment 6

Figure 4-44 andFigure 4-45 present the hourly temperature and pH values obtained from the sonde during experiment 6. The temperature ranged from 20 ºC to 23.5 ºC, with an average value of 21.7 ºC and the pH varied between 7.8 and 8.1, with an average value of 7.9.

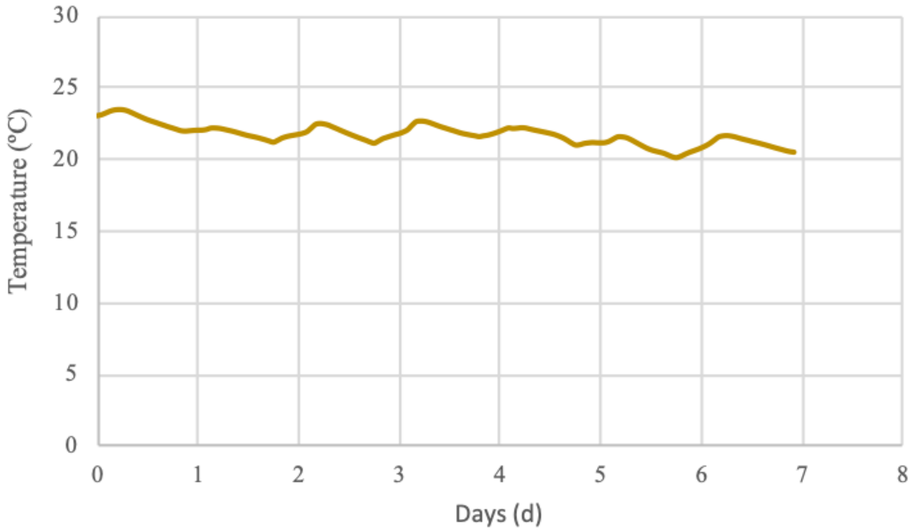

Figure 4-44 Probe data for temperature during experiment 6

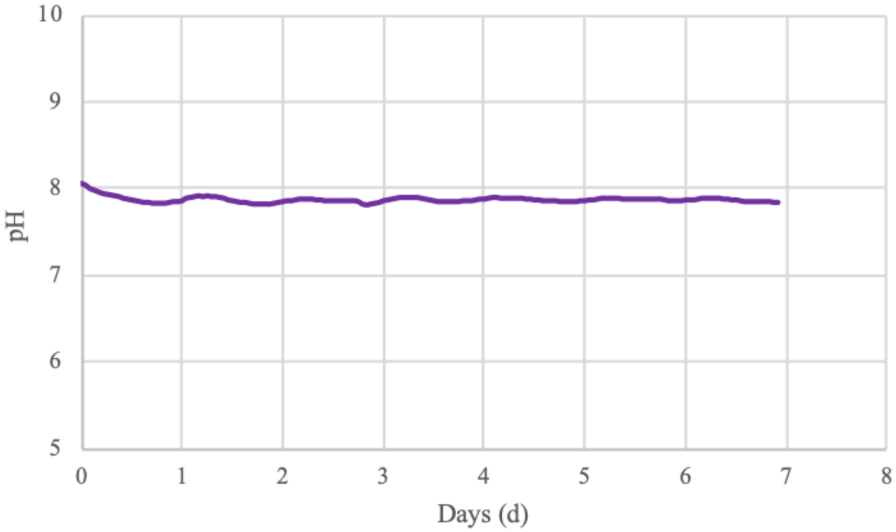

Figure 4-45 Probe data for pH during experiment 6

Figure 4-46 andFigure 4-47 indicate the changes in ORP and DO concentrations in the water during experiment 6, monitored by the YSI probe. The ORP increased from 208.8 mV at the beginning of the experiment to 250.5 mV at the end of the test, thereby improving the water quality over the filtration test. Dissolved oxygen concentration ranged between 8.1 mg/L to 8.6 mg/L, with an average value of 8.3 mg/L (Figure 4-47).

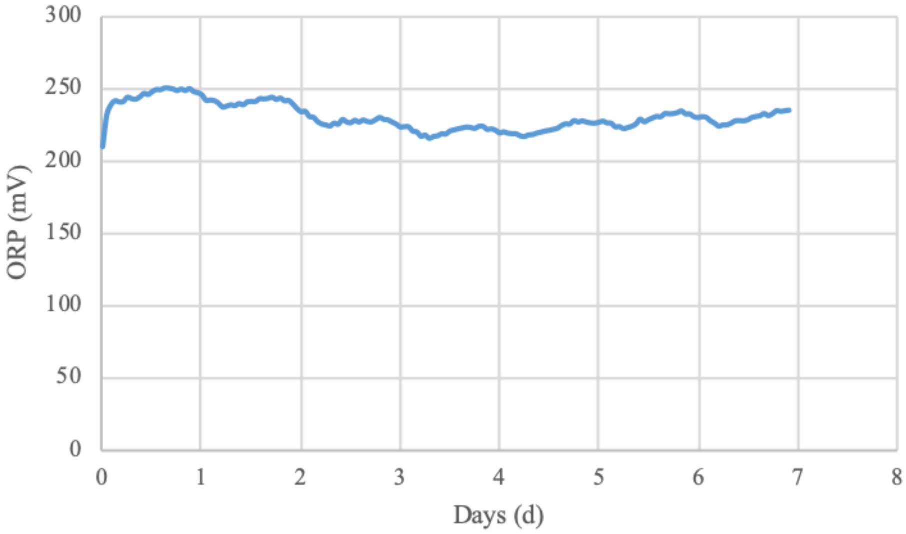

Figure 4-46 Probe data for ORP during experiment 6

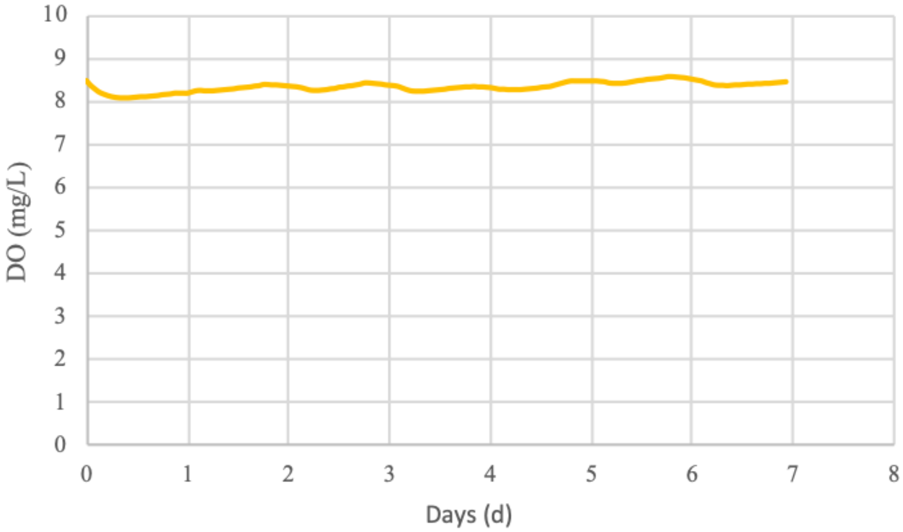

Figure 4-47 Probe data for DO during experiment 6

Table 4-15 shows the overall percent removal obtained for TSS, turbidity, TP, COD, and chlorophyll-a using the geotextile combination of two layers of 100 microns followed by two layers of 90 microns, and two layers of 70 microns. Similar to the experiments in previous categories, results of total nitrogen and nitrate tests are not shown in this table as the majority of TN and $NO_3^-$ were in their dissolved forms. Table 4-16 shows the removal rates obtained for different parameters for experiments in this category.

Table 4-15 Overall percent removal obtained for different parameters for experiments in category 3

| | **TSS** | **Turbidity** | **TP** | **COD** | **Chlorophyll (exp 6)** |
|---|---|---|---|---|---|
| Removal efficiency (%) | 74.9±6.9 | 67.2±4.2 | 54.2±8.1 | 21.4±3.0 | 31.2 |

Table 4-16 Removal rates obtained for different parameters for experiments in category 3

| | **TSS** (g /m$^2$-d) | **TP** (mg /m$^2$-d) | **COD** (g /m$^2$-d) | **Chlorophyll (exp 6)** (mg /m$^2$-d) |
|---|---|---|---|---|
| Removal rate | 8.3±1.6 | 11.6±1 | 9.8±1.2 | 11.1 |

### 4.3.4 Filter combination: 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm (Category 4)

Seven experiments were carried out using this combination as a filter media to find out the efficiency of geotextiles. Two of them were conducted in 2017 (experiments 8 and 9), and the rest were performed in 2018 (experiments 12 to 16). Since experiments 8 and 9 showed good results in 2017, this combination was selected to be tested in the following year to insure reproducibility. The initial water quality values for the experiments in this category are given in

Table 4-17. Considering the water quality guidelines for the protection of aquatic life, COD was the only parameter that its concentration exceeded the acceptable limits for all the experiments.

Table 4-17 Initial water condition of each experiment in category No. 4

| Experiment No. | Initial water condition | | | | | |
|---|---|---|---|---|---|---|
| | Turbidity (NTU) | Total suspended solids (mg/L) | Total phosphorus (µg/L) | Chemical oxygen demand (mg/L) | Total nitrogen (mg/L) | Nitrate (mg/L) |
| 8 | 4.57 | 7.00 | 17.0 | 32.00 | 0.657 | 0.045 |
| 9 | 3.55 | 5.34 | 15.5 | 31.20 | 0.722 | 0.061 |
| 12 | - | 4.25 | 14.5 | 21.65 | 0.700 | 0.103 |
| 13 | - | 5.56 | 14.5 | 22.25 | 0.673 | 0.113 |
| 14 | - | 6.25 | 14.5 | 23.45 | 0.721 | 0.111 |
| 15 | 5.52 | 7.50 | 25.5 | 27.40 | 0.955 | 0.118 |
| 16 | 3.91 | 5.5 | 15.0 | 24.80 | 0.876 | 0.135 |

Figure 4-48 shows the reduction trend of total phosphorus concentration during different experiments in category 4. The minimum and maximum initial TP concentration were 14.5 and 25.5 µg/L, respectively. These experiments were run continuously for six to thirteen days, and at the end of the tests, the TP concentration in the treated water was reduced to 5.5-11 µg/L, which places the trophic state of the water in the oligotrophic class. The TP removal trend was found to be similar for all the experiments and overall percent removal obtained for TP was 24.1-64.5% depending on the initial water quality. As can be seen in Figure 4-48, total dissolved phosphorus accounted for a small percent of the TP in experiment 8 and 9 (9-16%), and its concentration remained almost the same or slightly changed during the filtration. Overall, 61.8% and 64.5% TP removal were achieved for experiments 8 and 9, respectively.

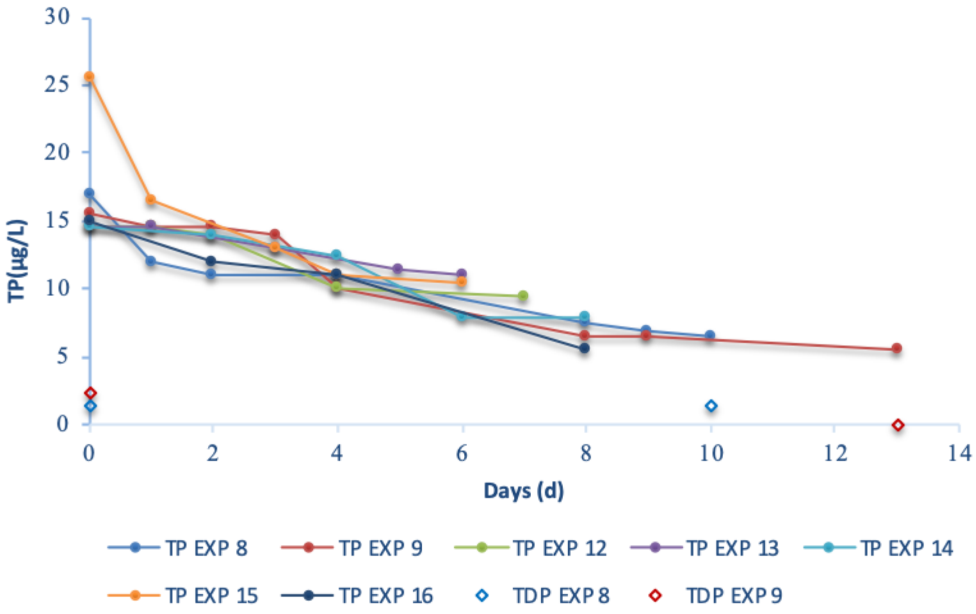

Figure 4-48 Removal trends of total phosphorus for the experiments in category No. 4

Figure 4-49 presents the removal pattern of COD during the experiments in category 4. As shown in Figure 4-49, the maximum allowable concentration was obtained for experiments 12 to 16, which were executed in 2018. However, it should be noted that the initial concentration of COD for experiments done in 2017 (8 and 9) was higher as compared to other experiments. The initial COD concentration was in the range of 21.7 to 27.4 mg/L in 2018 whereas in 2017, when the initial COD concentration was around 32 mg/L. Like previous experiments, COD was mainly in its dissolved forms (about 78%) and thus resulted in less COD removal (20-31%) by filtration.

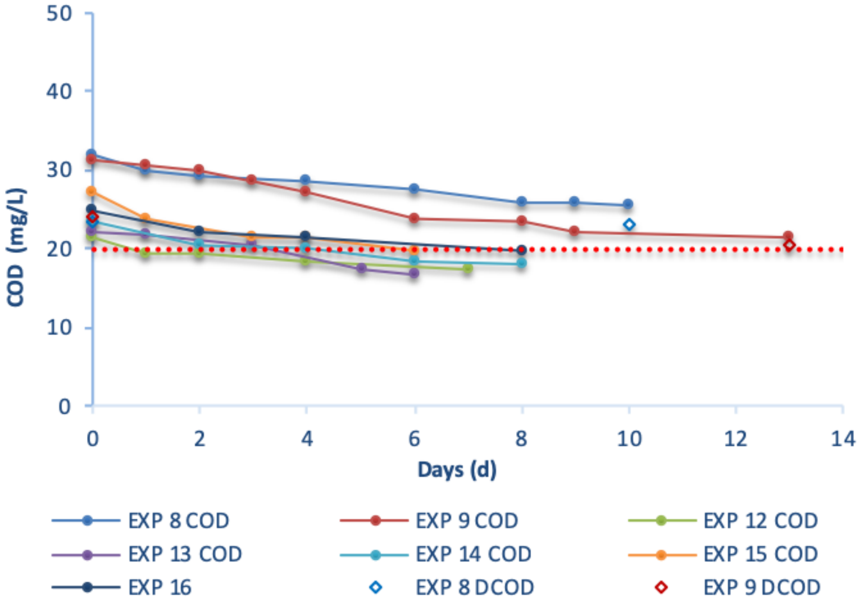

Figure 4-49 Removal trends of COD for the experiments in category No. 4

Table 4-18 indicates the concentration of total nitrogen and nitrate before and after filtration for experiments in category 4. As stated earlier, most of the total nitrogen and nitrates were in their dissolved forms which cannot be removed by filtration. Therefore, the concentration of total nitrogen remained almost the same or changed slightly throughout the filtration. Only the particulate form can be removed which was a small fraction of the total nitrogen (16%). No removal was observed for nitrate. Also, a very slight increase was observed in nitrate concentration which might be due to the oxidation of other reduced nitrogen species in the water (Palakkeel Veetil et al., 2017).

Table 4-18 Concentration of TN and $NO_3^-$ before and after filtration for the experiments in category No. 4

| | Total nitrogen (mg/L) | | Nitrate (mg/L) | |
|---|---|---|---|---|
| | Initial | Final | Initial | Final |
| Exp 8 | 0.657 | 0.666 | 0.045 | 0.056 |

| | | | | |
|---|---|---|---|---|
| Exp 9 | 0.722 | 0.661 | 0.060 | 0.065 |
| Exp 12 | 0.7 | 0.69 | 0.1 | 0.13 |
| Exp 13 | 0.67 | 0.61 | 0.11 | 0.14 |
| Exp 14 | 0.72 | 0.64 | 0.11 | 0.16 |
| Exp 15 | 0.96 | 0.86 | 0.12 | 0.14 |
| Exp 16 | 0.88 | 0.75 | 0.14 | 0.19 |

The removal trend of total suspended solids and turbidity for experiments in this category are shown in Figure 4-50 and Figure 4-51, respectively. The initial TSS concentration for these experiments varied in the range of 4.25 and 7.5 mg/L. At the end of the experiments, TSS were removed to 2.25 mg/L or less by this filtration system. As can be seen in Figure 4-50, experiment 9 could successfully remove all total suspended solids after 9 days. This combination of the geotextile filters resulted in about 59.5 to 100% TSS removal, and the water was clear enough to see the bottom of the tank. The turbidity removal was also significant for these tests, ranging from 45.2 to 100% depending on the initial water turbidity (Figure 4-51). For experiment 9, initially the turbidity was 3.55 NTU, 82.4% of that was reduced within the six days, and at the end, there was negligible turbidity in the water.

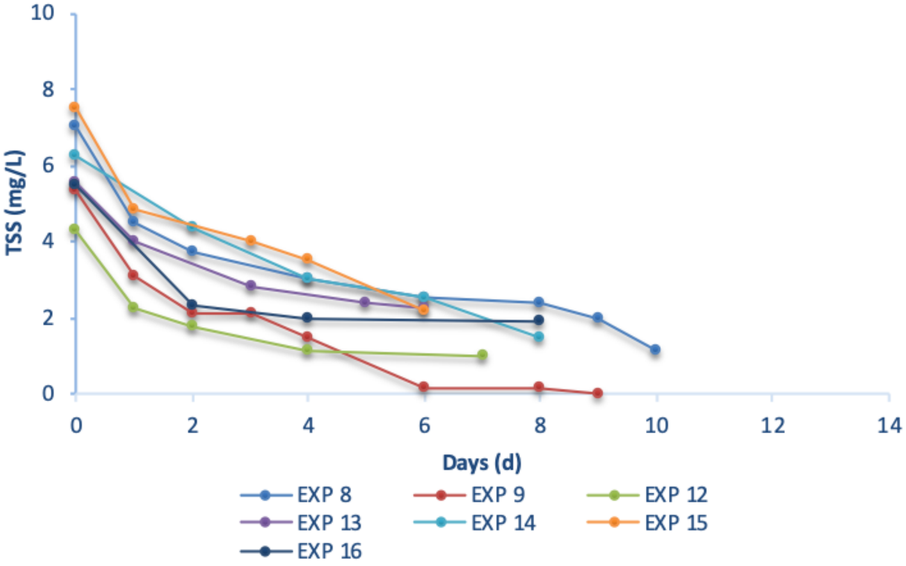

Figure 4-50 Removal trends of total suspended solids for the experiments in category No. 4

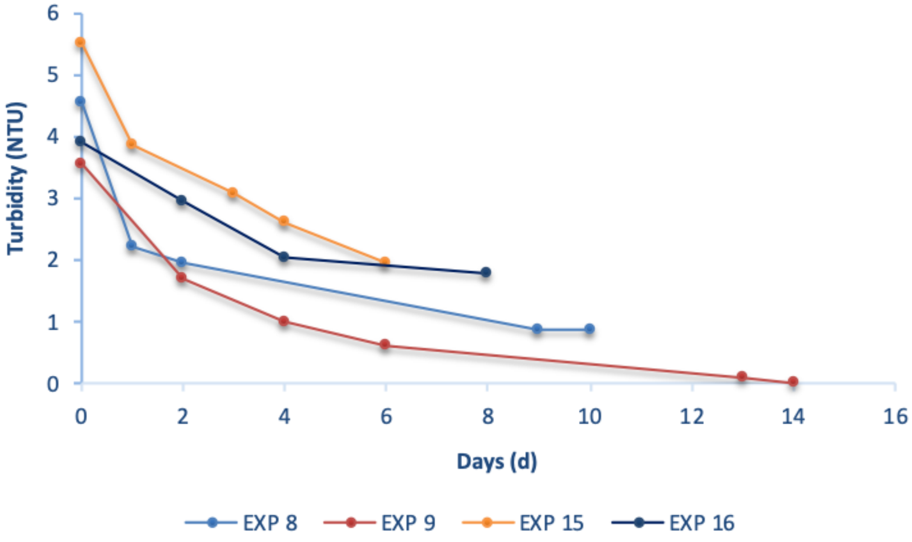

Figure 4-51 Removal trends of turbidity for the experiments in category No. 4

The PSA of water samples collected during the filtration tests is given in Figure 4-52. As stated earlier, experiments 8 and 9 were performed in 2017, whereas experiments 12 to 16 were executed in 2018. As can be seen in Figure 4-52, the particle size distribution of the samples taken in each year was found to be similar to each other. Initially, about 90 % of the particles were below 77.3 µm and 51 µm in 2017 and 2018, respectively. Filtration could successfully remove the large and fine suspended solids and resulted in around 90% of the particles in the filtered water below 10.8 µm in 2017 as well as 6.4 µm in 2018. The minimum pore size of geotextile used in this combination was 65 microns. Therefore, no particles larger than 65 microns were found in the final filtered water.

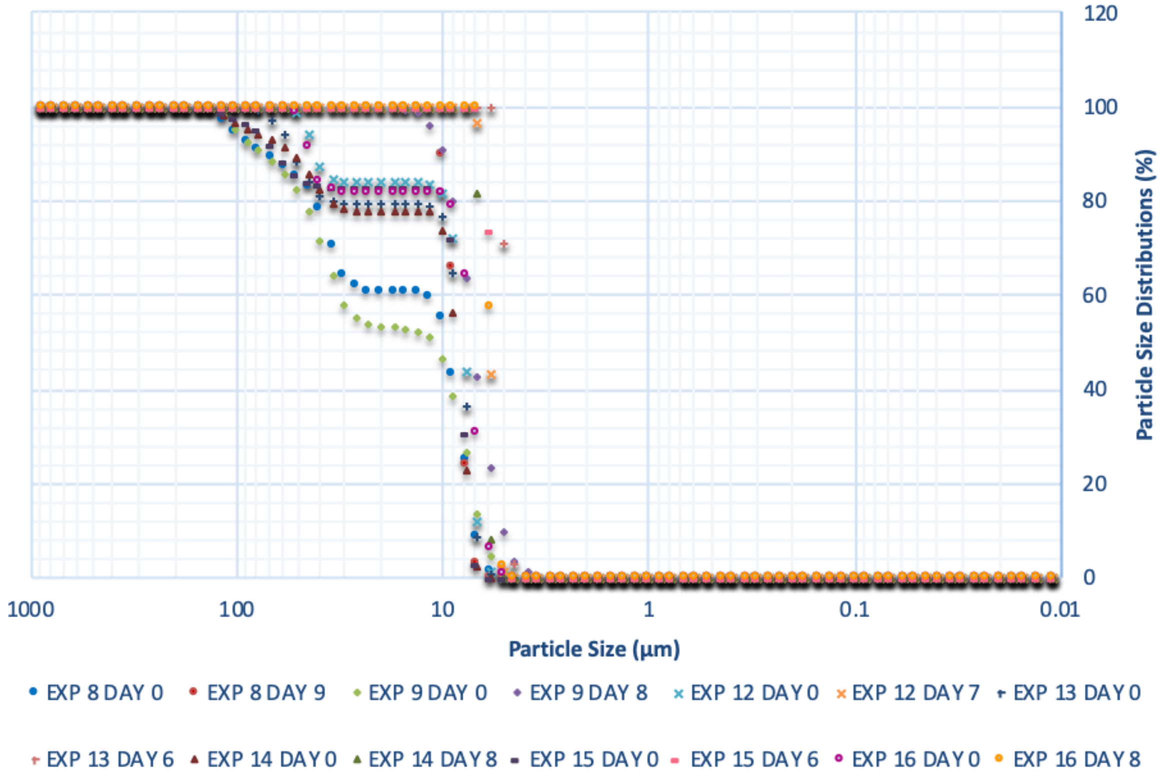

Figure 4-52 Grain size distribution of SS in the lake water for the experiments in category No. 4

In situ measurements of parameters such as pH, temperature, dissolved oxygen, etc. taken by the sonde for experiment 8 are presented here. Figure 4-53 illustrates the reduction trend of turbidity of water over the filtration test, monitored by the YSI probe. As seen in Figure 4-53, the turbidity of water was reduced from 3.6 to 0.8 NTU, within ten days of filtration. About 45% of the turbidity was removed within the first day of the run, and the rest was removed gradually during the remaining days of the test.

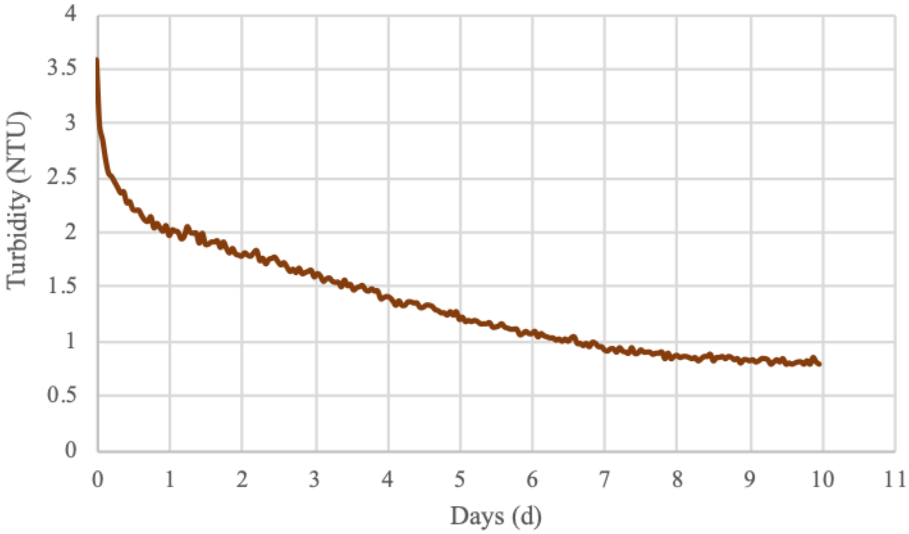

Figure 4-53 Removal trend of turbidity for experiment 8

Figure 4-54 and Figure 4-55 indicate the removal patterns for chlorophyll-a and BGA during experiment 8, respectively. Both chlorophyll-a and BGA concentrations were found to decrease, gradually, with a similar trend. The concentration of chlorophyll-a varied in the range from 33.4 to 12 µg/L with an average value of 21 µg/L. As mentioned in previous chapters, high concentrations of BGA in the water can cause stress to aquatic life since the decaying algae can reduce the level of oxygen in the water, thereby causing death to aquatic animals. In this experiment, initially BGA concentration was 1.13 µg/L which decreased to 0.6 µg/L at the end of the experiment. This indicated that the amount of BGA was decreasing with the removal of nutrients from the water. The average concentration of blue-green algae was 0.9 µg/L. Overall, about 50% chlorophyll-a and 42% BGA removal was achieved during the filtration test.

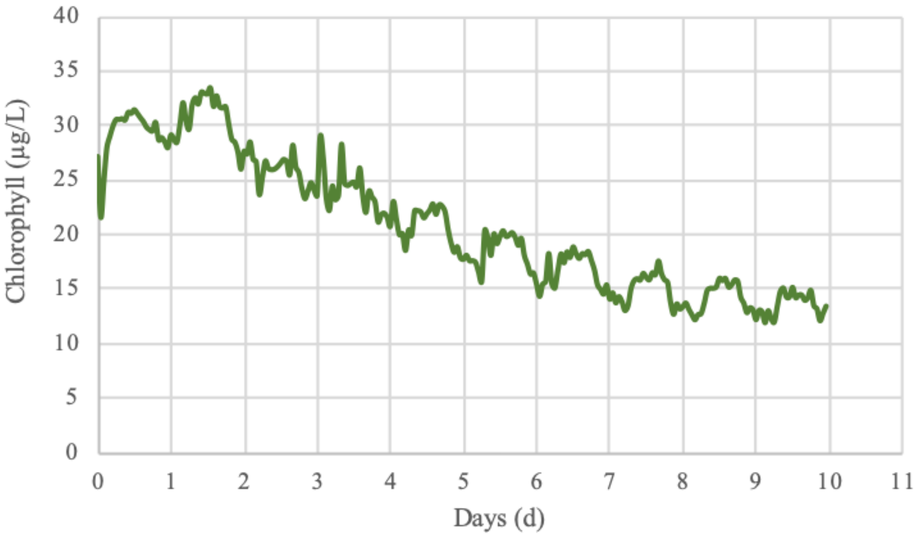

Figure 4-54 Removal trend of chlorophyll-a for experiment 8

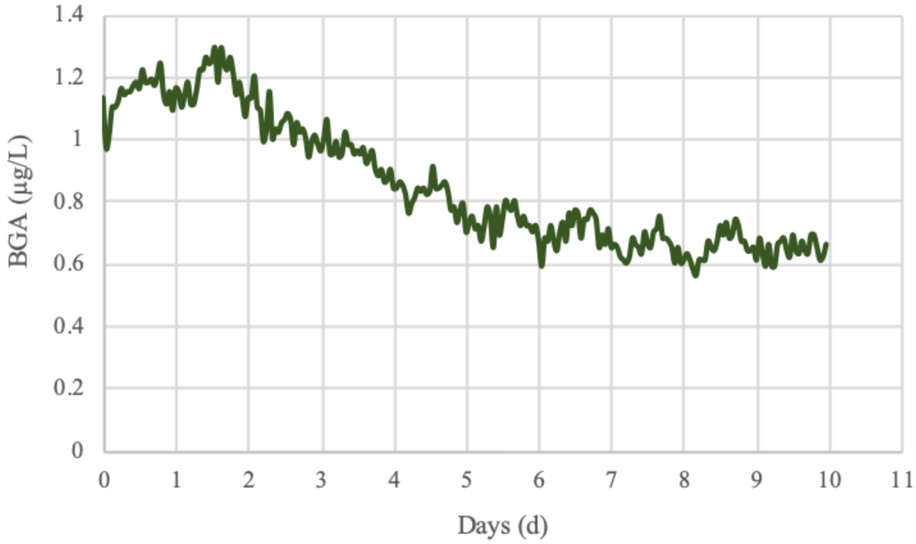

Figure 4-55 Removal trend of BGA for experiment 8

The change in temperature and pH of the water monitored by the sonde during experiment 8 are presented in Figure 4-56 and Figure 4-57, respectively. The temperature varied in the range between 15.9 and 19 ºC, with an average value of 17.5 ºC. pH varied in the range of 7.8 and 8.1, with an average value of 7.9.

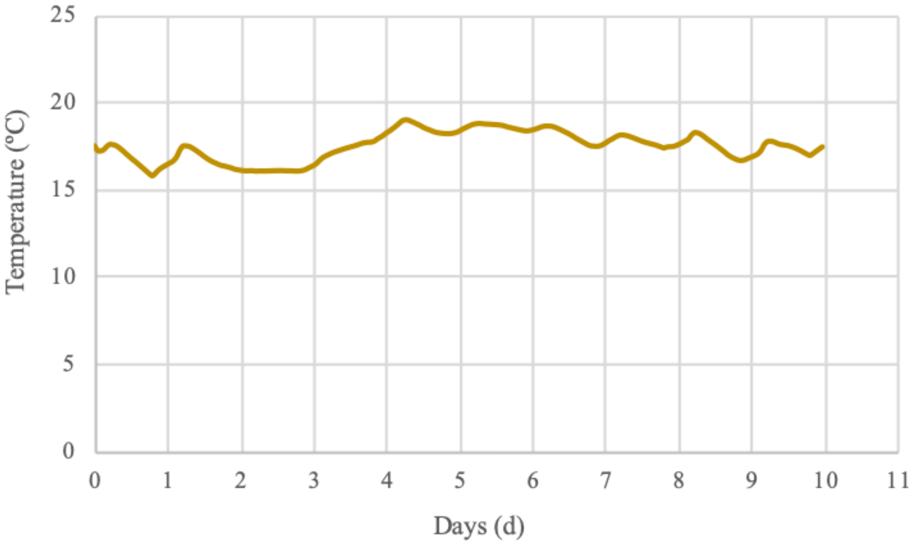

Figure 4-56 Probe data for temperature during experiment 8

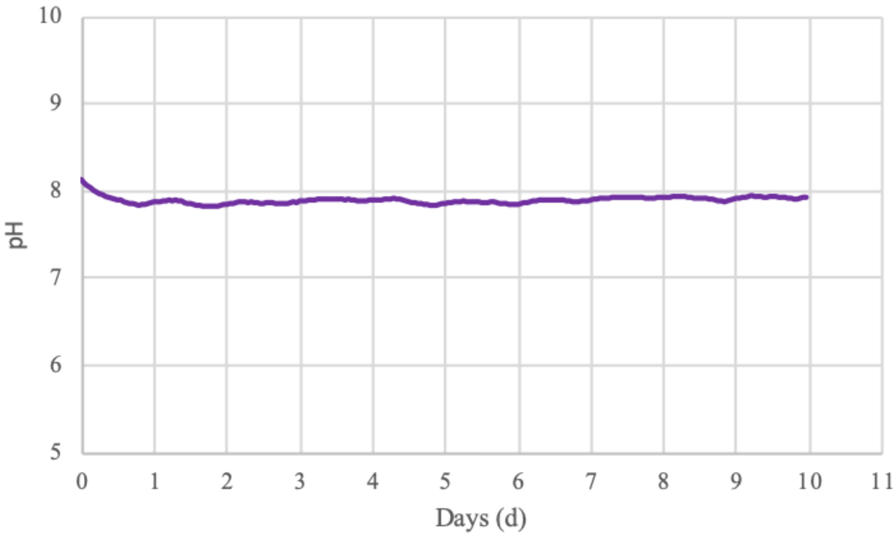

Figure 4-57 Probe data for pH during experiment 8

The graphs for hourly oxidation-reduction potential and dissolved oxygen with time for experiment 8 are presented in Figure 4-58 andFigure 4-59, respectively. During this experiment, the ORP value increased from 258.5 to 295.2 mV, which showed that the water quality was gradually improving by removing nutrients. The dissolved oxygen was from 8.8 to 9.5 mg/L, with an average value of 9.1 mg/L during the filtration test.

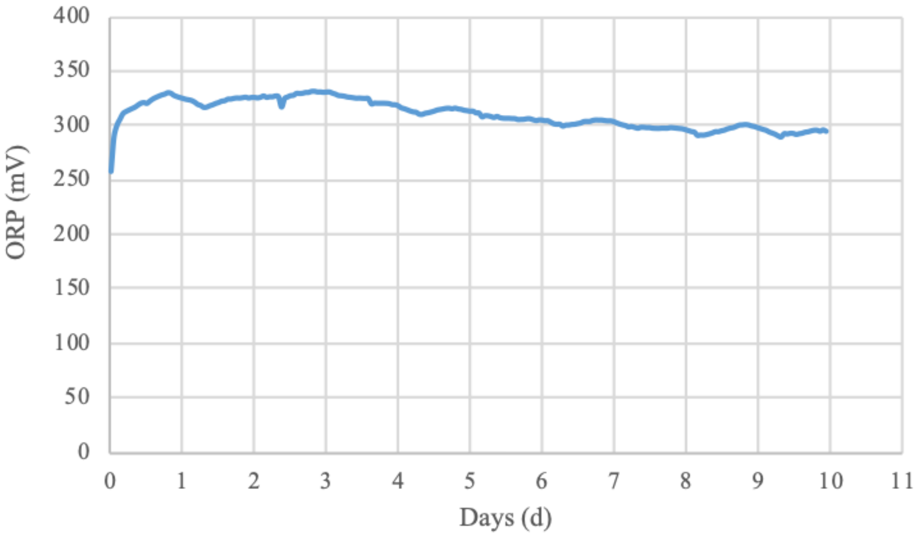

Figure 4-58 Probe data for ORP during experiment 8

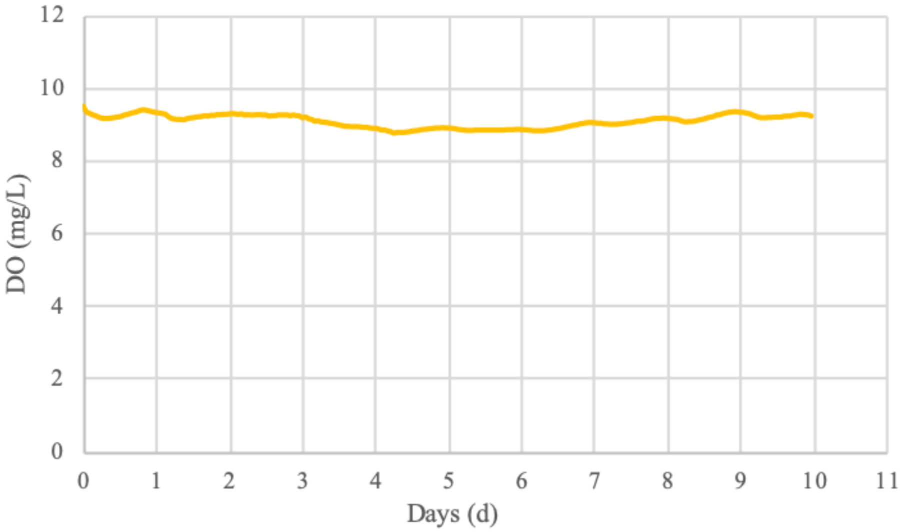

Figure 4-59 Probe data for DO during experiment 8

The overall percent removal obtained for TSS, turbidity, TP, COD, and chlorophyll-a for the experiments in category 4 is given in Table 4-19. As previously mentioned, the filter combination used for these filtration tests included one layer of 110 µm followed by one layer of 100 µm, one layer of 90 µm, one layer of 70 µm, and one layer of 65 µm. Table 4-20 shows the removal rates obtained for different parameters for experiments in this category.

Table 4-19 Overall percent removal obtained for different parameters for experiments in category 4

| | **TSS** | **Turbidity** | **TP** | **COD** | **Chlorophyll (exp 8)** |
|---|---|---|---|---|---|
| Removal efficiency (%) | 76.1±13.1 | 73.9±19.7 | 50.3±16.0 | 24.1±4.3 | 50 |

Table 4-20 Removal rates obtained for different parameters for experiments in category 4

| | **TSS** (g /m$^2$-d) | **TP** (mg /m$^2$-d) | **COD** (g /m$^2$-d) | **Chlorophyll (exp 8)** (mg /m$^2$-d) |
|---|---|---|---|---|
| Removal rate | 5.4±1.5 | 10.4±6.3 | 7.6±2.3 | 13 |

### 4.3.5 Particle size distribution

The particle size analysis of water samples taken before starting the filtration experiments showed that most of the particles were silt (4 to 60.5 µm). However, there were small amounts of sand (60.5 to 2000 µm) in the samples. Similar results were also observed for the samples taken from different stations of the lake. For example, Figure 4-60 shows the particle size analysis for experiments 6 and 9 before and after filtration. The geotextile combination used in these two tests were different. For experiment 6, it included two layers of 100 µm followed by two layers of 90 µm, and two layers of 70 µm, while for experiment 9, the combination included one layer of 110 µm, 100 µm, 90 µm, 70 µm, and 65 µm, respectively.

As can be seen in Figure 4-60, the particle size before the filtration varied from 4 to 200 µm and 4 to 133 µm in experiments 6 and 9, respectively. For experiment 6, about 70% of particles were silt, and the remaining 30% were sand, ranging from 60 to 200 µm. For experiment 9, 85.5% of the particles had a diameter of less than 60.5 µm (silt), and the remaining 14.5% were sand. However, the analysis of the final filtered water samples showed that 90% of the particles were below 39 µm and 10 µm in experiments 6 and 9, respectively, and there were no sand particles in the water samples. Therefore, the filters were able to remove even particles slightly below the smallest pore size that was used. This is because upon continuous filtration, particles captured on the filter media fill the pores, thereby reducing the opening size.

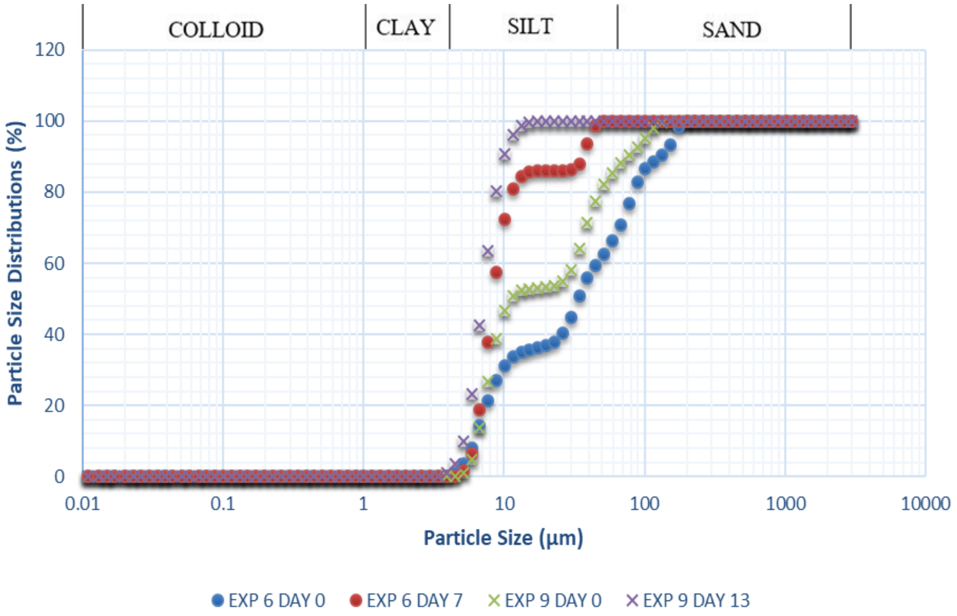

Figure 4-60 Particle size distribution before and after filtration for experiments 6 and 9

### 4.3.6 Relationship between SS and TP

In this study, to determine the relationship between total suspended solids removal and total phosphorus reduction, the results of SS removal and P removal are plotted in one graph. Figure 4-61 indicates the correlation between SS removal and phosphorus reduction with respect to each filter combination. A good correlation was obtained between these two parameters with a regression coefficient ranging from about 0.71 to 0.86. As can be seen in Figure 4-61, with the removal of suspended solids due to the filtration, the concentration of total phosphorus also decreased. This showed that the majority of phosphorus in the water was associated with suspended particles. Moreover, it was found that the relationship was almost linear for all the filter combinations, while the regression coefficients obtained for combinations 3 and 4 ($R^2$=0.86) were higher. Overall, it can be concluded that if the suspended solids contain a high level of organic matter, water quality can be improved significantly by removing SS. The list of filters used in each combination is given in Table 4-21.

Table 4-21 List of filters used in each combination

| **Combination number** | **Filters used in each combination** |
|---|---|
| 1 | 2*110 + 2*90 + 1*75 µm |
| 2 | 2*110 + 1*90 + 1*75 + 1*65 µm |
| 3 | 2*100 + 2*90 + 2*70 µm |
| 4 | 1*110 + 1*100 + 1*90 + 1*70 + 1*65 µm |

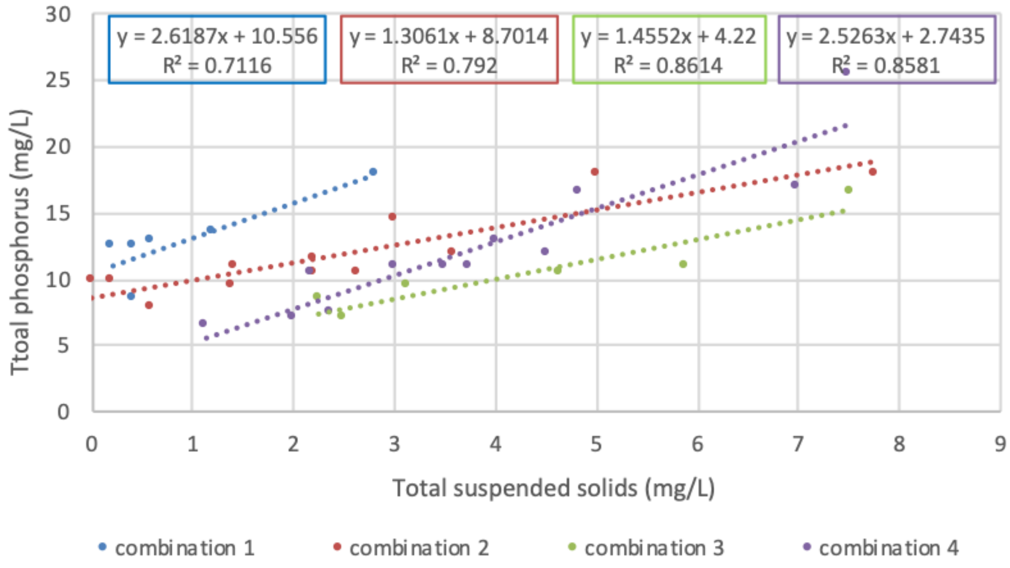

Figure 4-61 Correlation between total phosphorus and total suspended solids

### 4.3.7 Relationship between SS and turbidity

Turbidity in the water comes from suspended matter, such as clay, silt, and algae. This parameter is used as an indicator of water quality, as it strongly influences water clarity. Turbidity is an indirect measurement of total suspended solids in the water, and thus, the two parameters are related. The relationship can be better determined by plotting the TSS concentration and turbidity values in one graph. Figure 4-62 indicates the correlation obtained between TSS concentration and turbidity value with respect to each filter combination used in this study. As shown in Figure 4-62, a very strong correlation was found between these two parameters with a value of correlation coefficient ranging from 0.89 to 0.97. This indicates that as filtration continued the turbidity values also reduced with the removal of total suspended solids. The results of another study done by Hannouche et al. (2011) also confirmed the existence of a very strong linear relationship between turbidity values and TSS concentration.

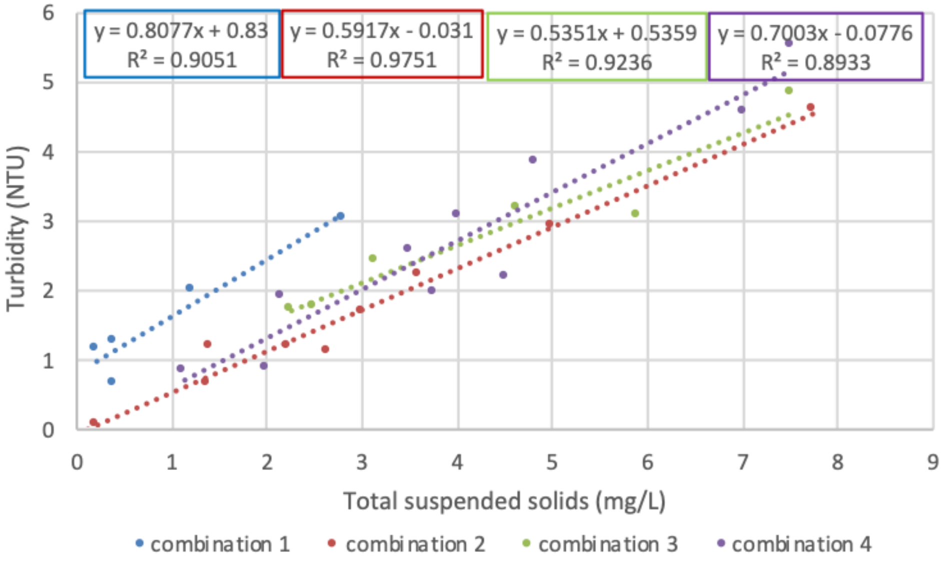

Figure 4-62 Correlation between turbidity and total suspended solids

### 4.3.8 Turbidity and total phosphorus removal

Figure 4-63 indicates the removal of turbidity and total phosphorus with respect to each filter combination. As can be seen, turbidity was removed significantly within the experimental period for each combination and that was reflected in the reduction of total phosphorus as well. As such, turbidity and total phosphorus removal was found to be related and thus, by removing the suspended particles or turbidity with the help of filtration, water quality can be significantly improved in terms of total phosphorus level (Palakkeel Veetil et al., 2017).

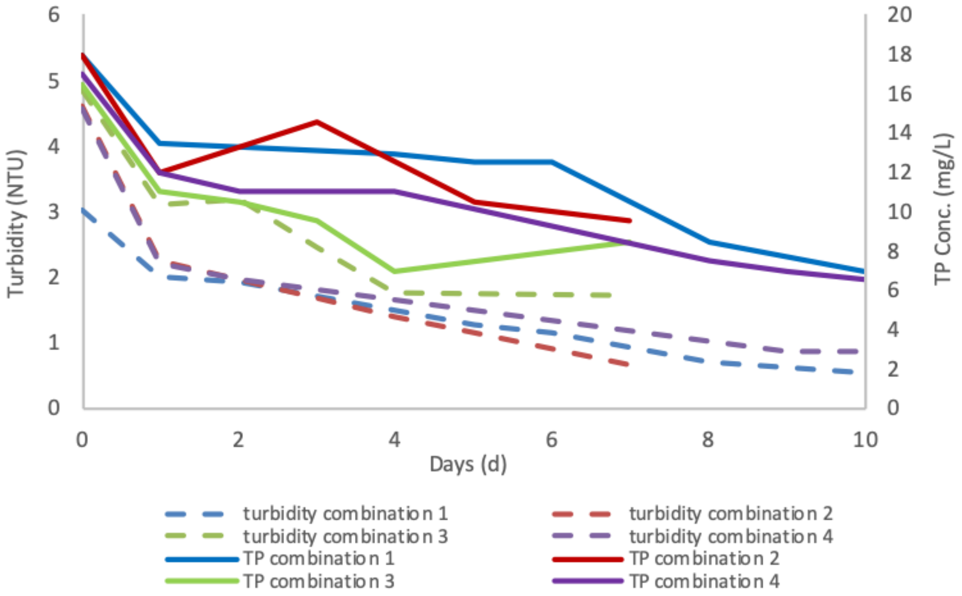

Figure 4-63 Removal of turbidity and total phosphorus over time

### 4.3.9 Comparison of geotextile combinations

Table 4-22 shows the removal rates obtained for different parameters in all experiments. As stated earlier, lake water sampling analysis and the results of onsite experiments showed that the concentration of total phosphorus was below the acceptable limit (0.03 mg/L) and thus TP concentration is not the main concern for this lake. However, the concentration of chlorophyll-a was very high, and the transparency of water was very low during the two monitored years. According to MELCC (2019a, 2019b), the transparency of 1 m characterized very turbid water and this value placed the trophic state of the lake in the eutrophic class. Also, the lake had the problem of algal blooms in the past. Therefore, microscopic algae are considered as the main issue for this lake which resulted in poor transparency in the water. Thus, by removing total suspended solids and turbidity the transparency of water and the overall water quality can be improved.

It should be noted that, although phosphorus is not the main concern in this lake, it is one of the main nutrients which promotes algal growth and eutrophication in the lakes. This filtration system was also successful in decreasing the TP concentration associated with particles by removing suspended solids (Table 4-22). As can be seen, the results obtained from all experiments conducted with different geotextile combinations were satisfactory. However, experiments in category 3 showed better results in terms of total suspended solids and turbidity removal which is the main focus in this lake. Also, the removal rate of COD (which its concentration was above the guidelines for all the experiments) obtained from combination 3 was higher as compared to the rest of combinations. The total phosphorus removal rate was also good for experiments in this category. Therefore, combination 3 which included two layers of 100 microns followed by two layers of 90 microns, and two layers of 70 microns could be the better geotextile combination.

Table 4-22 Removal rates obtained for different parameters for all the experiments

| **Experiments in** | **Removal rate** | | | |
|---|---|---|---|---|
| | **TSS ($g/m^2$-d)** | **TP ($mg/m^2$-d)** | **COD ($g/m^2$-d)** | **Chlorophyll-a ($mg/m^2$-d)** |
| **Category 1** | 3.5±2.1 | 7.6±2.1 | 7.4±2.8 | 7.1 |
| **Category 2** | 5.7±2.8 | 6.3±5 | 8±1.5 | 16.8 |
| **Category 3** | 8.3±1.6 | 11.6±1 | 9.8±1.2 | 11.1 |
| **Category 4** | 5.4±1.5 | 10.4±6.3 | 7.6±2.3 | 13 |

### 4.3.10 Potential implementation

According to the obtained results, the filtration system used in this study was successful in removing suspended solids, turbidity, and total phosphorus, thus improving the lake water quality. Furthermore, it did not have the problems associated with the common conventional filtration methods such as the sand filter technique. The latter method is difficult to operate and maintain, has higher maintenance costs, needs mechanical plants for backwashing, and requires chemicals for the coagulation, etc. However, none of these disadvantages is a matter of concern regarding the geotextile filtration unit used in this study. Also, it can be easily carried to wherever the water needs to be treated. Therefore, the geotextile filtration technique can be a potential method to improve the quality of surface water without exerting any environmental impact. However, some pilot tests need to be carried out to further evaluate this technique prior to full-scale implementation. This can be done by isolating a small portion of the lake and then performing the in-situ filtration. The results of pilot experiments can be used as guidelines for large scale implementation.

The following guidelines are provided to design the filtration unit for full-scale implementation based on this study:

In this research, the filtration system was used for the treatment of low turbidity water ranging from 0.7 to 5.7 NTU. Although the results of all experiments were satisfactory, experiments that were conducted using combination 3 (2*100 + 2*90 + 2*70 µm) showed higher removal rates. Therefore, if the turbidity of water is low and lies within the same range of this study, combination 3 can be selected as a filter media to treat the water. Also, considering that the filtration duration and number of units decrease as the size of the filtration unit increases, a larger-sized filtration system should be selected for treating the entire lake water. However, the size of the unit should not be so large so that it becomes difficult to carry it. Based on the volume of the contaminated water and the duration of filtration, the number and size of the filtration units can be calculated. In the following section, a sample calculation is presented for Lake Johanne.

According to the sampling results for two years, the turbidity of Lake Johanne varied in the range of 2.7 and 4.2 NTU. The filtration unit used in this study was 0.2 m in diameter and 0.25 m in height and the average filtration duration was 8 days. The results of experiments indicated that this filtration unit could successfully treat 0.3 $m^3$ of water with an initial turbidity ranging from 0.7 to 5.7 NTU in 8 days.

Lake water volume: 76300 $m^3$

Considering that 1 filtration unit can treat 0.3 $m^3$ of water in 8 days, this unit can treat 76300 $m^3$ of water in = $\frac{76300*8}{0.3}$ $m^3$ = 2034667 days

If the filtration is carried out in 4 months or 120 days (June to September) for the entire lake, the number of units required is $= \frac{2034667}{120} =$16956

Volume of 1 filtration unit = $\frac{\pi*0.2^2}{4}$ * 0.25 = 0.00785 $m^3$

So, the total volume of 16956 units is = (16956 * 0.00785) = 133.1 $m^3$

To avoid having a high number of filtration units for full scale implementation, larger sized filtration units should be used. Therefore, the diameter (d) of the larger filtration unit is assumed as 1.6 m.

Considering the ratio of diameter (d) to head (h) of the filtration unit which is $\frac{d}{h} = \frac{0.2}{0.25}$ = 0.8, the height (h) of the larger filtration unit is calculated: $h = \frac{d}{0.8} = \frac{1.6}{0.8} =$ 2 m

And, the volume of the larger filtration unit is = $\frac{\pi*1.6^2}{4}$ * 2 = 4 $m^3$

Thus, the required number of filtration units is = $\frac{133.1}{4}$ = 33

Therefore, having 33 filtration units with a 1.6 m diameter and a 2 m height each, the entire lake water can be treated in 120 days.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The results obtained from this study confirmed that Lake Johanne was in an advanced intermediate stage of eutrophication. According to the results, the concentration of chlorophyll-a was very high, which indicated that the microscopic algae in suspension was very high in the water. Also, the lake was exposed to algal blooms during the hot summer in the past. The transparency of the lake water was found poor even in some shallow areas with transparency value was less than 1 m. Based on the results mentioned above, microscopic algae are considered as the main concern for this lake which resulted in poor transparency in the water. Therefore, in order to prevent further degradation of the lake and protect the aquatic ecosystem, it is important to remediate the lake by removing suspended solids, including fine sediments, algae, etc.

To address this issue, a series of small-scale field experiments were conducted besides the lake using a filtration technique. Different combinations of custom-developed nonwoven geotextiles were tested as filter media in this study. Each combination included 5 or 6 layers of filters with different apparent opening sizes, i.e., 110, 100, 90, 75, 70, and 65 microns. A total of sixteen experiments were carried out with the objective of evaluating the effectiveness of filters in removing suspended solids and nutrients which promote the algal growth to improve the water quality of the lake. Experiments were classified into four categories with respect to the filter combination to evaluate the efficiency of each combination in removing suspended solids and nutrients.

The results obtained from experiments in all four categories were satisfactory. However, combination 3 which included two layers of 100 microns followed by two layers of 90 microns, and two layers of 70 microns showed better results in terms of suspended solids removal rate. Moreover, the results obtained from this combination demonstrated higher removal rate for COD which was the only component that its initial concentration exceeded the allowable limit for all experiments. The TP removal rate achieved using this filter combination was also good. According to the results, nonwoven geotextiles can work as an effective filter media to improve water quality by removing suspended solids, turbidity, phosphorus and chlorophyll-a. At the end of the experiments, there was a negligible amount of suspended solids in the water, and the water was clear enough to see the bottom of the tank.

Analyses of water samples collected from different stations of the lake showed that the concentrations of total phosphorus lied within the allowable limit to protect the aquatic life. The average concentration of total phosphorus in the lake water was 15.7 µg/L in 2017 and 11.5 µg/L in 2018. Therefore, total phosphorus concentration was not a matter of concern in this lake. However, it should be noted that this element is considered as the main limiting factor in algal growth and eutrophication. As results showed, this filtration technique was also successful in lowering the TP concentration by removing suspended particles from water. Considering that phosphorus mostly presents in its particulate form in overlaying water, removing suspended solids could reduce the concentration of this element and thus improve the quality of water. As observed for TSS, combination 3 also showed a higher removal rate for TP. This combination resulted in the removal rate of 8.3 g/m$^2$-d for TSS, 11.6 mg/m$^2$-d for TP, 9.8 g/m$^2$-d for COD and 11.1 mg/m$^2$-d chlorophyll-a.

As stated earlier, most of the phosphorus was in its particulate form and with the decrease of suspended solids concentration, the concentration of TP was also lowered. A good correlation was obtained between these two parameters, with a regression coefficient ranging from 0.71 to 0.86. Therefore, it can be concluded that phosphorus was mostly associated with suspended solids, such as algae, and by removal of these particles via filtration, significant water quality improvement can be achieved. Moreover, there was a very good correlation (0.89 to 0.97) between suspended solids and turbidity concentrations which meant that turbidity value reduced with the decrease in suspended solids concentration.

The results of particle size distribution indicated that filtration could successfully remove the large and fine suspended particles, and at the end of the experiments, there were no sand size particles in the water. Also, it was found that using multiple layers of filters that cover different pore sizes – from large to small respectively – removed particles more efficiently as they are able to trap a larger pool of particles of different sizes (larger than 110 microns to slightly below 65 microns).

In conclusion, these tests have indicated the potential use of geotextile filtration technique for removing suspended solids and nutrients associated with them that promote the growth of algae leading to eutrophication in the water. According to the results, the nonwoven geotextiles that were used in this study can work effectively as a filter media to improve the surface water quality. Combination 3 including 2 layers of 100 microns followed by two layers of 90 and two layers of 70 microns was found to be more effective filter combination as compared to the rest of the filter combinations used in this study for treating Lake Johanne. Overall, this filtration method can be considered as an alternative remediation technique for treating surface water without disturbing aquatic life and adding any chemicals or foreign materials to the lake. The simple design and flexibility of the filtration unit would make it an ideal restoration system for treating the lakes suffering from a high concentration of algal blooms and suspended solids. Furthermore, this floating filtration unit can be simply transported to any area where water is contaminated, and treatment is required. By developing this technique, it can be possible for eutrophic lakes to return to the clean and safe water bodies for public uses for recreational activities.

## 5.2 Recommendations for future work

The results obtained from this study indicated that the small-scale geotextile filtration system could successfully improve the water quality of Lake Johanne. Thus, for the next phase of the project, the in-situ use of geotextile filtration at large scale should be evaluated under real lake condition to improve the water quality. The results from the in-situ filtration experiments will provide realistic data which are needed for full-scale implementation. Another recommendation can be to target the source and test the filtration system where the water from the wetland enters the lake. Reuse of the used geotextile filters and finding the best place for implementing the full-scale unit are other issues that should be addressed in the next phase of the project.

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