Removal of nutrients and suspended solids from a eutrophic lake

Shrabani Sarma

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By: **Shrabani Sarma**

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Signed by the final examining committee:

______________________________ Chair
Dr. S. Samuel Li

______________________________ Examiner
Dr. Saifur Rahaman

______________________________ Examiner External (to program)
Dr. Govind Gopakumar

______________________________ Supervisor
Dr. Catherine Mulligan

Approved by

____
Chair of Department or Graduate Program Director

____
Dean of Faculty

Date

____

ABSTRACT

Removal of nutrients and suspended solids from a eutrophic lake

Shrabani Sarma

Eutrophication, the rapid growth of blue green algae in surface water, has become an environmental issue worldwide. In Canada, it has been also identified as one of the leading risks to surface water quality especially lake water quality. Lake Caron, an artificial lake, located in the municipality of Saint-Anne Des Lacs, Quebec, has been suffering from eutrophication due to high concentrations of nutrients and chlorophyll α since 2008. The objectives of the study are to evaluate the water quality parameters of a eutrophic lake, to treat eutrophic lake water samples by filtration using non-woven geotextiles and hence evaluate the effectiveness of non-woven geotextiles as a filter media, and assess the relationship among various water quality parameters. To achieve these objectives, water samples from the lake were analysed for two consecutive years. Further, a small scale field experiment was conducted beside the lake by using non-woven geotextiles as filter media. Custom made geotextiles of distinct apparent opening sizes and materials (TE-GTX300 – 110 µm, TE-GTN300 – 90 µm, TE-GTN350 – 90 µm and TE-GTN340 - 75 µm) were used in different combinations to find the best combination providing maximum efficiency in removing nutrients and suspended solids to achieve acceptable level within shorter period of time. Several combinations of geotextile filters were tried for different initial turbidity range of lake water. For an initial turbidity ranging from 4 to 9 NTU, filtration with the combination of 2 layers of 110 µm (TE-GTX300) followed by 3 layers of 90 µm (TE-GTN350) showed the best result at 7^{th} day of filtration, whereas filtration with a filter media consisting of 2 layers of 110 µm (TE-GTX300) and 3 layers of 75 µm (TE-GTN340) geotextiles had been found to restore the water quality at the 3^{rd} day of filtration for an initial turbidity ranging from 9 to 14 NTU. The combination of 1 layer of 110 µm (TE-GTX300) with 4 layers of 90 µm (TE-GTN300) showed the best result at 2^{nd} day during filtration for an initial turbidity higher than 14 NTU. For the first two category (4 to 9 NTU and 9 to 14 NTU) the removal efficiencies were 66, 100 and 96% for removing total P (TP), TSS and turbidity, respectively. For the remaining categories (14 to 19 NTU and higher than 19 NTU), the removal efficiencies were more than 90% for TP and turbidity and more than 96% efficiency had been found in case of TSS removal. TSS removal correlates with the reduction of turbidity, TP and COD concentration. Initial flow rates through

the filter decrease with increasing number of filter layers and decreasing pore size of the filter media. A higher TSS decreases the flow rate through the filter and increases clogging. Geotextiles as a filter media have shown potential for improvement of surface water quality in terms of nutrients, turbidity and TSS removal.

Acknowledgements

It was a great pleasure for me to work with all the amazing people in Department of Building, Civil and Environmental Engineering in Concordia University, Montreal, Quebec. I would like to thank my supervisor Dr. Catherine Mulligan for giving me the opportunity to conduct my Master's degree under her guidance and supervision. Her invaluable support, encouragement, motivation, and continuous guidance throughout the project made its successful completion. During this period, I learned a lot and I am fully confident that this knowledge will help me in future.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Surface water resources play an important role in everyday life. Quebec has an abundance of water, but the quality of the province water is decreasing (Water Management in Québec - Public Consultation Document, 2014). The water quality is mostly affected by urbanization, industrialization and intensification of agriculture. Water quality is mostly affected by human activities like: the use of fertilizers and pesticides, animal wastes, industrial waste which includes many toxic synthetic chemicals, municipal discharge, runoff, spills, deposition of airborne pollutants, septic tank discharge etc. Sometimes, nature itself is responsible for pollution, for example, constant erosion from rocks and lands, snow melt, organic matter degradation etc. Any harmful changes in physical, chemical and biological properties of water are known as water pollution. There are many elements both natural and manmade that can pollute lakes. They are organic and inorganic substances, nutrients, fine solids etc. Contaminants entering into a lake settle in bottom sediments and work as potential contaminant sources into overlaying water (Mulligan et al., 2001, Ritter et al., 2002). The main reason for eutrophication is the release of phosphorus and nutrients from the sediments (Inoue et al., 2009). It takes thousands of years for a lake to change naturally while human activities can transform the lake for better or worse in just a few years.

1.2 MOTIVATION

Lake Caron is referred to as eutrophic lake since 2008 and is restricted to use the water even for recreational purposes like swimming but not boating. Both natural and human activities play a significant role in deteriorating the lake water quality. Human activities like fertilizer, phosphate detergents and septic tank discharge from the nearby neighbourhood have been degrading the lake water quality. There is constant erosion from rocks and land that accumulate at the bottom of the lake. Also, another contributor of internal phosphorus loading is the runoff from the forested area and plant growth, death and decomposition inside the water. That's why, it becomes difficult to prevent eutrophication of Lake Caron.

For controlling internal phosphorus and nutrients release into water, several methods have been proposed and examined, like the use of chemicals – alum, calcite, lime (Chambers, 1990; Cooke et al., 1993), sediment dredging (Reddy et al., 2007) in situ capping etc. But all of them have their own limitations such as maintenance, cost factor, insufficient removal, constraints of particle sizes etc. So, it is necessary to identify some materials and techniques to treat small lakes that will not only be cost-effective but also be ecologically compatible.

Use of chemicals to treat polluted water has a major drawback, i.e., some chemicals can increase the toxicity of water like aluminium due to alum application. It is also essential to find out a way to use chemicals for water treatment which will treat the water properly without increasing the toxicity or metal concentrations.

Geotextiles can be used as filter media in filtration technique. It is a permeable material used in different man-made projects, structure or system, construction of roads, harbor works as an integral part of a geotechnical engineering work. It is made from synthetic fibers such as polyester, polyethylene and polypropylene (Rollin & Lombard, 1988). It is used in layers or strata separation, soil improvement, reinforcement, filtration and drainage (Franks et al., 2012, Quaranta & Tolikonda, 2011, Tota-Maharaj et al., 2012). Very limited work has been done to remediate surface water by using geotextiles as filter media. Removing nutrients from a eutrophic lake using geotextiles as filter media can be an effective technology.

1.3 OBJECTIVES OF THE CURRENT STUDY

The main objective of the study is to treat eutrophic lake water by reducing the nutrients and suspended particles. More specifically, the study will:

- Evaluate the water quality parameters of a eutrophic lake.

- Treat eutrophic lake water samples by filtration using non-woven geotextiles and hence evaluate the effectiveness of non-woven geotextiles as a filter media.
- Assess the relationship among various water quality parameters.

1.4 OUTLINE OF THE THESIS

This thesis includes five chapters. The background, motivation and objectives for this research work have been stated in the previous sections of Chapter 1.

Chapter 2 reviews previous literature work. The main topics in this chapter includes overall lake water quality in Quebec, water quality indices, causes of contamination, eutrophication, parameters influencing lake water, surface water treatment methods, etc.

Chapter 3 is the methodology. This chapter describes the lake description and morphology, sample collection and storage, equipment used and description of the analytical measurement.

Chapter 4 reports the results and discussion. The results and discussions from experiments meeting study objectives are described in this section.

Finally in Chapter 5, conclusions drawn from the analyses are included. Recommendations and suggestions for further work are also provided.

The references cited in this thesis are listed in the reference section.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

Lakes are not only a source of great natural beauty but also provide a wide range of practical benefits. Generally in Canada, most of the lakes are used as sources of water for the nearby cities and towns. The lakes are used for swimming and water sports. Some accommodate water transportation etc. These uses of lakes indicate the immense essentiality and importance of them in creating a pleasant and healthy environment for the cities and the people.

2.2 OVERALL LAKE WATER QUALITY IN QUEBEC

Quebec is the largest province of Canada with almost 17% of the total Canadian territory. The total area of the province is 1,667,000 km^2 (Regroupement des organismes de bassins versants du Québec, 2015). Quebec is mostly enclosed with water. The land is divided into three main geographical regions: the Canadian Shield, the St. Lawrence lowlands and the Appalachian Mountains. The Canadian Shield is the oldest mount range of the world and covers about 60% of the land mass. Quebec is a land of water as the province includes 430 major watersheds, more than half a million lakes and also 4500 rivers. Among the watersheds, 100 cover a catchment area of more than 4000 km^2 and 30 lakes have an area greater than 250 km^2. The St. Lawrence River links the Atlantic Ocean with the Great Lakes and it is the most important part of Quebec's hydrographical landscape (Regroupement des organismes de bassins versants du Québec, 2015)

There is an abundance of water in Quebec throughout its territory. This resource is linked to the annual rainfall which reaches over 750 mm each year and the ocean receives about eighty percent of this rainfall by hydrographic network. According to the MDDEP, only 0.5% of the annual gross volume of available water is collected in Quebec. Among the collected water, municipalities use 49%, manufacturing and mining and agricultural sectors account for 46% and 5% respectively (Water Management in Québec - Public Consultation Document, 2014).

Though Quebec has an abundance of water, the quality of the province water is decreasing (Water Management in Québec - Public Consultation Document, 2014). The water quality is mostly affected by urbanization, industrialization and intensification of agriculture. Water quality is mostly affected by human activities like: the use of fertilizers and pesticides, animal wastes, industrial waste which includes many toxic synthetic chemicals, municipal discharge, runoff, spills, deposition of airborne pollutants, septic tank discharge etc. Sometimes, nature itself is responsible for pollution, for example, constant erosion from rocks and lands, snow melt, organic matter degradation etc.

2.3 CAUSES OF CONTAMINATION

Lakes have very complex ecosystems. So for a pleasant and healthy environment for the nearby cities and for the people, it is very important to monitor the lakes regularly. Pollution is one of the major threats to the life of a lake. There are many elements both natural and man maid that can pollute lakes. It takes thousands of years for a lake to change naturally while human activities can transform the lake worse or better in just a few years. Storm water runoff, nutrients and fertilizer from agriculture areas, municipal and industrial wastewater, failing septic tank, urban development, land cleaning, runoff from construction projects and other recreational activities are some major causes for lake pollution (Jones, 2015).

2.4 EUTROPHICATION

Recently, eutrophication has become one of the biggest problems in water areas (Harper, 1992, Mulligan et al., 2011). Eutrophication is a natural process by which a lake or other water body becomes enriched in dissolved nutrients (nitrogen and phosphorus) that catalyst the aquatic plant growth. These aquatic plants increase organic sediments on the bottom of a lake. Over time, maybe centuries, this process makes the lake shallower.

Chemical pollutants containing nitrogen and phosphorus compounds accelerate eutrophication. The degradation of dead algae and other plant consumes most of the dissolved oxygen in the water. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disturbs the ecosystem, causing a variety of problems such as a lack of oxygen which is needed for fish to survive. The water becomes cloudy, and becomes colored in a shade of green, yellow, brown or red. Eutrophication conditions hamper drinking water treatment and also cause health problems. It also decreases the value of rivers, lakes and estuaries for fishing, hunting, recreation and aesthetic enjoyment (Eutrophication, 2016).

Eutrophication caused by elevated nutrient levels in ecosystems enhances the excessive growth of aquatic plants and thus increases the amount of phytoplankton per unit volume of water (Mccuen & Agouridis, 2007, Moslemizadeh, 2009). Eutrophication can be controlled by removing the nutrients from water. Molen et al. (1998) did an experiment in Lake Veluwe, the Netherlands. They found that eutrophication decreased by using filtration and removing dissolved solids.

In enclosed water areas, eutrophication is one of the biggest problems around the world. According to the World Health Organization (1999), 54% of lakes in the Asian Pacific Region are eutrophic. For Europe, Africa, North America and South America the proportions are 53%, 28%, 48% and 41% respectively (Inoue et al., 2009). Eutrophication is a naturally slow process but can be accelerated by human activities through nutrient inputs. These activities can be a direct source of phosphorus (e.g. sewage, fertilizer) or an indirect source (e.g. erosion without vegetation cover).

The assessment of the trophic status of a lake is measured by phosphorus concentration of the lake, its chlorophyll α concentration (an indicator of algal abundance) and transparency of water (measured by secchi disk). According to Figure 2.1, the chlorophyll α concentration increases proportionally with that of phosphorus and the water transparency decreases as a result of increased algae production. Figure 2.1 covers the set of values that are observed in Quebec lakes. The trophic status is classified into five zones: ultra-oligotrophic (very little phosphorus enriched), oligotrophic, mesotrophic, eutrophic and hyper-eutrophic (very high phosphorus enriched) and two transition zones: oligo-mesotrophic and meso-eutrophic between the main classes.

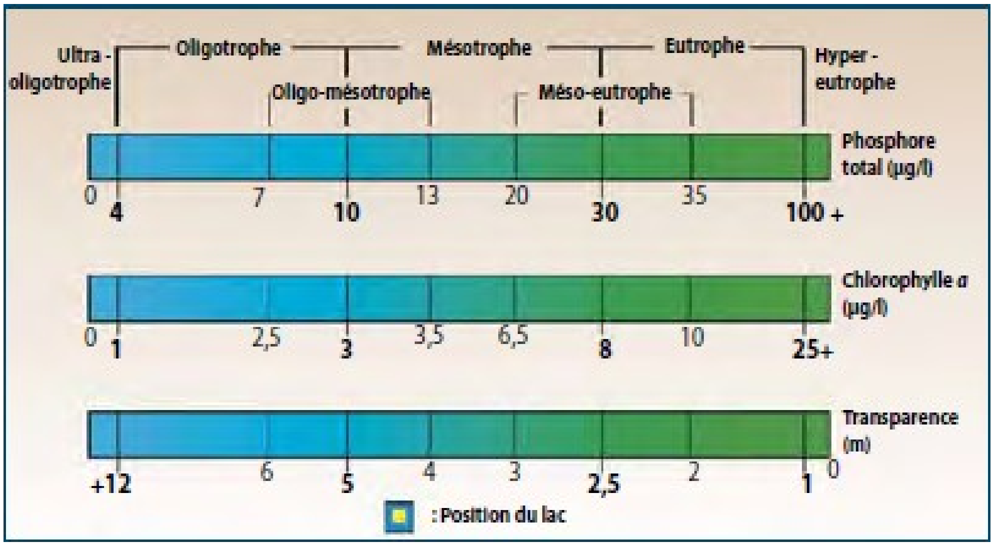


Figure 2.1 Chart of trophic level of lakes (Rivers and lakes, Ministère du développement durable, de l'Environnement, de la faune et des parcs, 2014)

Figure 2.2 shows the trophic classification of the 537 recreational lakes in Southern Quebec monitored from the results of Réseau de surveillance volontaire des lacs (RSVL) program during 2004-2009. According to Figure 2.2, 27% of lakes are in the categories between mesotrophic and meso-eutrophic. 3% of the lakes are in hypereutrophic conditions. 40% of the lakes are in oligo mesotrophic category. The results show a good indication of the trophic status of lakes in Quebec during the year from 2004-2009. Though the presence of organic matter in the water body is important for the cycle of ecosystems, but at the same time the unrestrained growth can be considered as contamination.

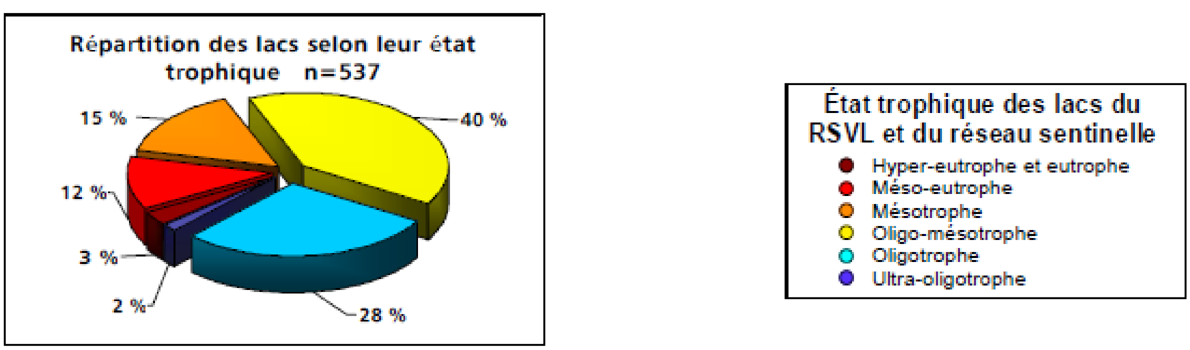


Figure 2.2 Trophic status of lakes in Quebec monitored by MDDEP from 2004 to 2009 (Rivers and lakes, Ministère du développement durable, de l'Environnement, de la faune et des parcs, 2014)

2.5 PARAMETERS INFLUENCING LAKE WATER QUALITY

2.5.1 Phosphorus

Phosphorus is an essential nutrient for aquatic plant and animal growth. For more than 50 years, researchers tried to find out the effects of abundance nutrients both phosphorus and nitrogen and the composition of lake phytoplankton (Barica et al., 1980; Fujimoto et al., 1997; Gerloff & Skoog, 1957; Gibson & Stevens, 1979; Xie et al., 2003). Excess amounts of phosphorus can cause significant problems to the lake including extreme algae blooms, low dissolved oxygen, and death of certain fish, invertebrates and other aquatic animals which change the lake to the eutrophication condition.

There are many sources of phosphorus including natural and human. For example, soil and rocks, runoff from fertilizer lawns and croplands, defective septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetland etc. Phosphorus in water exists in either particular phase or in dissolved phase. In lake water phosphorus is found in three different fractions: soluble reactive phosphorus, soluble organic phosphorus and particulate phosphorus (Selig et al., 2002). Particulate matter includes living and dead plankton, precipitates of phosphorus, phosphorus adsorbed to particulates and amorphous phosphorus while the dissolved phase consists of inorganic phosphorus, generally in the soluble orthophosphate form, organic phosphorus excreted by organisms and macromolecular colloidal phosphorus (Kathryn et al., 2014). Phosphorus usually exists as an inorganic orthophosphate molecule (PO_4^{3-}). Algae can take up this form of phosphorus directly. Soluble reactive phosphorus (SRP) is a measure of concentration of orthophosphate. If SRP increases, it means that phosphorus is either not needed by the algae or that is being supplied at rates faster than it can be taken up the algae. So, it can be used as an indicator of the degree pf phosphorus limitation of the algae (Carlson & Simpson, 2009). Dissolved phosphorus is one of the main reasons for freshwater eutrophication (Li & Recknagel, 2002). Aquatic plants immediately take this dissolved orthophosphate from water. But various research showed that other form of phosphorus can be hydrolyzed to the orthophosphate form (Pote & Daniel, 2000). Total phosphorus measures all the forms of phosphorus in the sample. So, researchers want to know the total concentration of phosphorus in water samples when determining the eutrophication of surface water due to phosphorus loading.

To measure total phosphorus the samples are digested in strong acids at high temperatures to oxidize the organic matter and release phosphorus as orthophosphate. Sometimes researchers used a combination of two strong acids. For example, Peters and Van Slyke (1932) used the combination of concentrated HNO_3 and H_2SO_4 and Robinson (1941) used perchloric acid digestion. But both of these methods are time consuming and dangerous (Pote & Daniel, 2000). Nowadays, for measuring total phosphorus, sulfuric acid-nitric acid digestion and persulfate digestion method are used. To measure dissolved phosphorus, the water samples are filtered through a 0.45 µm pore diameter membrane filter before starting the digestion procedure.

2.5.2 Total nitrogen

Nitrogen is one of the most ample elements on earth. It is essential to the life, growth and reproduction of all organisms. However, excessive amount of nitrogen input to the lake can be a reason for large phytoplankton and macrophyte production and the death and decay of these organisms decrease dissolved oxygen (Ferree & Shannon, 2001). Nitrogen exists in different inorganic and organic forms including nitrite (NO_2^-), nitrate (NO_3^-), and ammonium (NH_4^+).

Nitrate

Nitrates (NO_3^-) are a naturally occurring form of nitrogen that is crucial for plants. Excess amounts of nitrates can cause significant problems such as accelerated eutrophication along with phosphorus. This eutrophication affects dissolved oxygen, temperature and other indicators. Nitrate is immediately taken up by the algae.

Nitrite

Nitrite (NO_2^-), an inorganic nitrogen oxyanion form, is produced due to the deprotonation of nitrous acids. It occurs in groundwater either naturally or artificially. The main sources of nitrite to the water are pesticides through runoff water, sewage, mineral deposits etc. Like other forms of nitrogen, higher level of nitrite stimulates the growth of bacteria in a water body. Nitrite accumulates in metalimnion (rapid temperature change zone) and hypolimnion (cooler zone) of a eutrophic lake. Generally, the concentration of nitrite in a lake is small except for higher organic pollution in lake (Hebert, 2008).

Ammonium

Another important nutrient containing nitrogen is ammonium nitrogen (NH_4^+) for aquatic plants and algae. Ammonia (NH_3) transforms into ammonium in the presence of water. The sources of ammonium nitrogen in surface water are fertilizer containing ammonium sulfate $(NH_4)_2SO_4$ or ammonium nitrate (NH_4–NO_3) and agricultural runoff, sewage, industrial waste, decaying plant and animal matter present in soil or water etc. In oxygenated water of deep lakes, ammonium nitrogen concentration is low as either it is taken up by the aquatic plants or it converts into nitrate or nitrite quickly (Quirós, 2003). Lower levels of ammonium nitrogen concentration may act as limiting factors for plant and algal growth while plant and algal growth increases at higher levels of ammonium nitrogen due to the influence of nitrogen available as nutrients (Robyn et al., 2015).

2.5.3 Suspended solids

Suspended solids are the little solid particles present in suspension in water as colloids or due to the motion of water. It is one of the most important indicators for measuring the water quality. Basically, two types of materials are present in water based on their size. They are particulate and dissolved. All the particles that pass through a 0.45 μm filters are dissolved and the rest remaining on the filters are particulate suspended solids. The method of measuring suspended solids in water is so simple and economical that in the laboratory it is used on a regular basis (Glysson et al., 2000).

The valuable nutrients contained in the dead plankton organisms and their waste products accumulate in the sediments in most natural lakes, which are one of the most important factors in the biological productivity of lakes (Kleerekoper, 1952). But, human activities that leave soil exposed without vegetation for long periods, construction, land development, agriculture near the lakes, and farming steep slopes leave soils vulnerable to erosion and accelerate sedimentation. Nutrients, fertilizers, metals contained in runoff from agricultural fields and urban areas settle on the bottom of the lakes and the lakes become polluted and shallow day by day (Jones, 2015). Some components of this polluted soil dissolve in water. So, the amount of suspended solids increases while the water quality decreases. Eisma (1993) said these sediments play an important role in the distinctive characteristics of particulate and dissolved suspended solids.

Suspended solids can adsorb hazardous materials, heavy metals, polycyclic aromatic hydrocarbons, bacteria etc. (Fukue et al., 2006). The particles can contain some metals i.e., calcium, magnesium, sodium and also some soluble organic matter (Hemond & Fechner, 2014). So removing these suspended solids will also remove some heavy metals. Fukue et al. (2006) found a relation between COD and suspended solids. Therefore, by removing suspended solids can improve the water quality in terms of COD, heavy metals and nutrients. One of the leading techniques to remove suspended solids from water is filtration.

2.5.4 Blue-green algae or cyanobacteria

The scientific name of blue green algae is cyanobacteria. They can be present in all water bodies with low density. But, these microscopic bacteria can be problematic when they begin to produce cells rapidly. This phenomenon is known as water bloom. In Quebec, if the density of cyanobacteria (blue-green algae) in a water body is equal to or greater than 20,000 cells/ml, then it is considered to be affected by a bloom of blue green algae (MDDEP : Algues bleu-vert, 2015).

The extent to which cyanobacterial blooms occur across Canada has not yet been recognized but, they can bloom in the hot summer months. There are many natural and environmental factors that favor the growth of blue-green algae. One of the main factors that triggers the development of algal blooms is phosphorus. Phosphorus accumulated in the bottom of water bodies act as the food source for blue-green algae. Other physical factors that influence the blue-green algae proliferation are nitrogen, temperature, brightness and movement of water. Blooms have some negative effects like it destroys the ecological balance and also decreases the water quality. Some cyanobacteria have the potential to produce toxins that can be a risk to human health (i.e., some toxins can attack the lever or nervous system). The blue-green algae can affect water uses such as drinking water and swimming (Romanowska-Duda et al., 2002).

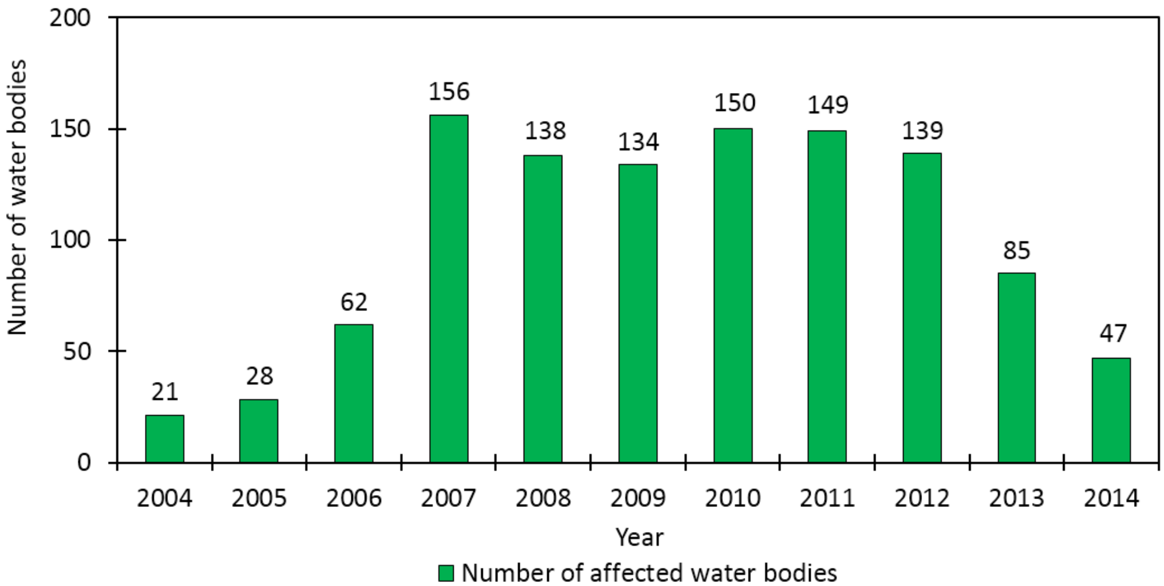


Figure 2.3 Number of water bodies affected during 2004-2014 in Quebec (data retrieved from MDDEP 2014, 2013, 2007-2012, 1999-2008)

Figure 2.3 represents the total number of water bodies in Quebec affected by blue green algae from the years 2004 to 2014. To plot this graph data was obtained from various reports published in different years by MDDEP (2009, 2013, 2014, and 2015). It is clearly shown that, from 2004, the number of water bodies affected by blue-green algae increases sharply. The number of water bodies affected by blue green algae reached its maximum value in the year 2007 (156 water bodies). Some reduction was found in the year 2008 (138), but after that the number again increased. The annual number of affected water bodies became relatively stable during 2010 to

2012 (i.e. ranged from 150 to 139). It has been found that the number of affected water bodies decreased significantly since 2012 (MDDEP 2014, 2015).

From 2007, the number of newly affected water bodies in Quebec in each year has decreased. In 2007, the highest number of water bodies was affected (70%). But, in 2008, the number decreased from 70% to 41% and after that the number decreased each year with the exception of the years 2009 and 2012. In 2013 and 2014, the numbers of newly affected water bodies were 24% and 39% respectively. Figure 2.4 shows the number of newly affected water bodies in Quebec from 2007 to 2014.

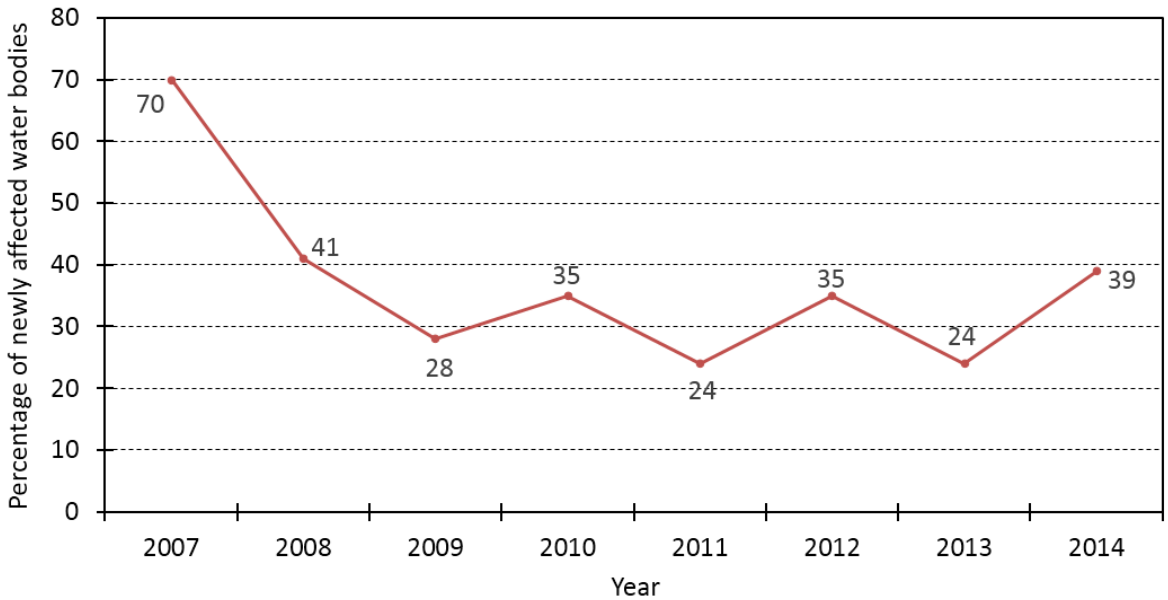


Figure 2.4 Percentage of newly affected water bodies from 2007-2014 (data retrieved from MDDEP 2014)

From the results of another analysis, it is clearly observed that most of the water bodies are affected once in a year. But, there are a large number of water bodies which were affected two of more times in a year. Even, some water bodies were affected six times in a year. Because, these water bodies are linked with vulnerable rivers which is the main reason for the proliferation of blue-green algae several times in a year (MDDEP, 2009).

Since 2007, the CEAEQ found that the presence of 42 genera of cyanobacteria affected water bodies among which 23 are potentially toxic. The most common types are *Anabeana sp.,* *Aphanizomenon sp., Microcystis sp.* and *Woronichinia sp*. These four types are generally 48 to 68% of the total abundance of cyanobacteria (MDDEP, 2013).

Large algal blooms were mostly seen in the months of June, July and August (81% of the total blooms occurred in these three months). In 2013, large algal blooms (≥ 100,000 cells/ml cyanobacteria) were seen in at least 71% of the affected water bodies. About 60% of the affected water bodies undergo multiple blooms in a year (MDDEP, 2013, 2014).

Cyanotoxin

The cells of blue green cyanobacteria produce some toxins named cyanotoxins. Recently, the presence of cyanobacteria has become a threat to aquatic life due to the potential toxic formation and release. Cyanotoxins have undesirable impacts both acute and chronic effects on health. The acute effects include gastrointestinal, neurotoxic, skin irritation etc. and liver damage, kidney damage, carcinogenic are some chronic effects shown by cyanotoxins (Knappe, 2004; Miao et al., 2010).

Cyanotoxins can be divided into five categories based on their different chemical structures and mechanism of toxicity. Cyanotoxins are classified as cyclic peptides, alkaloids and lipopolysaccharides in terms of chemical structure and hepatoxins (toxins that affect the liver), neurotoxins (toxins that affect the nervous system), cytotoxins (i.e. toxins that affect the kidney and liver) and dermatotoxins (toxins that affect the skin) in terms of mechanisms of toxicity. In the world`s freshwater sources hepatotoxic microcystins have been detected most frequently among all cyanotoxins (Knappe, 2004).

Cyanotoxins may exist in two forms: intracellular and extracellular (dissolved). If the cells contain the toxins, physical removal is the best way to remove them. But, if the toxins are released from the cells, the removal becomes very complicated and additional treatment is required. Filtration does not perform well for removal of dissolved toxins.

2.6 CRITERIA FOR SURFACE WATER QUALITY FOR AQUATIC LIFE

Aquatic organisms live in water for all or for a part of their lifetime. Microorganisms, plants, invertebrates and vertebrates are four major groups of aquatic organisms (RAMP, 2014). Though their biological characteristics, habitat and adaptation are different from each other, all of them are connected within a complex network of ecological roles and relationships. To protect human health and aquatic life, water quality standards have been developed. Water quality criteria is the numeral concentration or narrative statement recommended to protect and maintain the designated uses of water body (Chapman & Kimstach, 1996). These uses include aquatic life, agriculture i.e., livestock watering and irrigation, recreation and aesthetics etc. Numeric criteria means the maximum pollutant concentration levels permitted in a water body and narrative criteria describes the desired conditions of a water body being "free from" certain negative conditions (Environment and Climate Change Canada, 2015). These criteria should be maintained by the states, territories and community in order to protect human health and aquatic life. Acceptable limits for different water quality parameters for surface water have been listed in Table 2.1. These standards have been recommended by Ministère du Développement durable, de l'Environnment de la Faune et des Parcs (MDDEFP), Ministère de Développement durable, Environnement et Parcs (MDDEP), Canadian Council of Ministers of the Environment (CCME), Environment and Climate change Canada and World Health Organization (WHO).

Table 2.1 Criteria for surface water quality for surface water

Parameter	**Acceptable limit**	**Suggested by/ Reference**
Turbidity (NTU)	<10	Environment and Climate change Canada, 2015
Total suspended solids (mg/L)	<25	MDDEP, 2009
pH	6.5-9	MDDEP, 2009
Dissolved oxygen (mg/L)	>5.5	CCME, 1999
Total Phosphorus (mg/L)	<0.03	MDDEP, 2009
Chemical Oxygen Demand (mg/L)	<20	WHO (Chapman, & Kimstach, 1996)
Total nitrogen (mg/L)	<1.00	Environment Canada, 2014
Nitrates (mg/L)	<2.9	CCME, 2003; MDDEFP, 2013; CCME, 2012
Chlorophyll α (µg/L)	<8	MDDEP, 2009
Oxidation-Redox potential, mV	300-500	WHO (Chapman & World Health Organization, 1996)

(a) Turbidity

In Quebec, the standard for turbidity for surface water is different for different water conditions. To protect aquatic life in surface water during dry weather, increase of 2 NTU (long term) is maximum when there is clear water flow at background level. But, a maximum increase of 8 NTU is allowed for back ground level between 8-80 NTU or a 10% increase is allowed if the background level exceeds 80 NTU during rain and snow. For the protection of recreational uses and aesthetics, when the background level is below 50 NTU maximum increase of 5 NTU is allowed (MDDEP, 2009). But, from the report, water quality guidelines used by Quebec prepared by Environment and Climate Change, Canada (2015), it is found that, the maximum allowable turbidity value for surface water is 10 NTU.

(b) Total suspended solids

MDDEP (2009) suggested that in clear water, the concentration of total suspended solids should not exceed 25 mg/L. However, a maximum increase of 5 mg/L is accepted over background level to protect aquatic organisms.

(c) pH

From Quebec surface water criteria suggested by MDDEP (2009), it is found that the pH value of surface water should be in the range of 6.5 to 9 to protect the aquatic life.

(d) Dissolved oxygen

To keep aquatic life safe, the minimum dissolved oxygen level in surface water is 5.5 mg/L as suggested by Canadian Aquatic Quality Guidelines (CCME, 1999).

(e) Total phosphorus

Generally, the total phosphorus concentration of a eutrophic lake water is within the range of 0.03 to 0.1 mg/L according to MDDEP (2009) trophic status classification. So, total phosphorus concentration of a water body should be lower than 0.03 mg/L in order to reduce algal growth and eutrophication.

(f) Chemical Oxygen Demand

There is no specific criterion for chemical oxygen demand (COD) to protect aquatic life in surface water in Quebec and Canada. But, World Health Organization (WHO) has been observed that the concentrations of COD in surface water range from 20 mg/L or less in unpolluted waters to greater than 200 mg/L in waters receiving effluents (Chapman. & Kimstach, 1996).

(g) Total nitrogen

Like chemical oxygen demand, for total nitrogen concentration, there is no specific standard for trophic status classification or protecting surface water quality in Quebec. However, Environment Canada (2014) suggested that the total nitrogen concentration in surface water should be lower than 1 mg/L.

(h) Nitrates

In Quebec, the standard for nitrate concentration for protecting aquatic life is 2.9 mg/L as suggested by CCME (2012) and MDDEFP (2013).

(i) Chlorophyll α

From the trophic status classification by MDDEP, the range of chlorophyll α concentration for a eutrophic lake is from 8 to 25 μg/L. So, the chlorophyll α concentration of lake water should be lower than 8 μg/L in order to improve the trophic status of a lake from eutrophic to mesotrophic (MDDEP, 2009).

(j) Oxidation Redox potential

Oxidation redox potential is an important water quality parameter to regulate the oxidized or reduced state of water bodies. Oxidation redox potential value lower than 200 mV indicates a reduced state of water bodies. In general, water bodies with an oxidation redox potential value of 300-500 mV are considered in good condition (Chapman & World Health Organization, 1996).

2.7 SURFACE WATER TREATMENT

The demand for clean water is increasing rapidly followed by the reduction of sources of clean water resulting from the fast population growth, industrialisation, less rainfall, and long-term droughts over the world (Chong et al., 2010). With this growing demand, scientists and researchers are trying to develop different practical strategies and solutions to yield more usable water resources. Water treatment methods developed in the early twentieth century. However, the in situ treatment for the remediation of lakes or surface water is limited. Adding chemicals lime (Chambers, 1990; Cooke et al., 1993), sediment dredging (Reddy et al., 2007), in situ capping etc. are some methods applied in many lakes to improve the water quality.

To limit the release of phosphorus from sediments, usually alum is added to a eutrophic lake (Berkowitz et al., 2006). Alum is added to the water to form an aluminium hydroxide floc that removes water column phosphorus and builds a reactive barrier that limits PO_4-P release from sediment (Berkowitz et al., 2006; Cooke et al., 2013; Rydin et al., 2000). It is found that the reduction of internal phosphorus loading can be achieved up to 54-83% and last for more than 10 years (Berkowitz et al., 2006; Rydin & Welch, 1999; Welch & Cooke, 1999). However, aluminium based water treatment residual can be used to remove phosphorus effectively in engineered wetlands. It carries the aid of reuse of a by-product that promotes sustainability (Babatunde et al., 2009).

Galvez-Cloutier et al. (2012) applied different restoration techniques to restore a eutrophic lake in Quebec named Lake Saint-Augustin. The objective of that study were to determine the effectiveness of alum and/or calcite application on improving the water quality especially by the removal of phosphorus, evaluate the possible formation of precipitates and their solubility added in water and also determine the potential adverse effects of adding chemicals on the lake ecology. As a part of the study, a floating platform able to test different treatment conditions was installed inside the lake. The results showed about 76-95% of total phosphorus was decreased by ‘alum + calcite’ while, only 59-84% was decreased by calcite only. Applying both alum and calcite, chlorophyll α concentrations were decreased by 19-78% and the secchi depth was 106% greater.

Though the lake water quality has been improved by using alum and calcite both, it was observed that the total phosphorus were still higher than the critical limit of 20 µg/L.

Some researchers tried to figure out the performance of potassium ferrate as a coagulant for drinking water and wastewater treatment. Potassium ferrate works better than ferric sulphate for colored water treatment due to its dual function chemical ability i.e., oxidant and coagulant (Jiang et al., 2001). In another study, the same researchers found that potassium ferrate can disinfect Escherichia coliform (*E.coli*) at a very low dose in drinking water. In wastewater, it reduces more COD than alum or ferric sulfate at a similar dose, produces less sludge volume and removes more pollutants (Jiang et al., 2006). Moreover, algae removal efficiency increases remarkably when the water was pretreated with potassium ferrate (Ma & Liu, 2002).

The best way to purify blue green algae affected water is to remove the blue green algae intact without breaking any cells because the broken cells can release cyanotoxins. As discussed in section 2.13.3, cyanotoxins have undesirable impacts both acute and chronic on health. An experiment was carried out at a surface water treatment plant with several treatment process like coagulation, clarification, sand filtration, ozonation, slow sand filtration and chlorination to remove the cyanobacteria, hepatotoxins produced by cyanobacteria, microcystins, phytoplankton, heterotrophic bacteria and endotoxins (Rapala et al., 2006). The results showed using coagulation-sand filtration reduced 1.2-2.4 and endotoxins by 0.72-2.0 log_{10} units and ozonation removed the residual microcystins effectively. Phytoplankton biomass and heterotrophic bacteria were reduced by 2.2-4.6 and 2.0-5.0 log_{10} units respectively. According to the authors, use of these treatment processes can effectively remove hepatotoxins, lipopolysaccharide endotoxin, large cyanobacterial and phytoplankton cells and heterotrophic bacteria. The critical point for removing microcrystins is to apply proper ozonation.

In laboratory cultures, it has been found that hydrogen peroxide (H_2O_2) can reduce cyanobacteria. However, to find out the effects of hydrogen peroxide for removal of cyanobacteria from wastewater, experiments were carried out at both the mesocosm and full-scale levels (Barrington et al., 2011). It was found that, a concentration of $1.1x10^{-4}$ g H_2O_2/µg chl-α is enough for a 32% decrease in cyanobacterial concentration after 24 h in laboratory scale experiment. Then, the same concentration of hydrogen peroxide is applied to a wastewater stabilization pond and found that cyanobacterial biomass was reduced by 57% and total phytoplankton biomass by 70% within 48 hours of H_2O_2 addition. According to Barrington et al. (2011), the synergistic effect of H_2O_2 addition with environmental factors can effectively increase the cyanobacterial removal compared with laboratory experiments.

A sequential treatment including dissolved air flotation (preceded by coagulation/flocculation) and microfiltration technologies was applied to find out the effects of removal of cyanobacteria (Aparecida et al., 2013). The combined process was used to find out the effects of DAF process as a pre-treatment for microfiltration to mitigate the impact on the microfiltration performance caused by the presence of the cells. For the coagulation and flocculation process 40mg/L of aluminium sulphate as a dose and polyvinylidene fluoride membrane (0.3µm) with 1 bar of pressure were used. The results showed that the combination of DAF and MF technologies can be a better option for cyanobacterial cell treatment.

Another research was carried out in a small full-scale plant at Saint-Caprais reservoir, France using pre-ozonation and powdered activated carbon both (Maatouk et al., 2002). The results showed that total removal of cyanobacterial cells and the low concentration of toxins was achieved by the combined action of pre-ozonation at 0.07 mg/l and adsorption on powdered activated carbon at 20mg/l. But, pre-chlorination at 0.42 mg/l with 20 mg/l of powdered activated carbon can remove only 45% of toxins.

The adsorptive removal of microcrystins from lake water was studied using molecularly imprinted polymer adsorbent (Krupadam et al., 2012). Molecularly imprinted polymer was synthesized from itaconic acid as a functional monomer and ethylene glycol dimethacrylate as a cross linking monomer. The result showed about 60% and 70% more removal efficiency by using a molecularly imprinted polymer than commercially used powdered activated carbon and resin XAD respectively.

2.7.1 Physical separation

Filtration is a physical-mechanical separation widely used in water treatment. In filtration, two or more compounds from a fluid stream are separated based on size difference (Cheryan, 1998). In mechanical separation, particles are removed either by gravity, by screening or by adhesion. Among them, gravity separation is the oldest and most widely used process in water treatment (Crittenden et al., 2012). Basically, gravity separation represents sedimentation, the process where water is allowed to stay for long enough time in a basin or tank so that the particles in the water sample settle to the bottom of the basin or tank. This process is simple, inexpensive and it consumes less energy. But the proper design of sedimentation basin is the major challenge as the performance of the process depends on it. A baffle equipped tank enhances the settling of solids more than a standard tank by directing them towards the bottom of the tank with high velocity (Goula et al., 2008).

Filtration is one of the major techniques used for water treatment along the world. Filtration is the mechanical or physical operation used for the separation of solids from liquids. The four driving forces, i.e., gravitational, vacuum, pressure and centrifugal help the liquid to pass through the filter media leaving the solids on the filter. Based on these criteria, various filter technologies, designs, continuous or batch processes etc. have been made (Perlmutter, 2015; Rushton et al., 2008). Filtration can remove algae cells effectively. But the main problem of using filtration is that it gets clogged rapidly by algae cells. So, the process alone cannot be effective for algae removal. However, the combined process of filtration along with coagulation and clarification will be more effective for algal removal and the clogging problem will be decreased (Knappe, 2004).

2.7.1.1 Filtration methodology

The filters retain all the suspended particles present in the fluid and allow the fluid to pass through its pores. There are several factors that affect the filtration process. They are filter opening size, grain size and shape, chemical properties of water and other particles, filtration velocity etc. Filtration flux reduces when these suspended particles block inside or top of the filters. Generally there are four mechanistic models for fouling (Grenier et al., 2008).

- Complete blocking - The pores of the filters are completely sealed. Therefore there is no flow through them and also reduction of flow area.
- Intermediate blocking - The pores of the filters are partially sealed and the rests are deposited on the top of them.
- Cake filtration - Particles accumulate at the surface in a permeable cake of increasing thickness which adds a hydraulic resistance to filtration.
- Standard blocking - Suspended particles accumulate on the pore of the filters which reduces the permeability of the filters.

2.7.1.2 Classification of filtration

Depth filtration and surface filtration are the main two categories of filtration. Different types of filtration techniques are used for different water quality purposes, i.e., purification, desalination, ion separation in drinking water treatment, medical or pharmaceutical purposes, chemical and food processing technologies. Among all the filtration technology, membrane filtration is able to separate gas mixtures or dissolved solutes in liquid streams. The membrane acts as a selective barrier. Hydraulic pressure enhances the transport process in membrane filtration system. The basic approach of filtration is:

- Microfiltration – it can separate the particles in the micron range (from 0.1 μm to 5 μm range) (Cheryan, 1998). As it separates suspended particles from dissolved substances, microfiltration is used as a clarification technique. It can remove major pathogens or large bacteria. The membrane used in this filtration is symmetric (Schafer, 2001).
- Ultrafiltration – Particles ranges from 0.001 μm to 0.02 μm are retained in ultrafiltration. It is used in purifying, concentrating and fractionating macromolecules or fine colloidal suspensions (Cheryan, 1998). Due to their small sizes, the membrane used in ultrafiltration is asymmetric (Schafer, 2001).

  Nano filtration – This process is relatively new compared to other techniques to separate low molecular weight organics and multivalent salts from monovalent salts and water. This is a crossflow, pressure driven process deals with dissolved materials in liquid (Yacubowicz & Yacubowicz, 2005).

- Reserve osmosis – Reverse osmosis is acknowledged as a dewatering technique as it retains all components other than water (solvent) itself. The process is used in wastewater purification, dialysis and food industry (Pierzynski et al., 2005).
- Desalination – In this process, salts and other minerals from water have been removed. Thermal and membrane separation are two types of desalination processes. Evaporation followed by condensation of the formed water vapor and freezing followed by melting of the formed water ice crystals are two categories of thermal desalination separation process. Reverse osmosis is the main membrane desalination process (El-Dessouky & Ettouney, 2002).

The use of coagulants is very common in the water treatment industry. Chemicals are used to remove harmful substances and bacteria from the water. But, chemicals that are used to treat the water also leave some by-products in the water. For example, the use of disinfectants can turn the water toxic causing health problems, high levels of exposure of some chemicals (hydrogen peroxide) can be carcinogenic etc. So, some scientists are working to develop some technologies to treat the water without using any chemicals.

In Quebec, MDDEP (2013) confirmed severe algal blooms in six water bodies. Lake Caron is one of them where 1540 µg/l microsystin-LR toxicity has been found. Lake Caron, located in the Laurentians region, is a shallow, artificial, phosphorus enriched lake that has undergone eutrophication. There were massive algal blooms in the lake in 2008 and 2012. Since 2008, the inhabitants around the lake were prohibited by MDDEP from using the lake water even for recreational purposes. Several techniques have been applied to restore Lake Caron. As a part of this lake restoration, Dr. Catherine Mulligan and her team conducted (Mulligan et al., 2013) a laboratory study using filtration technique with Lake Caron water samples. The main objective of this study was not only assessing the effectiveness of non-oven geotextiles to reduce the nutrients (phosphorus and nitrogen) concentration but also improving the lake water quality. The experiments were carried out with two different apparent opening sizes geotextiles. Clean sediments were assimilated onto the filters so that these sediments may act as adsorbents materials for nutrients and will increase the treatment efficiency. From the test it was found that the total P was reduced from 40 µg/L to 10 µg/L by filtration and for protecting aquatic life in Quebec surface waters, this is the safest level of P. The overall removal efficiency by filters is for TP 62.5-75%, for turbidity 77-85% and for total nitrogen 37-52%. According to Mulligan et al. (2013), it could be a potential alternative remediation technique for improving the water quality of eutrophic shallow lakes without using chemicals or creating any environmental impact.

Suspended solids (SS) adsorbed most of the pollutants, nutrients, organic compounds, bacteria. In order to control the elements in the propagation of eutrophication in water bodies and algal blooms, it is necessary to remove P along with the SS. Another experiment was carried out by Mulligan et al. (2011) with the aim to improve water quality by removing suspended solids (SS) and phosphorus (Mulligan et al., 2011) by using the filtration technique. The experiment was conducted on a pilot scale set up at Lac Caron by filtration tests with a non-woven geotextiles as filter medium. It was found that, a nonwoven geotextiles with apparent opening size 150 μm and 0.3 cm was effective to remove 61% and 41% of SS concentration and phosphorus respectively. Filtration using non oven geotextiles could be a useful potential alternative remediation technique for improving surface water quality.

For water treatment, Coveney et al. (2002) tried a wetland filtration technique to reduce the level of nutrients, phytoplankton, cyanobacteria etc. For example, a pilot scale wetland was constructed to reduce high levels of nutrients, phytoplankton and suspended matter from a hypereutrophic lake in Florida, USA (Coveney et al., 2002). Lake water was recirculated for 29 months. The results showed that about more than 90% particulate matter was removed and the level of nutrients was low in the lake water. Based on the pilot scale results, the first phase improved wetland filter has been constructed.

Another experiment was carried out to investigate the influence of chemical feed characteristics on nano filtration performance for cyanotoxins removal (Teixeira & Rosa, 2006). And the results found that almost all cyanotoxins have been completely removed using nano filtration. A nano filtration membrane barrier can be an effective barrier against cyanotoxins.

2.7.1.3 Geotextiles

A permeable textile named as a geotextile is used in different man-made projects, structure or system, construction of roads, harbor works as an integral part of geotechnical engineering work. It is made from synthetic fibers such as polyester, poly-ethylene and polypropylene (Rollin & Lombard, 1988). Geotextiles have been broadly used in geotechnical and geo-environmental work in the past 30 years as drainage and filter materials (Palmeira & Gardoni, 2002). Over the past few years, geotextiles have replaced the graded granular filters successfully and become a highly effective filter in various applications. The main reasons for becoming successful over graded granular filters are the use of lower quality drainage aggregate and smaller sized drains, no collector pipes, small risk of aggregate contamination and segregation, reduced excavation and less amount of wasted materials, etc. (Christopher & Fischer, 1992). Generally geotextiles are classified as knitted, woven and non-woven (Rollin & Lombard, 1988).

- Knitted – it is developed by lateral interlacement of parallel yarns and the mesh size are free within a wide range (Ingold, 2013).
- Woven – have a noticeable geometrical shape pattern and significant opening sizes.
- Non-woven – don’t have visible pattern like woven geomembranes (Koerner, 2012). It is developed by randomly placed fabric strings or threads.

The pore size of geotextiles should be lower than the particles in order to retain them and the textiles should be permeable enough to pass through the water through it (Luettich et al., 1992). Generally the materials used for making non-woven geotextiles are very permeable and compressible. So, not only the thickness of geotextile but also the coefficient of permeability and pore dimensions reduce under stress (Palmeira & Gardoni, 2002).

The maximum acceptable water head loss in the geotextile may correspond to the clogging criterion. Basically, clogging of a non-woven geotextiles depends on various parameters, like variation of water head loss along with retained particles quantity with time, dispersed particles quantity, soil granulometry, geotextile porometry and water flow (Faure et al., 2006). According to Faure et al. (2006), geotextiles clogging by fine particles in suspension in water can be predicted by the use of an empirical model that describes the increase of head loss in the geotextile due to clogging.

Water with fine particles can flow through a pipe net structure of a geotextiles. When there is no clogging, the total water flow rate circulating through the filter is the sum of the different flow rates in each pipe. But, particles in suspension continuously settle in each pipe, leading to an accumulation and filter head losses increase faster. Finally the pipes have been blocked completely and the geotextiles are clogged (Faure et al., 2006).

2.8 PROBLEMS OF LAKE CARON

During summer 2007, the people around the lake observed that the lake water became cloudy with shades of green, yellow and brown. There was a large blue green algae bloom and high suspended solids concentrations that reduced the transparency of the water. The water smelt very bad and some aquatic plants were floating on the surface of the water in the shallow part of the lakes (Zaghtiti, 2013). After primary visual observation MDDEP (ministère du Développement durable, de l'Environnement) did all the laboratory analysis (Rivers and lakes; Ministère du développement durable, de l'Environnement, de la faune et des parcs.). They found that the lake was in hyper eutrophication state due to the high concentration of nutrients (phosphorus) and chlorophyll α. So, they put a restriction on the use of lake water not only for drinking purposes but also for recreational activities. Since 2008 to 2015, the lake was under this restriction due to eutrophication. According to several reports published by MDDEP (2013), algal bloom had been observed for the last couple of years in this lake. So, Lake Caron was selected for this study.

2.9 SUMMARY

There are various techniques applicable to treat a eutrophic lake. Most of them require the involvement of large operations and construction designs. However, they are expensive also. As mentioned in the previous sections, pollutants containing phosphorus, and nitrogen compounds accelerate eutrophication. When the growth of algae and other plant life is over stimulated, they quickly consume most of the dissolved oxygen in the water. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disturbs the ecosystem, causing a variety of problems such as a lack of oxygen which is needed for fish to survive. In situ filtration is the simplest, cheap and reliable technology for treating the surface water. The treatment cost of water of a lake can be minimized by applying in situ filtration technology. Therefore this method needed to be investigated further.

Chapter 3

METHODOLOGY

This chapter consists of the location, physical parameters of Lake Caron, methodology and the experimental procedures followed in this study. This chapter also contains a detailed description of the sample collection and preservation, equipment used, and procedures of different water parameter measurements.

3.1 LAKE DESCRIPTION AND MORPHOLOGY

Lake Caron is located about 75 km north of downtown Montreal in the municipality of Saint-Anne Des Lacs, Quebec in the Laurentian Mountains. The geographical coordinates of the lake are 74°08'50" O and 45°50'28" N.

Lac Caron is an artificial lake. It is a shallow pond collected rain water and snow melt which are the only sources of water of this lake. According to Environment Canada (2008), the annual precipitation is approximately 1000 mm and the snow depth reaches up to 226.9 cm. The lake starts to freeze by the end of October until May when the snow starts to melt.

In the 1960's, the Ste-Anne Des Lacs municipality increased the surface area of the pond and considered it as a lake. According to CRE Laurentides (Lac Caron, 2013), the surface area and volume of the lake is approximately 35,300 m^2 and 48,400 m^3 respectively. The maximum depth is 2.6 m and the average depth is 1.4 m in most parts of the lake and 0.5 m in the shallow parts. The altitude of the lake is 333 m. The renewal time of the lake is about 0.86 years and the drainage ratio is 2.79.

Though, most of the parts of the lake is surrounded by wild trees, there are some private properties around the lake shore. During the summer time, there are some food growing activities around the lake by the house owners.

Lake Caron is an artificial and closed water body. The only water source is natural precipitation and the surface runoff from the surrounding area. During summer, infiltration and evaporation are the two prime natural phenomena of water discharge from the lake. At some points, the height of the lake walls are lower than usual so that if the water level in the lake exceeds a certain level, then the additional water can flow out through those points (Zaghtiti, 2013). Figure 3.1 and Figure 3.2 show the map and photo of Lake Caron respectively.

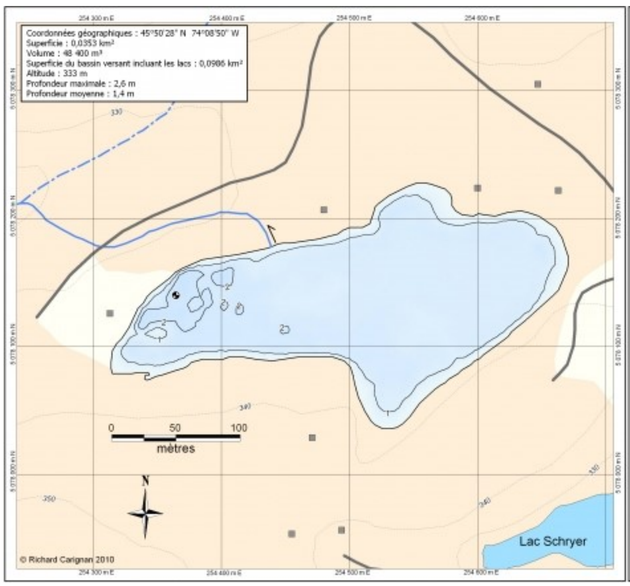


Figure 3.1 Map of Lake Caron (Lac Caron, 2013)

Figure 3.2 Photo of Lake Caron

3.2 SAMPLE COLLECTION AND STORAGE

Water samples were collected during the summer and fall in 2014 and summer 2015 (from June 2014 to September 2014 and from June 2015 to August 2015) when the lake water quality showed the worst condition with highest amounts of blue green algae blooms. To analyze the whole lake water quality, the lake was divided into 8 stations (shown in Figure 3.3) from the shallow parts. Samples were collected from the eight stations using 50 ml glass tubes for chemical tests, 1L brown bottles for measuring the suspended solids and for particle size analysis. For each sampling, some in-situ experiments were performed on the lake (i.e. turbidity, water pH, water temperature, dissolved oxygen, oxidation reduction potential etc.). For the filtration test using geotextiles, the setup was installed beside the lake. The location of filtration experiment was indicated in Figure 3.3.

After sampling and experiments, the samples were kept in a cooler to preserve the sample conditions or avoid sun light interactions, as they may incite any chemical or biological reactions. Then, the samples were transferred into the Concordia University's laboratory's incubator at a temperature of 4^0C before further use.

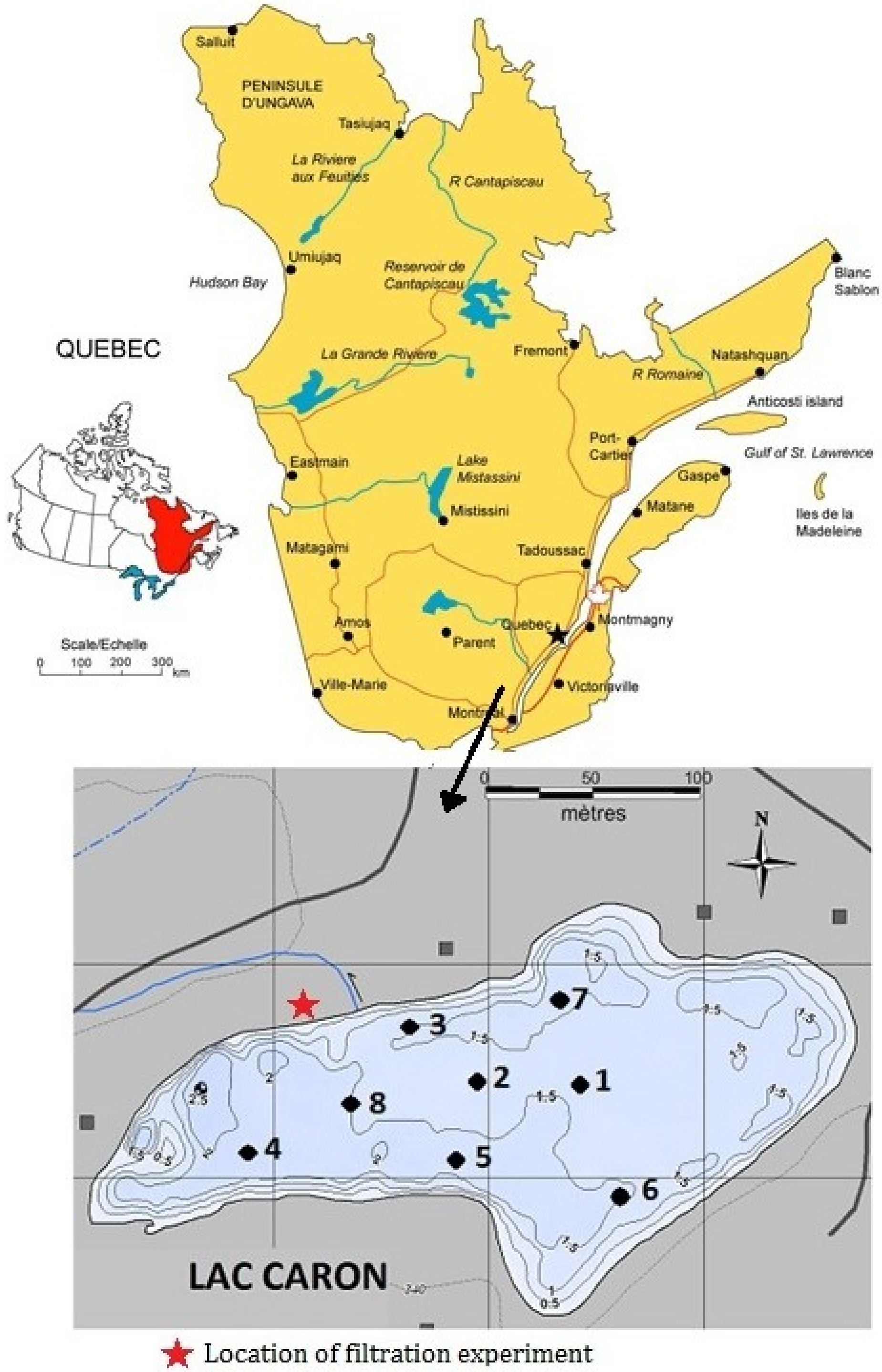


Figure 3.3 Geographic location and map of Lake Caron indicating sampling stations according to the numbers and the filtration experiment location (Free US and world maps, 2014)

3.3 EQUIPMENT USED

3.3.1 Filtration equipment

The objective of this study was to remove nutrients, total suspended solids, and turbidity from lake water by filtration using geotextiles as filter media. To accomplish that goal, a series of small scale field experiments were done beside the lake using a laboratory scale filtration unit. Figure 3.4 showed the schematic diagram of the filtration unit used in this study. The photo of the unit is shown in Figure 3.5.

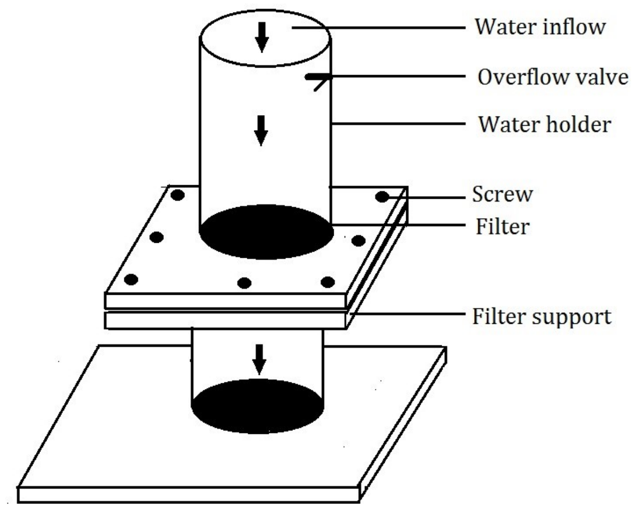


Figure 3.4 Schematic diagram of the filtration unit

The filtration column was cylindrical in shape and made of plexiglas with an internal diameter of 20 cm and a height of 25 cm. This column was placed at the top of the base to hold water and support a hydraulic head of 18 cm above the filter. To support the column another square shape base was used with a circular hole at the centre with the same internal diameter of the filtration column. Some screws were used to fix and tighten the filtration column with the square base. Water was pumped into the top of the filter column with a water pump. There was a valve at a height of 18 cm of the cylinder which is able to stop the pump automatically when the head above the filter exceeded 17 cm.

Figure 3.5 Photo of the filtration unit

3.3.1.1 Field experiment setup

A suitable place was chosen beside the lake to install the field experiment setup. At the beginning of the experiment, the ground was leveled with some gravel and a square tank with a height of 35.6 cm and width of 97.8 cm and a capacity of 543 L was placed above it. Then, the tank was filled with 300 L of lake water with the help of a pump. The whole filtration unit was placed on a flotation base. The flotation base is made of polystyrene insulation with a laminated film applied to both sides (DuroFoam, 2015). There was a circular hole with 20 cm diameter at the centre with the objective to float the filtration unit into the water, as well as to pass through the filtered water into the tank again. Finally the whole filtration unit with the flotation base was placed on the water in the tank. Four submergible pumps inside the tank were used for continuous water circulation with the objective to filter all water inside the tank. The pump used to supply water through the filtration unit was operated with a flow rate of 7.47 L/min and 3.8 L/min depending upon the flow of water through the filter. To operate the pumps, power was supplied from the nearest home beside the lake. A YSI 6600 V2 Sonde (6600 V2-2 multi-parameter water quality sonde, 2015) was kept inside the tank to measure the hourly pH, temperature, dissolved oxygen (DO), redox potential, chlorophyll α (chl α), blue green algae of the water during the experiments. The whole unit was covered by a plastic cover in order to protect it from rain water or any other external damage. Figures 3.6 and 3.7 show the schematic diagram and picture of the field experiment setup, respectively.

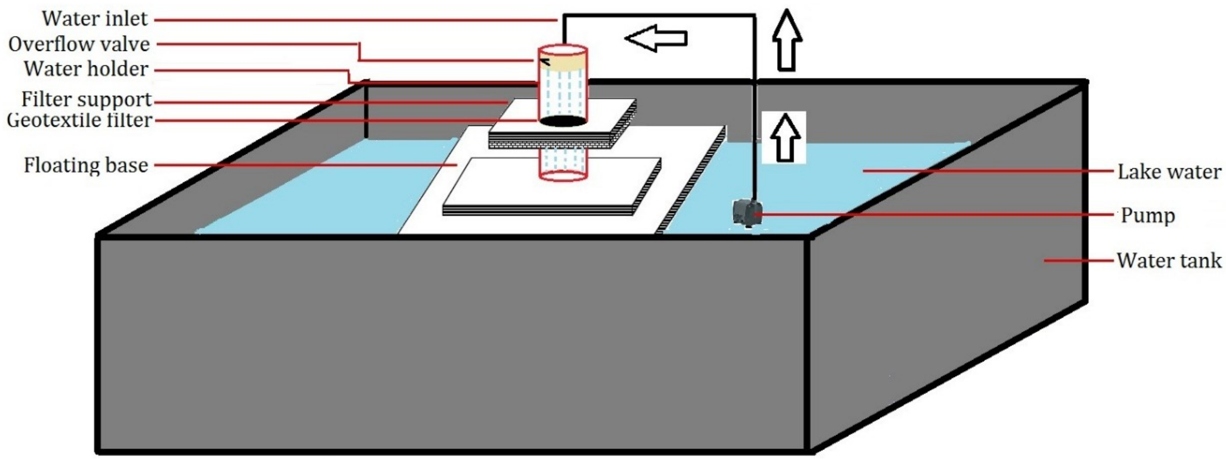


Figure 3.6 Schematic diagram of filtration unit with geotextiles

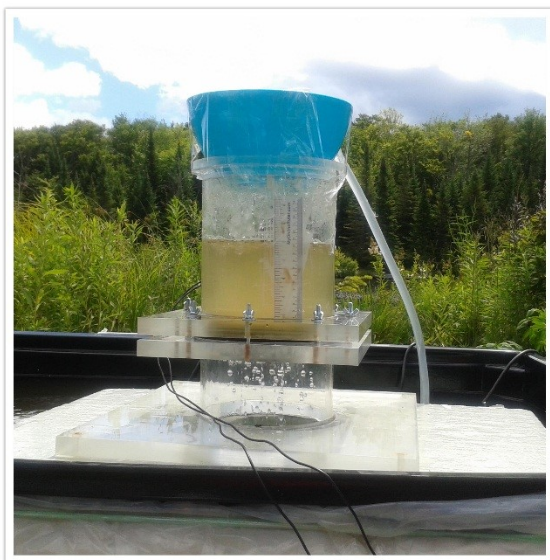


Figure 3.7 Photo of filtration setup during experiments

In general, 5 layers of geotextiles were used except for the first four tests, where 4 layers were used. The water was passed through the filter using a pump and returned to the tank for subsequent re-filtration. Before starting an experiment, water samples were collected and turbidity, flow rate through the filters, and clogging time were measured. As suspended particles became trapped by the geotextiles, water permeability through the geotextiles gradually decreased, and eventually it clogged. During the first half an hour, the filters clogged rapidly depending on the amount of total suspended solids present in the water. The clogged set of filters was replaced by a new set. After changing the filters for two or three times, the unit started filtering the water smoothly due to the reduction of total suspended solids on water. Though a low hydraulic head was obtained during the first few hours, it increased with time due to the capture of suspended particles by the filters. The experiments were carried out for an average of seven days and the treated water was collected every day during the experiments.

3.3.1.2 Geotextile filter

Geotextiles of distinct apparent opening sizes and materials (TE-GTX300, TE-GTN300, TE-GTN350 and TE-GTN340), fabricated by Titan Environment Containment Inc. Toronto, were used in several layers (4 and 5 layers) in different combinations as filter media during the field experiments. The characteristics of filters were given in the following table. The materials used to produce geotextiles were polypropylene and polyester. Three distinct apparent opening sizes, i.e., 110 µm, 90 µm and 75 µm with different combinations were used. The filters were cut in circular shapes with a diameter of 22 cm before using as filter media. A total of fourteen experiments were carried out using different combinations of geotextiles to find out the best combination providing maximum efficiency in removing nutrients and suspended solids.

Table 3.1 Characteristics of the geotextile filters used in this study

Filter	Apparent opening size (AOS) (µm)	Mass (gm^{-2})
TE-GTX300	110	300
TE-GTN300	90	300
TE-GTN350	90	350
TE-GTN340	75	340

In this study, water was filtered continuously throughout the experiment duration. Water that passed through the filter and retained in the tank was pumped to the filter unit again and the process was continuing. This was done to improve the efficiency of the filter media. As the water passed through the geotextiles filters, smaller particles that retained on the filter filled the pores and hence reduced the pore size. As a result, smaller sized particles had been trapped by the geotextile filters.

This process helped to remove the maximum suspended particles from the water samples and eventually improve the water quality.

3.3.1.3 Sample collection during experiments

Fourteen experiments were carried out beside the lake on an average of seven days duration for each experiment from June to October, 2015. To determine the initial water condition, turbidity, pH, electrical conductivity, temperature, dissolved oxygen, redox potential, chlorophyll α, blue green algal and cyanobacterial cells were measured and samples were collected to do chemical analyses as well as to measure total suspended solids, particle size distribution before starting the experiments. After starting the experiments, the flow rate through the filter, head development with time and clogging time were measured. Almost every time, a new set of filters were used by replacing the clogged one. After a set of filter clogged, again all the water quality parameters were measured and water samples were collected for further analyses. Each experiment was carried out for an average of seven days and for each day, turbidity of the water, head development and flow rate through the filter were measured and samples were collected to measure total suspended solids, particle size, total phosphorus, dissolved phosphorus, total nitrogen, nitrate, COD etc. After the collection of samples, they were kept in a cooler to avoid changes in the samples or sun light interactions and were transferred into the Concordia University's laboratory's incubator at a temperature of 4^0C before further use.

3.4 MEASUREMENT OF FLOW RATE THROUGH THE FILTER

To calculate the flow rate, the water holder of the filtration unit (having diameter *d*) was filled with a certain height of water (h). Then this amount of water was allowed to pass through the filter and the required time (t) was measured using a stopwatch.

Now, the volume of water passed through the filter, $V = \frac{\pi d^2}{4} * h$

So, the flow rate = $\frac{V}{t}$

3.5 ANALYTICAL MEASUREMENTS

In the laboratory of Concordia University, the water samples were analysed to determine the water properties. Water quality parameters that were analyzed in the study period are listed in Table 3.2.

Table 3.2 Physical, chemical and biological water quality parameters

Physical	Chemical	Biological
Turbidity	pH	Chlorophyll α
Temperature	Total phosphorus (TP)	Cyanobacteria
Electrical conductivity (EC)	Dissolved phosphorus (DP)	Zooplankton
Total suspended solids (TSS)	Total nitrogen (TN)	Phytoplankton
	Nitrate (NO_3^-)	
	Chemical oxygen demand (COD)	
	Dissolved oxygen (DO)	
	Redox potential (ORP)	

Total suspended solids (TSS)

Total suspended solids were measured by following the standard procedure of ASTM 5907-13 (2013). Filters with pore size of 0.45 µm and diameter of 47 mm were used to determine the total suspended solids. At first, the filters were rinsed with deionized water with three times while vacuum was applied through the vacuum filtration. Then the filters were dried by placing them in an oven with a temperature of 105±5^{0}C for a minimum of one hour.

After drying, the weight of the washed filters was recorded in a digital balance. The detection limit of the balance is 0.001g. Then the same procedure was repeated using a sample instead of deionized water and dried in the filter at the same temperature for an hour. After one hour, again the weight of the dried filters were taken. Finally, the following equation was used to calculate total suspended solids

$$TSS\left(\frac{mg}{L}\right) = \frac{(Residue+Filter)(mg)-Filter(mg)}{Sample\ volume\ filtered\ (mL)} x1000(\frac{mL}{L})$$

Particle size distribution

The particle size distribution for the water samples was determined using the Laser Scattering analyzer (HORIBA, LA-950V2). This instrument can measure the particle size of dry or wet samples within a range of 0.01- 3000 µm. It contains two light sources and an array of high quality photodiodes. A sample handling system inside the instrument can control the interaction of particles and incident light between light source and photodiodes. The main concept in laser diffraction is that a particle scatters light at an angle determined by that particle's size. Larger particles scatter at short angles while smaller particles scatter at wide angles. The collection of particles with different sizes produce a pattern of scattered light defined by density and angle (Introducing new particle size analyzer (LA-950V2).2014). For each sample, triplicate measurements were done and the distribution of the particle sizes was generated using Excel Microsoft Office by plotting the accumulated percentage finer to the particle diameter on a semi log scale.

Total nitrogen test

Nitrogen is one of the most ample elements on earth. It is essential to the life, growth and reproduction of all organisms. Nitrogen typically is found in three forms, ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-). Nitrate is immediately taken up by the algae. In this study, total nitrogen had been determined by following the per sulphate digestion method (method 10208) using a HACH total nitrogen test kit (TNT 826).

Total nitrate test

Nitrate (NO_3^-) is a naturally occurring form of nitrogen and a crucial nutrient for plants. The excess amount of nitrates can cause significant problems. Nitrates in surplus amounts can accelerate eutrophication along with phosphorus. This eutrophication affects dissolved oxygen, temperature and other indicator. Nitrates in the water sample were measured using the Nitrate TNT plus (TNT

835), low range test kit (from HACH by following the dimethylphenol method (method 10206) (Water: Monitoring & assessment, 2012).

Chemical Oxygen Demand test

Chemical oxygen demand (COD) is a "measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant". In this study, the USEPA reactor digestion method (method 8000) was followed to measure the chemical oxygen demand of the lake water. For COD testing, test kits were purchased from HACH (TNT 820).

Phosphorus test

In this study, dissolved phosphorus (DP) and total phosphorus (TP) have been measured by following ascorbic acid method (method 10209/10210). The water samples were filtered through 0.45 μm filters and then dissolved phosphorus was measured using the same ascorbic acid method. The test kits were obtained from HACH (Phosphorus (Total) TNT reagent set, low range).

Phytoplankton analyses

For phytoplankton analysis, water samples were collected from the tank before starting and after ending the experiments. Water was collected in 100 ml sterile polyethylene bottles, and a few drops of Lugol solution were added to prevent growth and to preserve them. The phytoplankton analyses were done at the University of Montreal.

Cyanobacteria

Cyanobacteria are photosynthetic bacteria that contain blue green pigment. The cyanobacteria concentration was measured using the ColiPlate^{TM} 400 test kit (Figure 3.8) provided by Bluewater Bioscience Inc, The test kit is designed to meet regulatory guidelines for surface water, recreational water and wastewater. It is based on a 96 well micro plate format with no sample dilution requirement. This kit quantifies the density of targeted bacteria ranging from 5 to 5,000 colony forming units (CFU) per 100 ml sample. Figure 3.8 shows the concentration of cyanobacteria and *E.coli* in a ColiPlate test kit. The blue wells refer to cyanobacteria and the fluorescent wells refer to a positive reaction for *E.coli.*

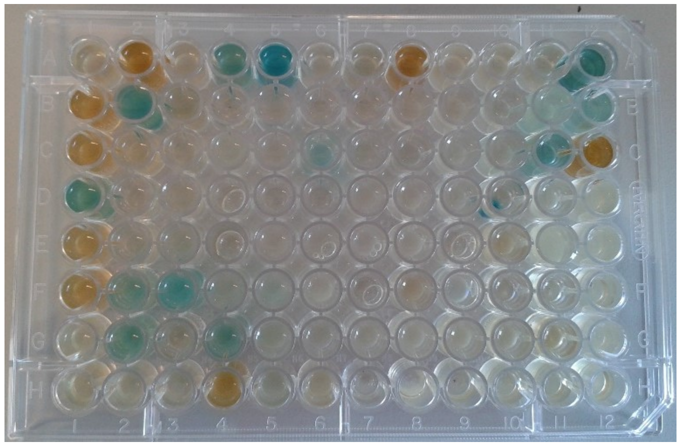


Figure 3.8 ColiPlate test kit showing cyanobacteria and *E.coli* concentrations

Chapter 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the overall water quality of Lake Caron and the results of the experiments are discussed. As mentioned earlier, the main objective of the study is to treat the lake water. To achieve this objective, filtration was conducted using geotextiles as filter media.

4.2 OVERALL WATER QUALITY OF LAKE CARON

Prior to the experiments, lake water samples were analysed with the objectives to determine the physical, chemical and biological characteristics of the water. Six samplings were conducted during the summer and fall of 2014 (1 sampling in June, August and September and 3 samplings in July) and three samplings were conducted in summer 2015 (1 sampling in June and 2 samplings in August 2015). During each sampling, in situ measurements were taken at eight different stations (Figure 3.3) for various water quality parameters such as pH, temperature, electrical conductivity, dissolved oxygen, redox potential, chlorophyll α and turbidity. Also, water samples were collected from these stations to analyze total phosphorus, dissolved phosphorus, chemical oxygen demand, total suspended solids, total nitrogen, and nitrate. To get an idea of overall lake water quality, the average values of the water quality parameters of all eight stations were calculated for each sampling. In the following sections, the average results of these in situ measurements and chemical analyses are presented. The results are also presented in Table 4.1.

pH

The pH of water is important to aquatic life. The aquatic life will be substantially impacted if the pH of the water is below 4 or above 9. The pH of Lake Caron increased from June to August and remained almost constant from August to October. The average pH of the water was about 6.8±0.1.

According to the MDDEP (Quebec water quality, 2015), for Quebec surface water, the pH range for protecting aquatic life is 6.5-9. Table 4.1 shows the average pH values of water samples during the summer and fall of 2014 and summer of 2015. In both years, the pH values of the lake water were almost same. In 2014 and 2015, it was 6.73 and 6.69, respectively.

Table 4.1 Overall water quality of Lake Caron

Parameters	Values	
	2014	**2015**
pH	6.73	6.69
Temperature(^{0}C)	22.5	21.07
Dissolved oxygen (mg/L)	6.78	7.06
Oxygen reduction potential (mV)	189.5	175.94
Chlorophyll α (μg/L)	6150	9000
Cyanobacteria (cells/mL)	4550	>2424

Temperature

Temperatures may influence many biological, physical and chemical characteristics of water and amount of oxygen that are dissolved in water. Water temperature was normally higher in summer. During summer, the lake water temperature varied in the range of 20.1-24.8^{0}C, while during the fall, the water temperature was as low as 12^{0}C. Table 4.1 shows the average temperature of water samples during 2014 and 2015.

Dissolved oxygen

This is the most important test to measure the water's ability to support plants and animals. The higher the dissolved oxygen concentration, the healthier the aquatic life. According to the Canadian Aquatic Quality Guidelines (CAQG), the lowest dissolved oxygen limits to support aquatic life in warm and cold waters are 6-6.5 and 9-9.5 mg/L, respectively (Canadian Council of Ministers of the Environment, 2014). The average dissolved oxygen concentration of the lake during 2014 was 6.78 mg/L while in 2015, it was slightly higher at 7.06 mg/L. Table 4.1 shows that the dissolved oxygen level for water samples during the summers of 2014 and 2015.

Oxygen reduction potential

Oxygen reduction potential (ORP) is a measure of its ability to break down contaminants by oxidation. Oxygen reduction potential determines the oxidized or reduced state of water bodies. Lower value of oxygen reduction potential means that higher contaminants in the water as a result reduced state of water bodies. Similarly, the higher the oxygen reduction potential level, the more ability the water has to destroy the contaminants. For Lake Caron, the oxygen reduction potential was found between 105.9 - 272.9 mV. In the summer 2014, the oxygen reduction potential value of the lake water was slightly higher as compared to summer 2015. The lower oxygen reduction potential value indicated that the quality of lake water was poor. Table 4.1 shows the oxygen reduction potential level for water samples during the summers of 2014 and 2015.

Electrical conductivity

Electrical conductivity is used to measure the concentration of dissolved salts or dissolved ions in water. For distilled or deionized water, the electrical conductivity is low because it has very few ions dissolved in the water (Lake Access, 2016). The electrical conductivity of Lake Caron water samples ranged between 28.5 and 32 μS/cm.

Chlorophyll α

Chlorophyll α is a photosynthetic pigment which is the source for green colour in algae and plants. The concentration of chlorophyll α present in the water is directly proportional to the concentration of algae living in the water. Table 4.1 shows the chlorophyll α concentration of the water during summer 2014 and 2015. The chlorophyll α concentration of water samples varied between 5300-7000 μg/L. In 2015, the concentration of chlorophyll α (6150 μg/L) was lower than that of 2014 (9000 μg/L). WHO (2003) suggests that the relative probability of acute health effect during recreational exposure is very high for a water body with chlorophyll α concentration higher than 5000 μg/L.

Cyanobacteria

For a eutrophic lake, where the nutrients are high, the amount of cyanobacteria can also be high. Generally, the cyanobacteria concentration for Lake Caron water varied from 3700- 5400 cells/mL. In summer 2014, the cyanobacteria concentration was 4550 cells/mL. Table 4.1 shows the results of cyanobacteria concentration for the summers of 2014 and 2015. According to the WHO (2003) guidelines, the probability of adverse health effects during recreational exposure is relatively low if the concentration of cyanobacteria in the water is lower than 20,000 cells/mL.

Total suspended solids (TSS)

Higher concentrations of total suspended solids can adversely affect aquatic health as well as water quality. The concentrations of total suspended solids during different months of summer and fall 2014 and summer 2015 are shown in Figure 4.1. During 2014 and 2015, the concentration of TSS was below the criteria for TSS in clear water (<25 mg/L) (Quebec water quality, 2015).

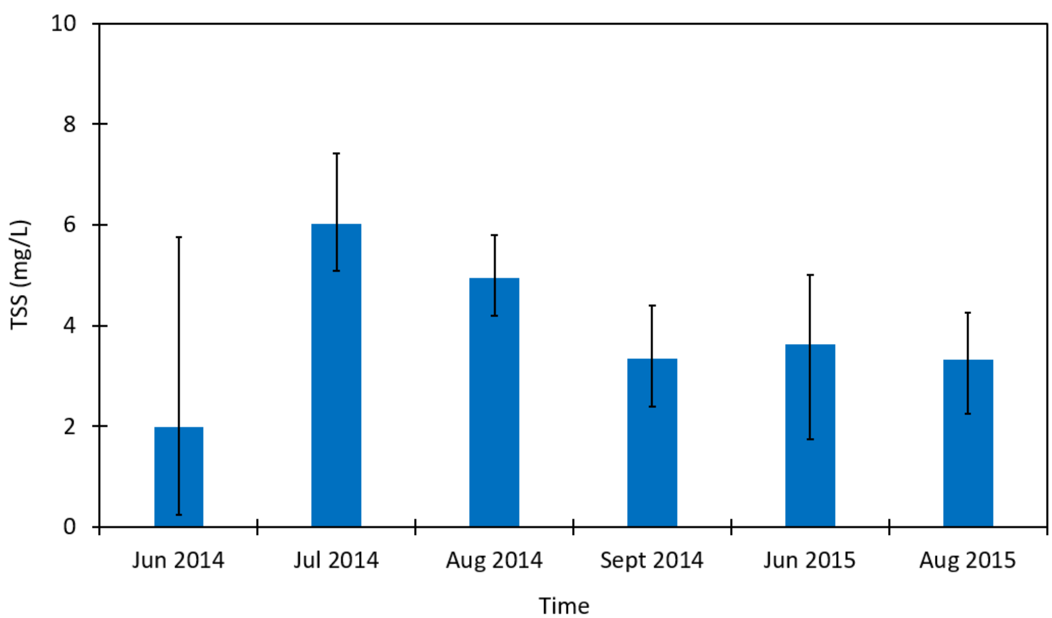


Figure 4.1 Total suspended solid concentration of Lake Caron water during 2014 and 2015

In summer 2014, the maximum and minimum concentrations of total suspended solids for Lake Caron were found as 2 mg/L and 6 mg/L in the month of June and July, respectively. It was also found that after July 2014, the concentration decreased during the following months of the same year. The concentration was almost similar in June and August 2015.

Turbidity

Turbidity is an important water quality parameter used to measure the water clarity. Low turbidity values indicate better water quality. The turbidity values during different months of summer and fall 2014 and summer 2015 are shown in Figure 4.2. From the report, water quality guidelines used by Quebec prepared by Environment and Climate change, Canada (2015), it is found that, the maximum allowable turbidity value for surface water is 10 NTU.

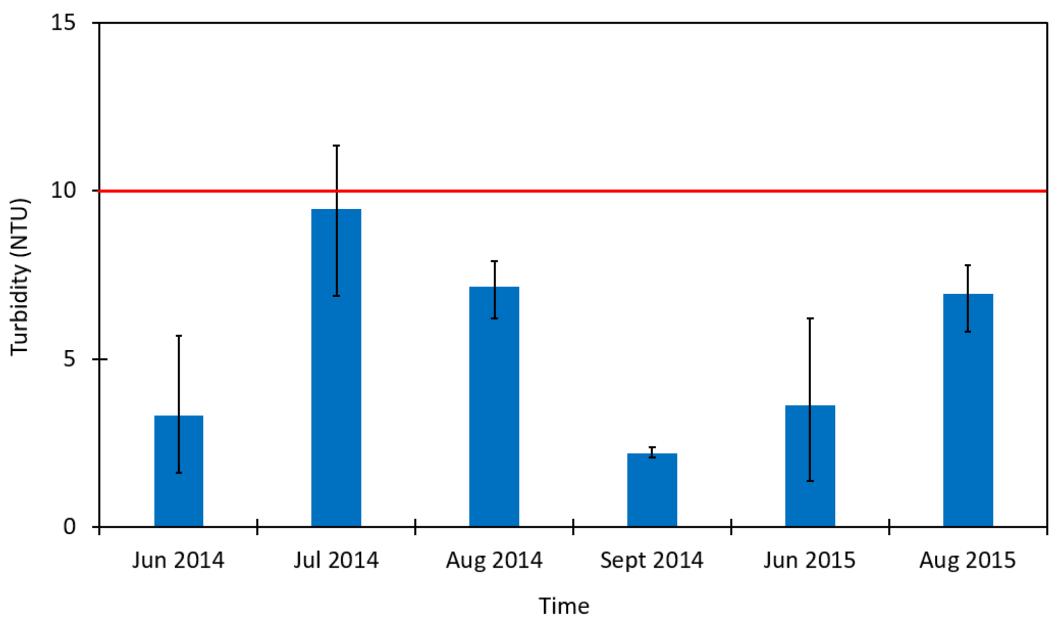


Figure 4.2 Turbidity values of Lake Caron water during 2014 and 2015

From Figure 4.2, it was found that in 2014, the turbidity of the lake water was maximum in July (9.5 NTU) and minimum in September (2.2 NTU). In July 2014, even though the maximum value was above the limit for some stations, but the average value was below the acceptable limit. Like TSS concentration, after July 2014, turbidity was also decreasing during the following months with a rapid decrease from August (7.1 NTU) to September (2.2 NTU) of the same year. Turbidity values were almost same in 2014 and 2015 during the month of June and August.

Total phosphorus

Figure 4.3 represents the average total phosphorus concentration of various months during summer and fall 2014 and summer 2015. The values of all eight stations were averaged for each sampling. Further, the final value was calculated by taking the average of all sampling for the months when more than one sampling was conducted. For each sample, three replicas were used to ensure reproducibility. According to the MDDEP (2009), if the concentration of total phosphorus for a water body is above 0.03 mg/L, then it is considered as eutrophic water body. Figure 4.3 clearly shows that the total phosphorus concentration was above 0.03 mg/L for all monitored months in 2014 and 2015, which indicated the eutrophic condition of the lake. The average total phosphorus concentration varied from 0.045 mg/L to 0.065 mg/L during the monitored months in 2014 and 2015. It was also found that the average concentration was increasing from June to September in 2014, whereas the average concentration was lower in August 2015 as compared to that in June 2015.

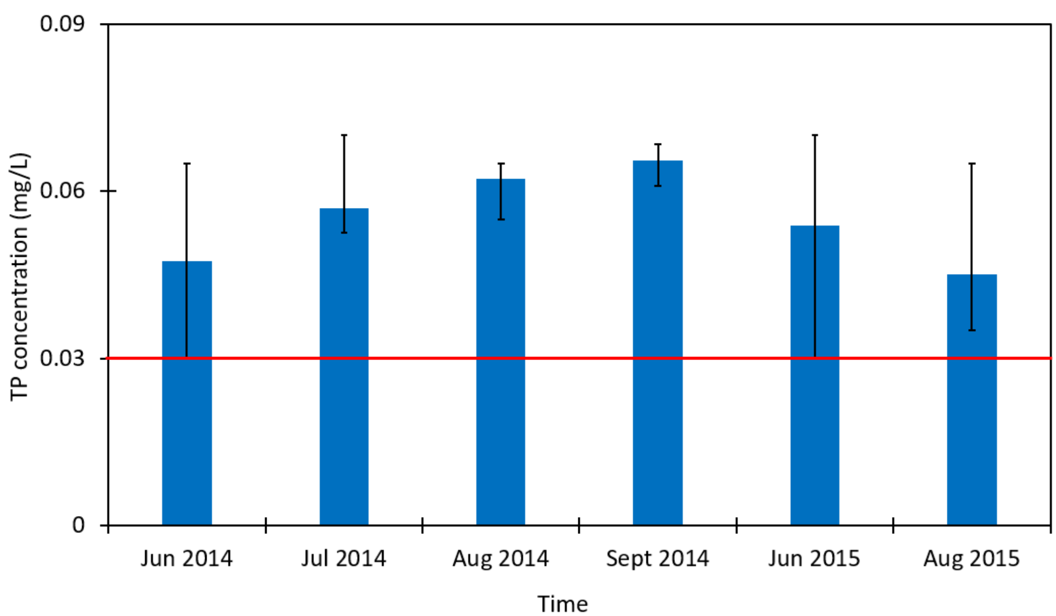


Figure 4.3 Total phosphorus concentration of Lake Caron water during 2014 and 2015

Total nitrogen

Figure 4.4 shows the average concentration of total nitrogen in lake water samples during different months of summer and fall 2014 and summer 2015. Nitrogen is an essential and limiting nutrient for algal and aquatic growth but excess concentration of nitrogen can cause eutrophication. Three replicates were used for each sample. There is no specific standard for trophic status classification or protecting surface water quality in Quebec for total nitrogen concentration. However, Environment Canada (2014) has suggested that the total nitrogen concentration in surface water should be lower than 1 mg/L to maintain a healthy aquatic life. From Figure 4.4 it was found that the average total nitrogen concentration was slightly higher than 1 mg/L in the month of June 2014. During July and August 2014 and June 2015, the maximum concentration was higher than 1 mg/L, though the average value was below the acceptable limit. In general, the total nitrogen concentration was decreasing from June to September 2014 except in August 2014.

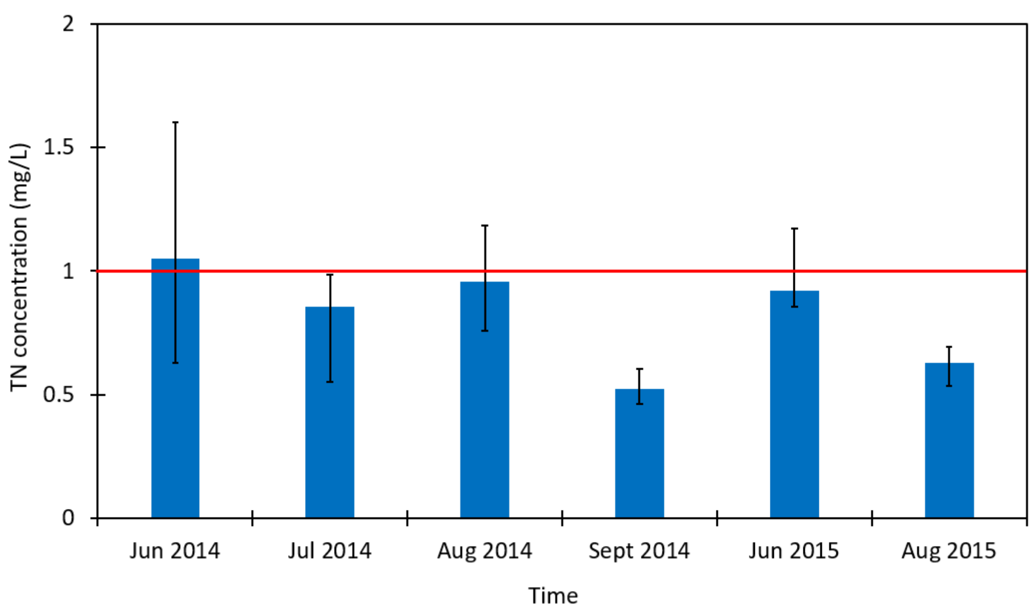


Figure 4.4 Total nitrogen concentration of Lake Caron water during 2014 and 2015

Nitrate

Figure 4.5 represents the concentration of nitrates in lake water. Nitrate is one of the available forms of nitrogen for algae and aquatic life. Excessive nitrate concentrations in water can accelerate the algal growth as a result depletion of dissolved oxygen in water. According to the MDDEP (2013), the maximum concentration of nitrates for aquatic life is 2.9 mg/L. From Figure 4.5, it was found that the concentrations of nitrate for all monitored months were sufficiently below the acceptable limit. The average value of nitrate concentration was maximum in the month of June in both years. The concentration decreased gradually after June 2014 to the following months for the year 2014.

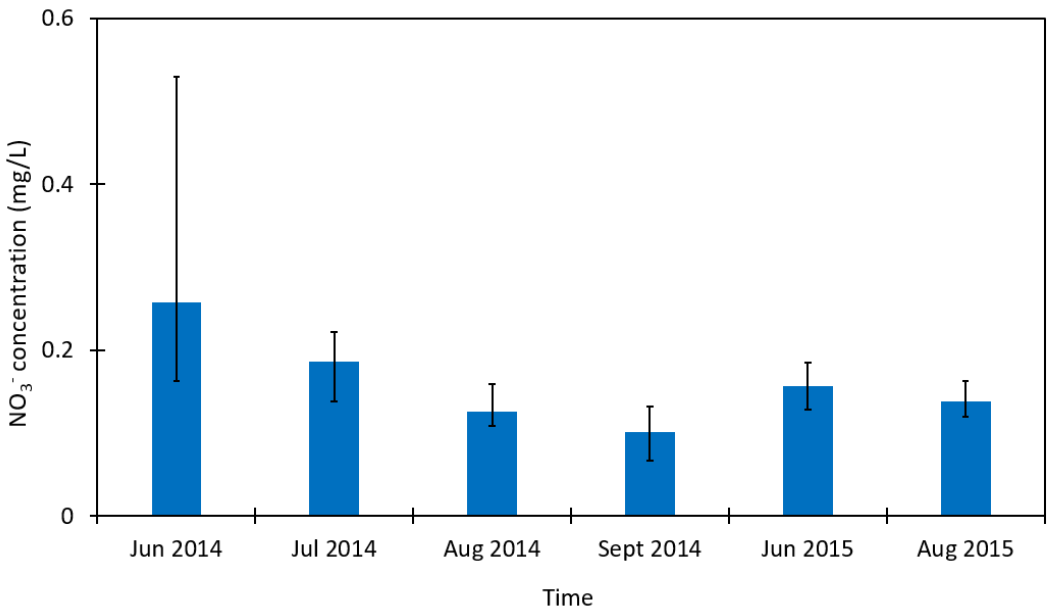


Figure 4.5 Nitrate concentration of Lake Caron water during 2014 and 2015

Chemical Oxygen Demand

Figure 4.6 shows the average concentration of COD of the Lake Caron water sample for different months in 2014 and 2015. There is no specific criterion for chemical oxygen demand (COD) to protect aquatic life in surface water in Quebec and Canada. But, World Health Organization (WHO) has been observed that the concentrations of COD in surface water range from 20 mg/L or less in unpolluted waters to greater than 200 mg/L in waters receiving effluent (Chapman & Kimstach, 1996). From Figure 4.6, it was found that the average COD concentration was higher than 20 mg/L for all the monitored months in 2014 and 2015 except in September 2014 and August 2015, though the maximum value was greater than 20 mg/L for these two months. In July 2014, the average COD concentration was maximum and showed a decreasing trend for the following months of the same year.

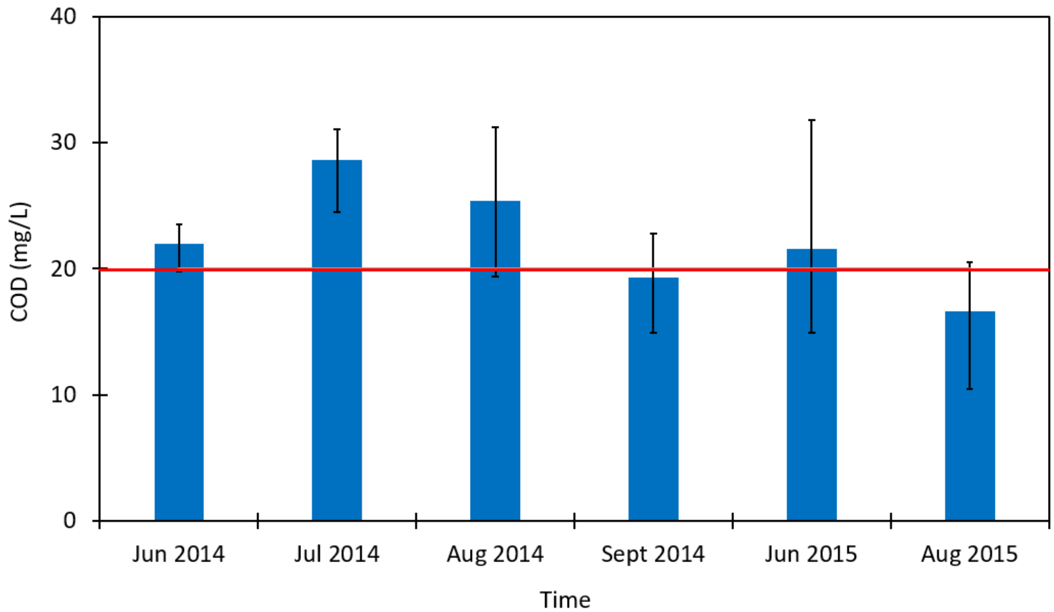


Figure 4.6 COD concentration of Lake Caron water during 2014 and 2015

Particle size distribution

Figure 4.7 represents the particle size distribution of lake water samples during different monitored months in 2014 and 2015. The values of all eight stations were averaged for each sampling. Also, the final value was calculated by taking the average of all sampling for the months when more than one sampling were conducted. For each sample, three replicas were measured. It was shown in a semi logarithmic scale with particle diameter (µm) in x axis and cumulative frequency in y axis. Particle diameters ranging from 0.1-1 µm are termed as colloids, 1-4 µm as clay, 4-60.5 µm as silt and 60.5-2000 µm is known as sand. The particle size distribution was almost similar for different months in 2014 and 2015. On average, the water samples for all the stations collected in 2014 and 2015 showed that only 5% of the particles were silt and the rest 95% were sand and there was no colloid and clay particles in the water samples. The mean particles size (d50) varied from 890 µm to 1020 µm whereas the average particles size ranged from 810 µm to 980 µm during the monitored months for both years.

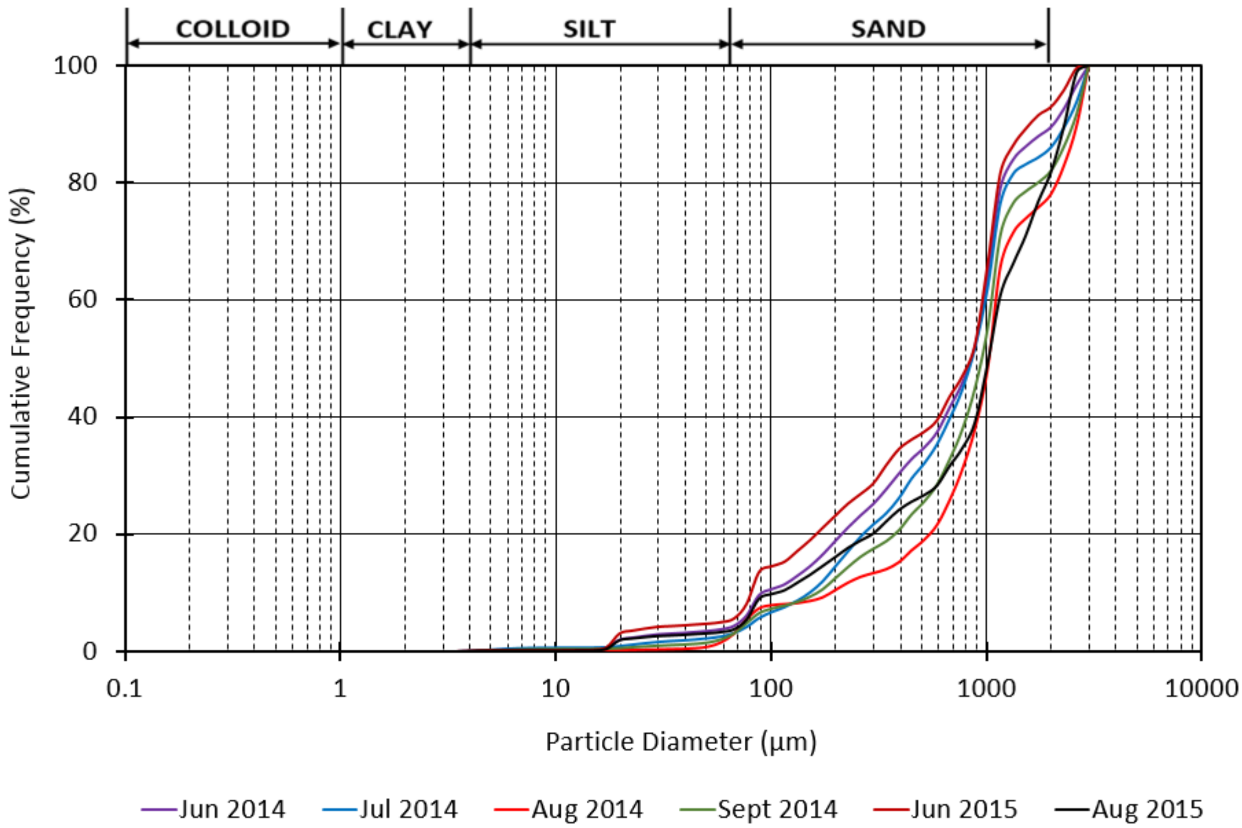


Figure 4.7 Particle size distribution of water samples in 2014 and 2015

4.3 RESULTS FOR FILTRATION EXPERIMENT

A small scale field experiment beside the lake using a filtration technique was conducted with the objectives to evaluate the effectiveness of non-woven geotextiles in reducing the nutrients and suspended solids to improve the lake water quality. To achieve that objective, custom made geotextiles with different materials and three apparent opening sizes were tested. The geotextiles were TE-GTX300, TE-GTN300, TE-GTN350 and TE-GTN340 and the three apparent opening sizes were 110 µm, 90 µm and 75 µm. A total of 14 experiments were carried out using different combinations of geotextiles to find out the best combination providing maximum efficiency in removing nutrients and suspended solids to acceptable limits within shorter period of time. While using a combination of 4 or 5 layers, the geotextile with higher opening size was kept on top because it would retain larger suspended particles in the filter water because of its higher opening size. The different combinations of geotextiles and the initial water conditions are shown in Table 4.2.

Table 4.2 Geotextile combination with initial water condition of each experiment

Experiment no.	Geotextile combination	Initial water condition					
		Turbidity (NTU)	Total suspended solids (mg/L)	Total phosphorus (mg/L)	COD (mg/L)	Total nitrogen (mg/L)	Nitrate (mg/L)
1	4 x 110 µm	4.01	8.20	0.08	25.80	0.99	0.17
2	4 x 110 µm	8.29	7.75	0.06	13.00	0.99	0.14
3	1 x 110 µm + 3 x 90* µm	8.19	9.25	0.05	27.50	4.20	0.14
4	1 x 110 µm + 3 x 90* µm	17.30	7.67	0.04	27.10	2.85	0.19
5	1 x 110 µm + 4 x 90* µm	19.01	6.83	0.07	14.60	1.09	0.19
6	1 x 110 µm + 4 x 90* µm	38.20	8.75	0.04	20.65	0.92	0.16
7	1 x 110 µm + 4 x 90 µm	14.25	6.00	0.06	27.35	0.63	0.15
8	1 x 110 µm + 4 x 90 µm	7.28	5.33	0.07	29.15	0.61	0.17
9	2 x 110 µm + 3 x 90 µm	16.98	10.33	0.07	34.70	1.00	0.12
10	2 x 110 µm + 3 x 90 µm	5.20	5.33	0.06	24.40	0.69	0.12
11	2 x 110 µm + 3 x 75 µm	9.15	9.00	0.06	8.02	0.53	0.13
12	4 x 110 µm + 1 x 75 µm	8.86	7.67	0.06	7.97	0.64	0.15
13	4 x 110 µm + 1 x 75 µm	10.39	8.00	0.06	10.50	0.96	0.17
14	2 x 110 µm + 2 x 90 µm + 1 x 75 µm	10.71	7.67	0.05	14.30	1.22	0.16

(110 µm: TE-GTX 300, *90 µm: TE-GTN 300, 90 µm: TE-GTN 350 and 75 µm: TE-GTN 340)

For only one experiment, the turbidity value was higher, i.e., 38 NTU and for the rest of the experiments, turbidity ranged from 4 to 19 NTU. To find out the best combination, the same combinations of geotextile filters were tested for different turbidities of water and also for the same turbidity with different combinations of geotextiles.

As shown in Table 4.2, the initial turbidity values for the experiments ranged from 4-38 NTU. Based on the initial turbidity values, the experiments were classified into four different categories. These are as follows:

Table 4.3 Categorization of performed experiments based on initial turbidity

Category	Turbidity range	Experiment no.
1	>4 to ≤ 9	1,2,3,8,10,12
2	>9 to ≤ 14	11,13,14
3	>14 to ≤ 19	4,5,7,9
4	> 19	6

The best results were chosen based on the decrease of water quality parameters (i.e., concentration of total phosphorus, turbidity, total nitrogen, chemical oxygen demand etc.) to acceptable level to protect aquatic life within the minimum period of time as aquatic organisms play an important ecological role in aquatic ecosystems. They provide the basis for aquatic food chain. They are crucially dependent on nutrients present in the water. But, excess amounts of nutrients in the water help promote excessive growth of aquatic organisms and thus this destroys the water quality. In the following sections, the best results for each category are described.

4.3.1 Initial turbidity range >4 to ≤ 9 NTU

Six among fourteen experiments were carried out in this turbidity range. They were experiment numbers 1, 2, 3, 8, 10 and 12. In experiments 1 and 2, four layers of 110 µm, and in experiment 3, 1 layer of 110 µm at the top and 3 layers of 90 µm at the below were used. In experiments # 8, 10 and 12 five layers of different geotextiles combinations were applied as filter media. For all experiments of this category, the initial concentrations of total suspended solids, turbidity, and nitrate were below the acceptable limits whereas the initial concentration of phosphorus was above the allowable level (Table 4.2). Only in experiment 3, the initial concentration of total nitrogen exceeded the allowable limit and the initial COD was below the acceptable limit for experiments 2 and 12. Therefore, the best filter combination was selected based on the removal of total phosphorus, total nitrogen and COD within minimum period of time to achieve the acceptable limits.

Figure 4.8 shows the removal trend of total phosphorus for experiments 1, 2, 3, 8, 10 and 12. The initial total phosphorus concentration for these experiments varied from 0.05 to 0.08 mg/L.

According to the MDDEP (2009), the maximum allowable range for total phosphorus concentration is 0.03 mg/L in order to reduce algal growth and eutrophication. From Figure 4.8, only experiments 2, 3 and 10 reached that concentration. Among them, experiments 2 and 3 took only 2 and 3 days whereas experiment 10 took 7 days to achieve that maximum allowable concentration. For experiment 2 and 10, the initial concentration was 0.06 mg/L and for experiment 3, it was slightly lower, 0.05 mg/L. A logarithmic correlation with higher R^2 value (more than 0.7 for most of the experiments) had been observed in the case of total phosphorus removal over time.

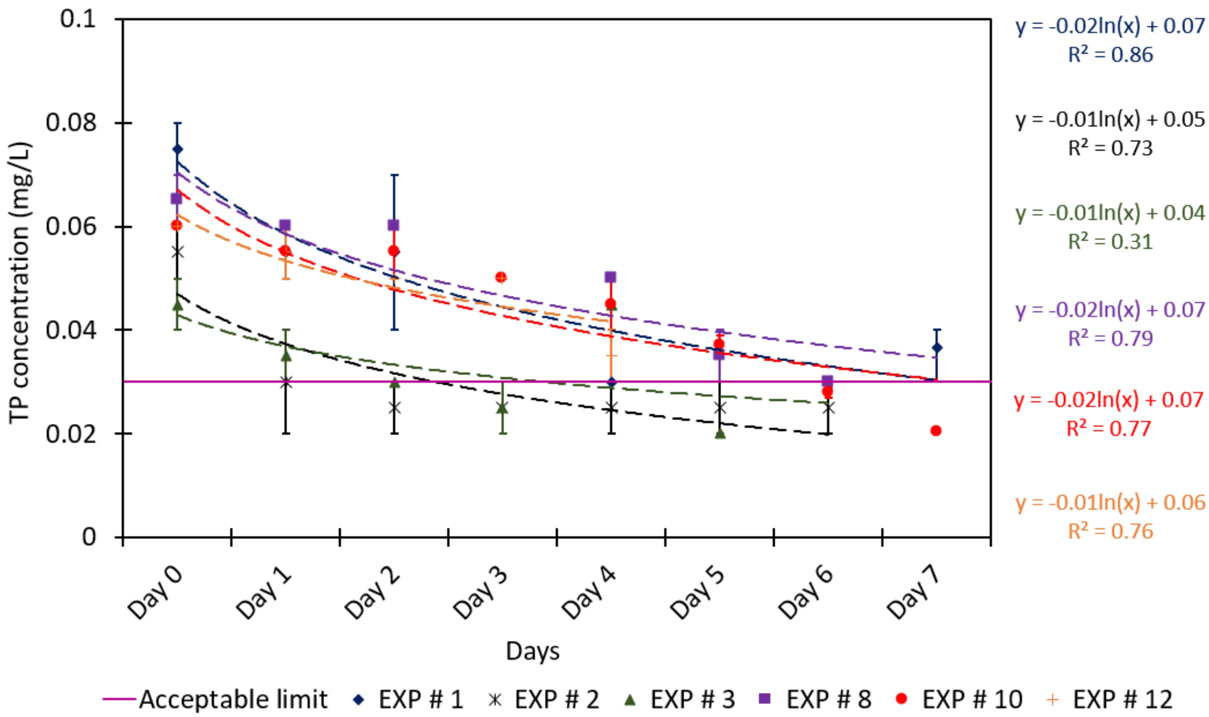


Figure 4.8 Removal trends of total phosphorus for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

Generally, total nitrogen in the lake water is the total N in the NH_4^+ form, and the oxidized forms of both NO_2^- and NO_3^-, and N bound to suspended particles and soluble organic forms. Figure 4.9 shows the removal pattern of total nitrogen for experiments 1, 2, 3, 8, 10 and 12. The initial total nitrogen concentration for experiment 3 only (4.20 mg/L) was above the allowable limit (1 mg/L) as suggested by Environment Canada (2014) among the 6 experiments. It was 0.99 mg/L for experiments 1 and 2 and for the rest of the experiments the initial concentrations were below 0.7 mg/L. At the end of experiment 3, the concentration of total nitrogen didn't reduce to 1 mg/L and for experiment 10, the concentration of total nitrogen was below the allowable limit throughout the experiment.

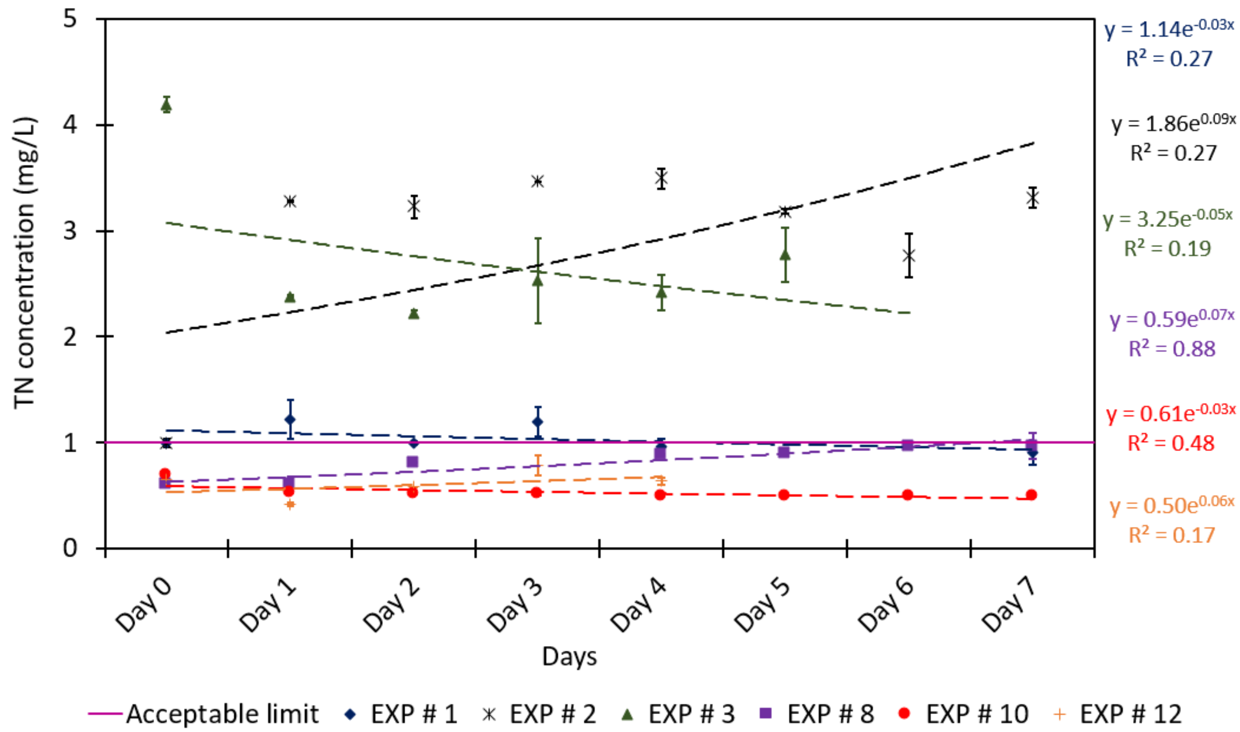


Figure 4.9 Removal trends of total nitrogen for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

Figure 4.10 shows the removal pattern of COD and R^2 value for experiments 1, 2, 3, 8, 10 and 12. As stated earlier, in unpolluted waters the concentrations of COD is less than 20 mg/L (Chapman & Kimstach, 1996). The initial COD concentration for experiments 2 and 12 was below 20 mg/L and for the rest, it varied from 22 to 30 mg/L. Among the experiments, at day 4, the COD concentration reduced to 20 mg/L both experiments 3 and 8. But, for experiment 10, it was below 20 mg/L at day 1 and at the end of experiment, it was 9.16 mg/L. Only experiments 8 and 10, a logarithmic correlation with higher R^2 value (0.96) had been observed in case of COD removal.

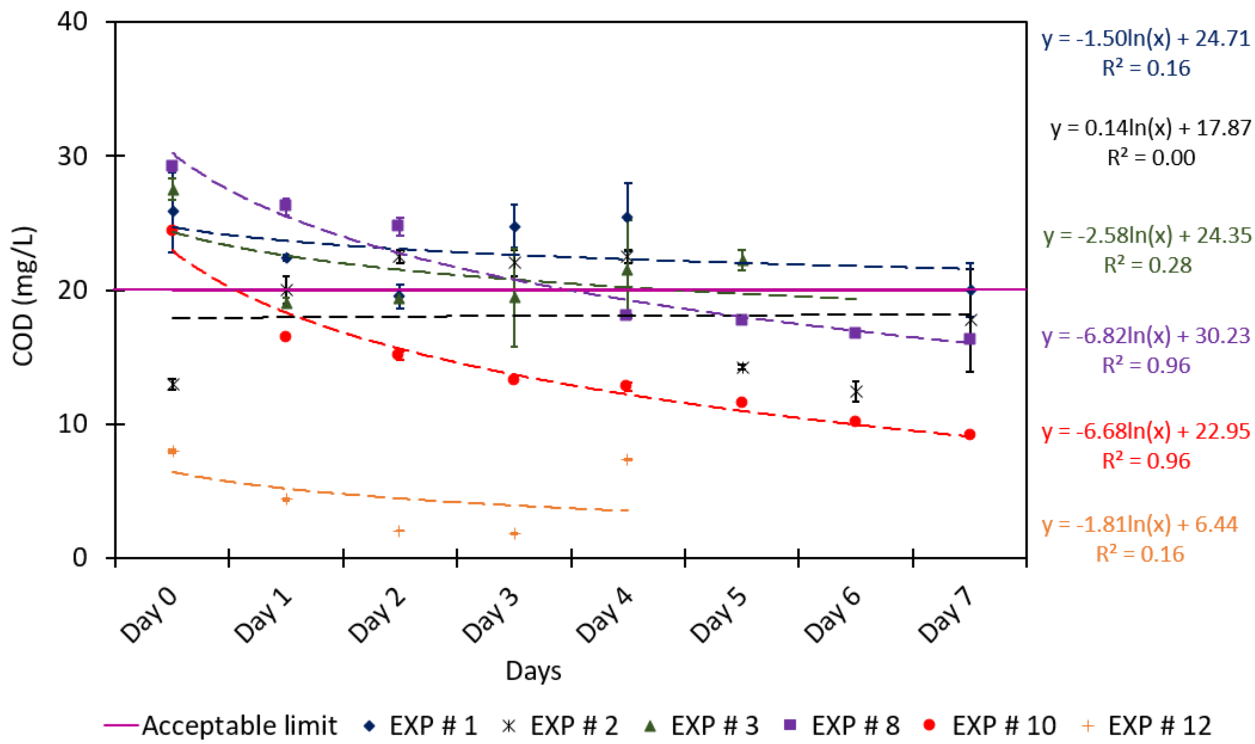


Figure 4.10 Removal trends of COD for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

Experiment 10 took more time to reduce the phosphorus concentration as compared to experiment 3. But, in experiment 3, the total nitrogen concentration didn't reduce to the allowable range. Moreover, the COD concentration became below 20 mg/L at day 1 in experiment 10 while it became below the range at day 4 in experiment 3. Therefore, based on removal of total phosphorus, total nitrogen and COD within shorter periods of time to achieve acceptable limits, the combination of geotextiles used in experiment 10, i.e., 2 layers of 110 µm at the top followed by 3 layers of 90 µm at the bottom were chosen as the best combination for the initial turbidity range of 4 to 9 NTU. The time required to achieve the allowable range was 7 days.

The removal patterns of turbidity, total suspended solids and nitrate for different days for all experiments lies within this turbidity range are shown in Figures 4.11 to 4.13. For experiment 10, the initial turbidity was 5.20 NTU and 96% of the initial turbidity was reduced at the end of the experiment (0.15 NTU). An exponential correlation with higher R^2 value (more than 0.9 for most of the experiments) had been observed in the case of turbidity removal. Total suspended solids concentration for experiment 10 was initially 5.33 mg/L, at day 4, it reduced to 0.2 mg/L and at the end there were no suspended solids. The decreasing trend of total suspended solids is presented in Figure 4.13.

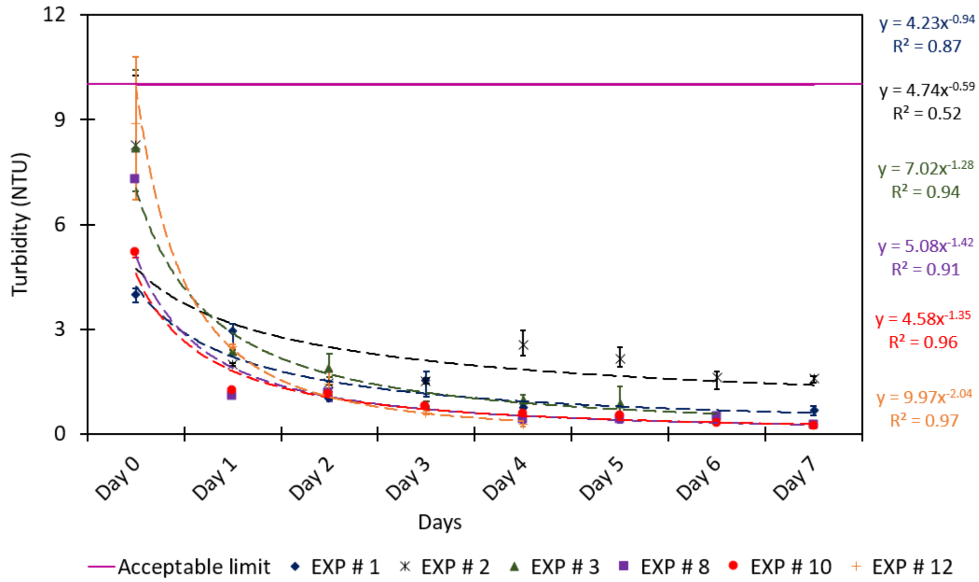


Figure 4.11 Removal trends of turbidity for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

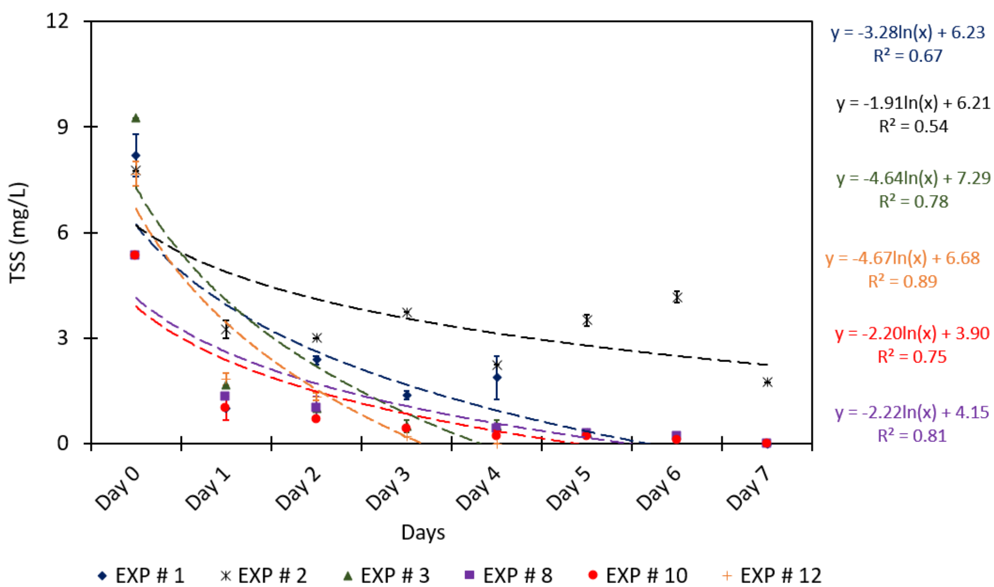


Figure 4.12 Removal trends of total suspended solids for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

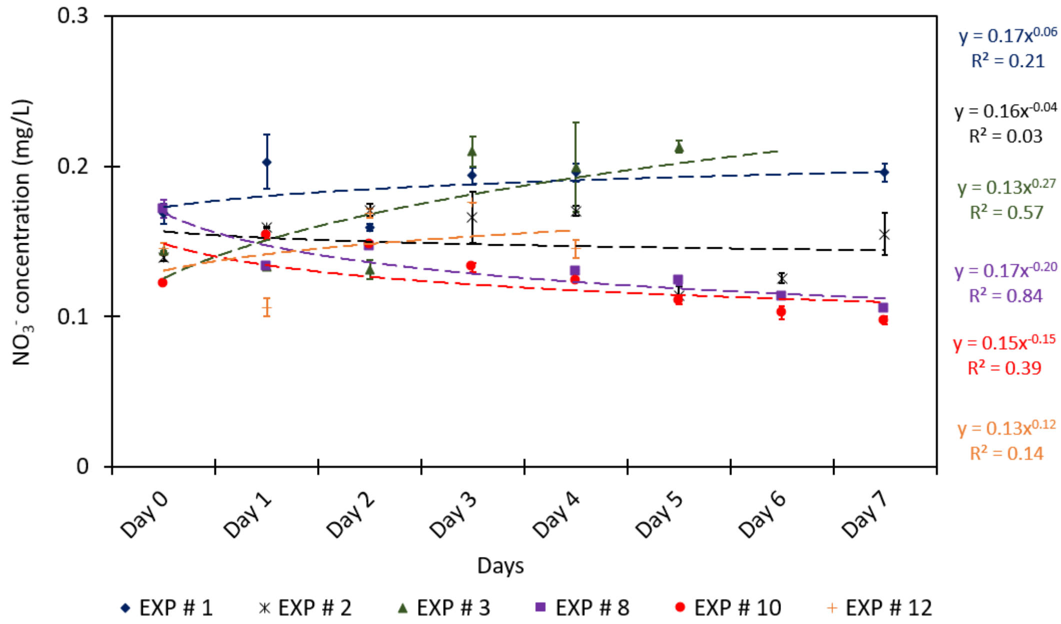


Figure 4.13 Removal trends of nitrate for the experiments with initial turbidities ranging from >4 to ≤ 9 NTU

Though the nitrate concentration was below the acceptable limit for all the experiments, it was found that nitrate concentration reduced to 0.098 mg/L from 0.122 mg/L at the end of the experiment 10.

Therefore, based on the results of this section, it can be concluded that, for the initial turbidity range 4 to 9 NTU, the geotextile combination (2 layers of 110 μm followed by 3 layers of 90 μm) used in experiment 10 worked efficiently to reduce the water quality parameters to the acceptable limits at day 7.

In this study, no dissolved phosphorus had been found in the water sample which indicated that all phosphorus was contained in the suspended particles. Previous studies showed that removal of suspended particles considerably improved the water quality for the cases where nutrients were contained in the suspended particles (Inoue et al., 2009). So, it is obvious that the filter combination, which is capable of removing maximum suspended particles, should show the best efficiency in removing the nutrients. The minimum pore size of geotextile filters used in the experiments conducted with initial turbidity ranging from 4 to 9 NTU was 90 μm except for experiment 12 where the minimum pore size was 75 μm. As a result these filters were capable of removing the particles higher than 90 µm and at the end of experiments, no particle higher than 90 µm had been found. Hence, the experiment which had highest percentage of particles having size more than 90 µm, should remove maximum nutrients. Figure 4.14 shows the percentage of particles higher than 110, 90 and 75 µm at the beginning of filtration for different experiments conducted within this initial turbidity range. As shown in the figure, experiment 10 had the highest percentage of particles with size greater than 90 µm (98.7%). So, the combination used in experiment 10 removed the highest amount of particles (98.7%) and that's why, experiment 10 provided maximum efficiency among all experiments conducted within this initial turbidity range.

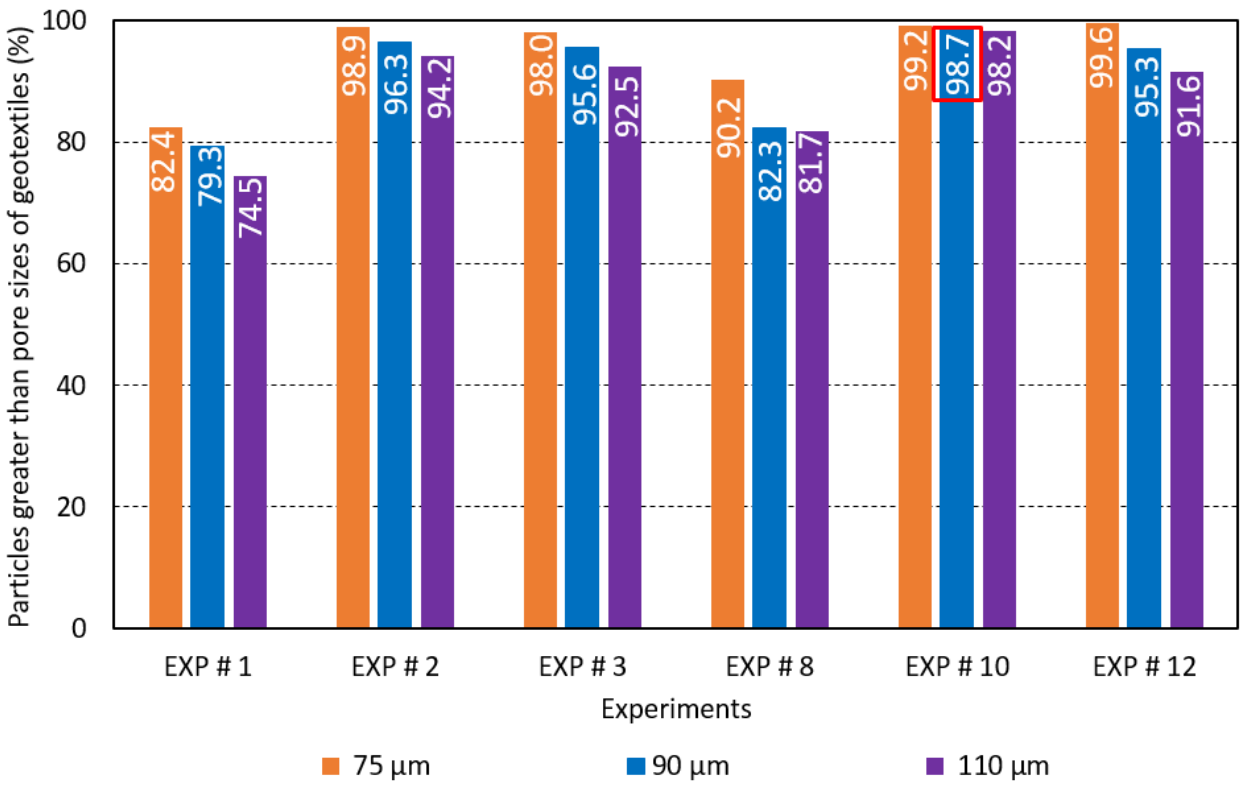


Figure 4.14 Percentage of particles higher than pore sizes of geotextiles at the beginning of filtration for different experiments with initial turbidities ranging from >4 to ≤ 9 NTU

As stated in the methodology section that a YSI 6600 V2 sonde was kept inside the tank to measure the hourly pH, temperature, dissolved oxygen (DO), redox potential, chlorophyll α and blue green algae (BGA) of the water during the experiments. The results for experiment 10 obtained from the sonde are presented here. The lower the concentration of chlorophyll α present in the water, the lower the concentration of algae living in the water. For experiment 10, initially the concentration of chlorophyll α was 3 μg/L and finally it reduced to 0.8 μg/L, which meant less living algae in the water. The average concentration of chlorophyll α was 1.6 μg/L. Figure 4.15 shows the decreasing trend of chlorophyll α for experiment 10. The graph was plotted with hourly data obtained from the sonde during the experiment. From the figure it was found that the chlorophyll α concentration reduced to 2 μg/L at day 2 and for the maximum time of the remaining days of the experiment, it was less than 2 μg/L.

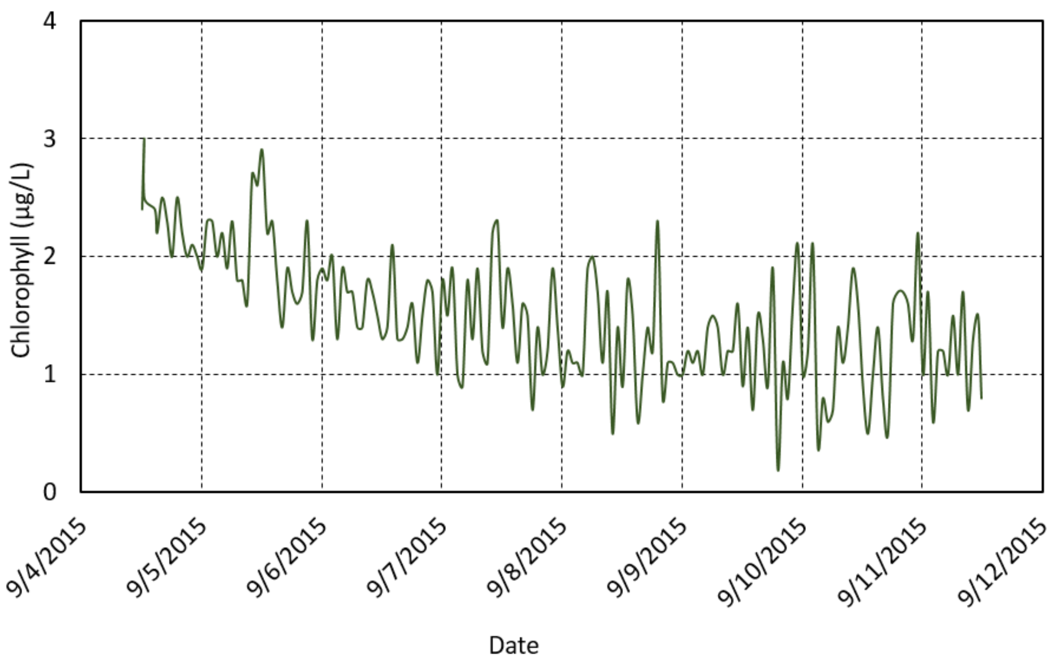


Figure 4.15 Decreasing trends of chlorophyll α for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

A lower amount of blue green algae in water is good for aquatic life. As discussed earlier, the concentration of nutrients present in the water is directly proportional to the growth of blue green algae (BGA). Figure 4.16 shows the hourly decreasing trend of BGA for experiment 10. In this experiment, from day 2 to the end, BGA concentration remained below 500 cells/mL. Initially it was 1343 cells/mL with an average concentration of 741 cells/mL.

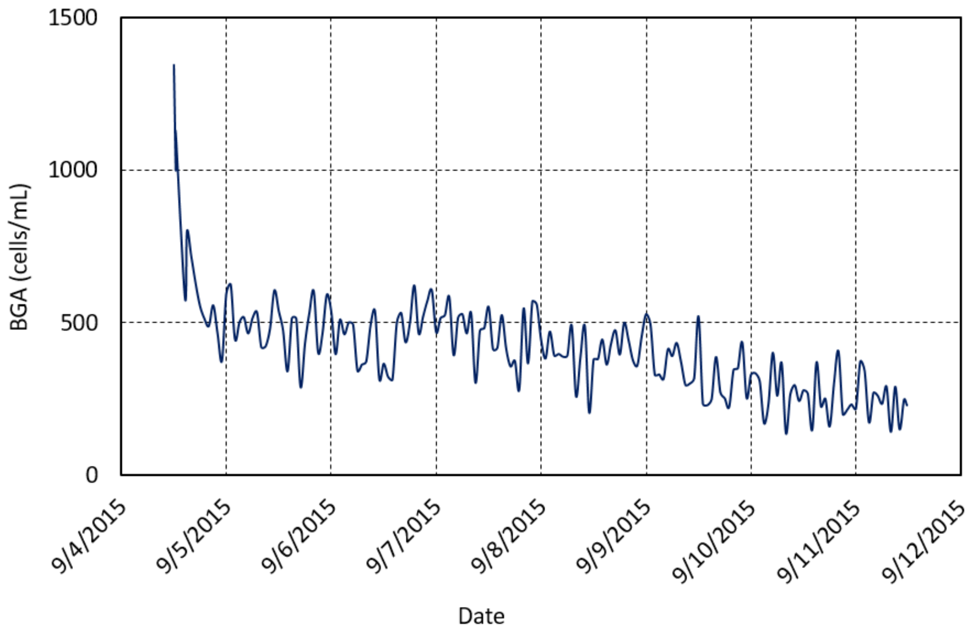


Figure 4.16 Decreasing trends of BGA for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

During the experiment, the temperature and pH varied from 31^{0}C to 24^{0}C and 6.69 to 5.97. The average temperature and pH were 28^{0}C and 6.33 respectively. The graphs for hourly temperature and pH with time for experiment 10 are presented in Figures 4.17 and 4.18.

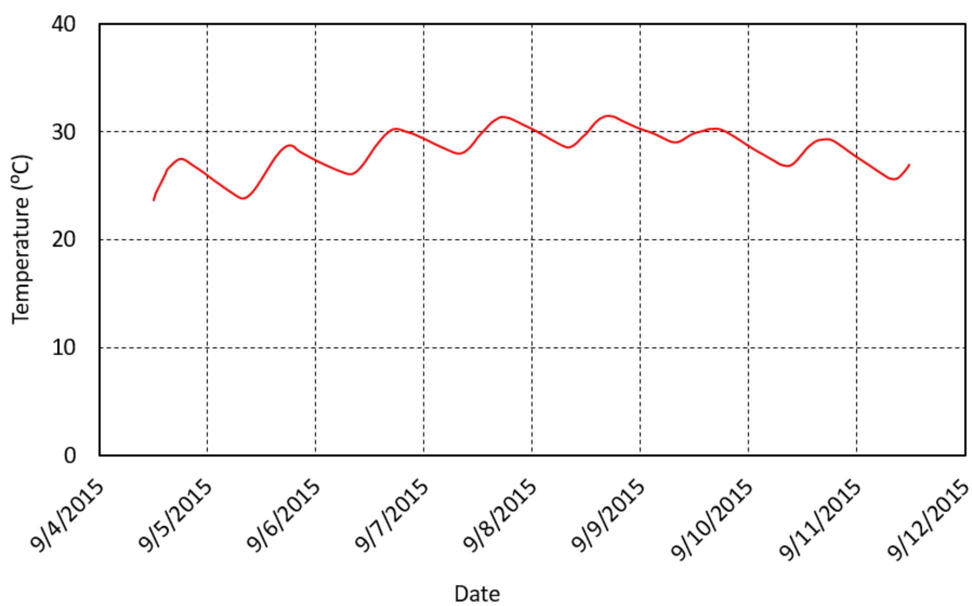


Figure 4.17 Results for water temperature variation with time for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

The reduced state of water bodies can be determined by measuring the oxygen reduction potential. The oxygen reduction potential for experiment 10 varied from 180 mV to 255 mV with an average value of 218 mV. The graphs for hourly ORP with time for experiment 10 are presented in Figure 4.19.

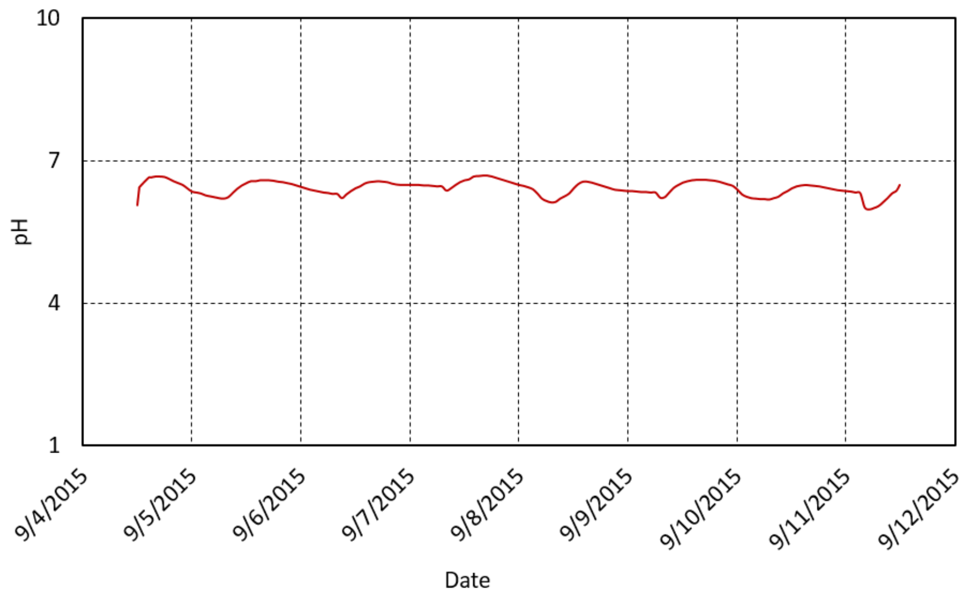


Figure 4.18 Results for variation of pH with time for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

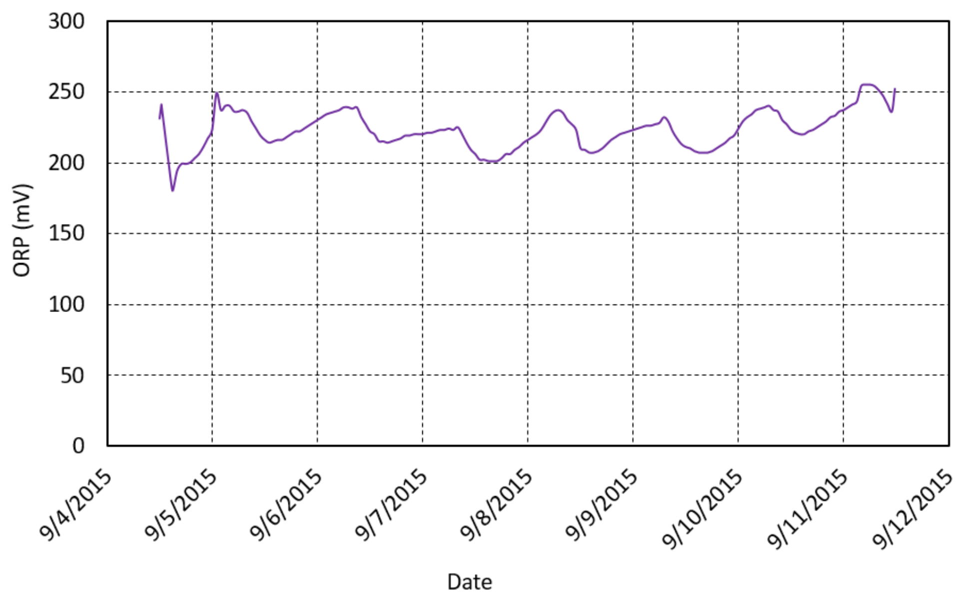


Figure 4.19 Results for variation of ORP with time for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

Figure 4.20 shows the hourly dissolved oxygen expressed as a percent of air-saturation (ODO%) with time for experiment 10. ODO% means the ratio of the amount of oxygen dissolved in water with the maximum amount that could be present in the water under air-saturated conditions. As aquatic plants and algae produce oxygen, dissolved oxygen saturation levels in the range of 80 - 120% are considered excellent for aquatic life (YSI, 2015). The ODO varied from 94% to 100% with an average value of 97 % during the experiment.

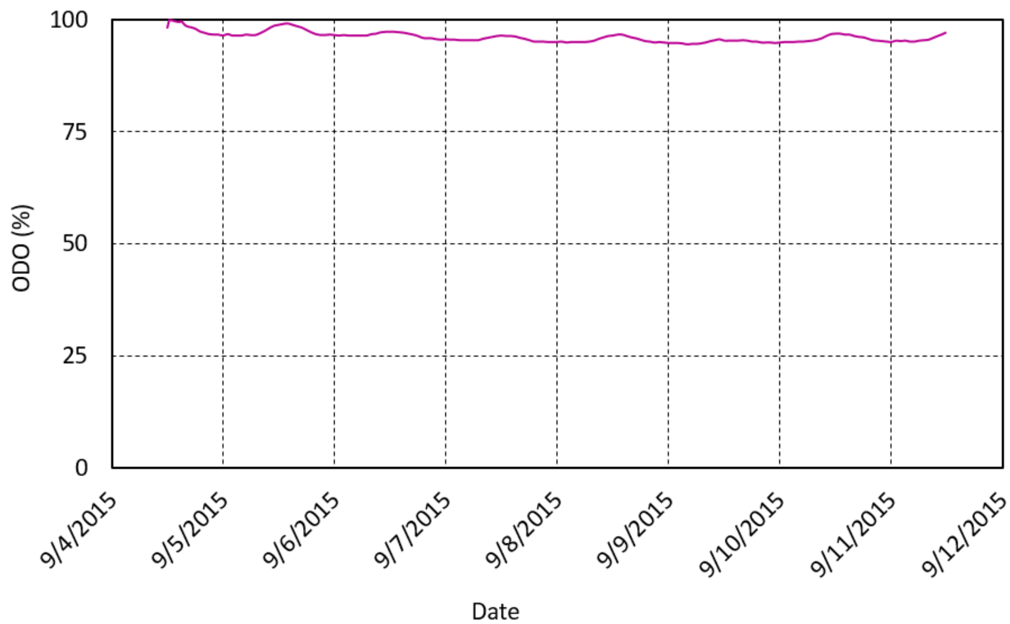


Figure 4.20 Results for variation of ODO (%) with time for the best combination (experiment 10) with initial turbidities ranging from >4 to ≤ 9 NTU

4.3.2 Initial turbidity range >9 to ≤ 14 NTU

Experiments 11, 13 and 14 were those experiments whose initial turbidity values ranged from 9 to 14 NTU. Experiment 14 was the only one where three apparent opening sizes were used together as a filter media.

For all experiments of this category, the initial concentrations of total suspended solids, COD and nitrate were below the acceptable limits whereas the initial concentration of phosphorus was above the allowable level (Table 4.2). Only in experiment 14, the initial concentration of total nitrogen exceeded the allowable limit and the initial turbidity was above 10 NTU for experiment 13 and 14. Therefore, the best filter combination was selected based on the removal of total phosphorus, total nitrogen and turbidity within shorter period of time to achieve acceptable limits.

Figure 4.21 shows the removal trends of total phosphorus for experiments 11, 13 and 14 where the initial total phosphorus concentration varied from 0.05 to 0.06 mg/L. As the lake is in the eutrophic state with a higher concentration of total phosphorus, so it was very necessary to remove total phosphorus from the water to an allowable range (0.03 mg/L) in order to stop eutrophication as well as to improve the water quality. From Figure 4.21, the concentration was obtained only for experiment 11 at day 3. For experiments 13 and 14, the final phosphorus concentrations at day 6 and 7 were 0.04 mg/L and 0.035 mg/L, higher than the allowable limit. The initial phosphorus concentration in experiment 11 was 0.06 mg/L. Similar to the previous turbidity range, a logarithmic correlation with higher R^2 value (more than 0.75) was observed in case of total phosphorus removal over time. For experiment 11, the R^2 value was 0.96.

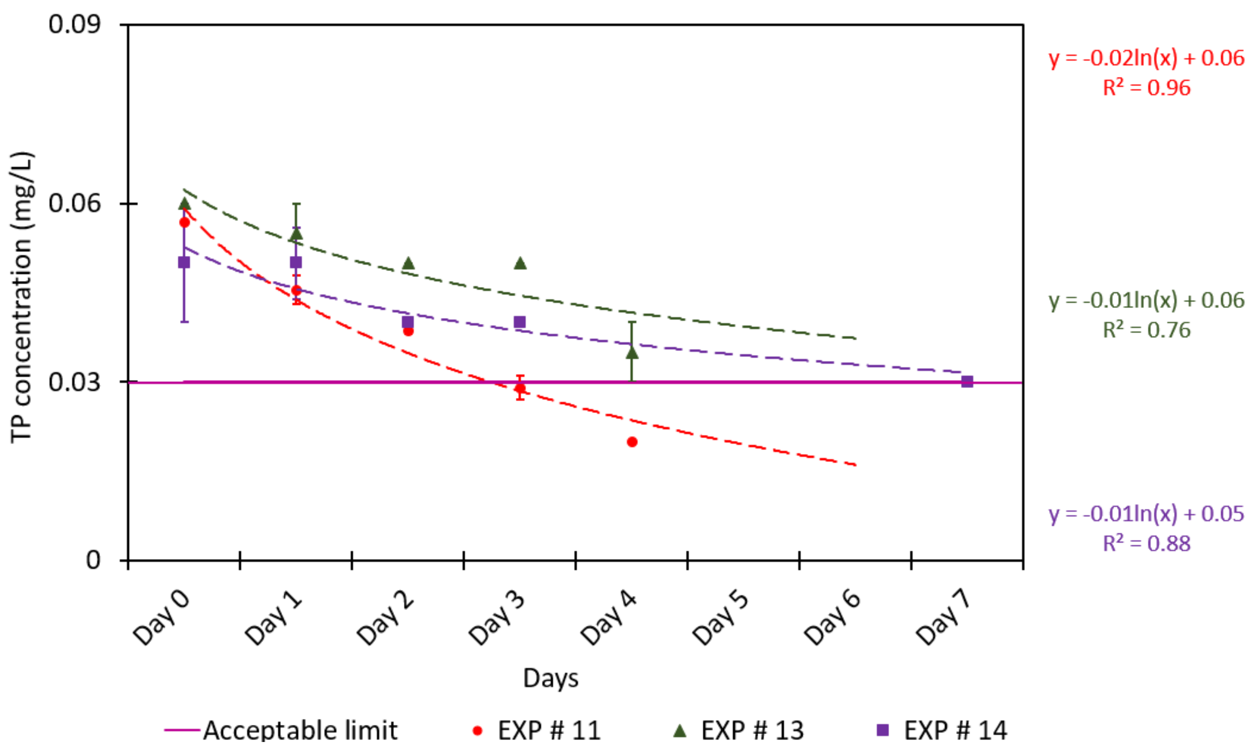


Figure 4.21 Removal trends of total phosphorus for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

As stated earlier, if the total nitrogen concentration of a water body is below 1 mg/L, then the water body is considered to be good (Environment Canada, 2014). Figure 4.22 shows the removal patterns of total nitrogen for experiments 11, 13 and 14. Here, the initial total nitrogen concentration for experiment 14 (1.22 mg/L) was only above the allowable limit and for the rest of the experiments the initial concentrations were below 0.6 mg/L. At the end of experiment 14 at day 7, the concentration of total nitrogen was 1 mg/L.

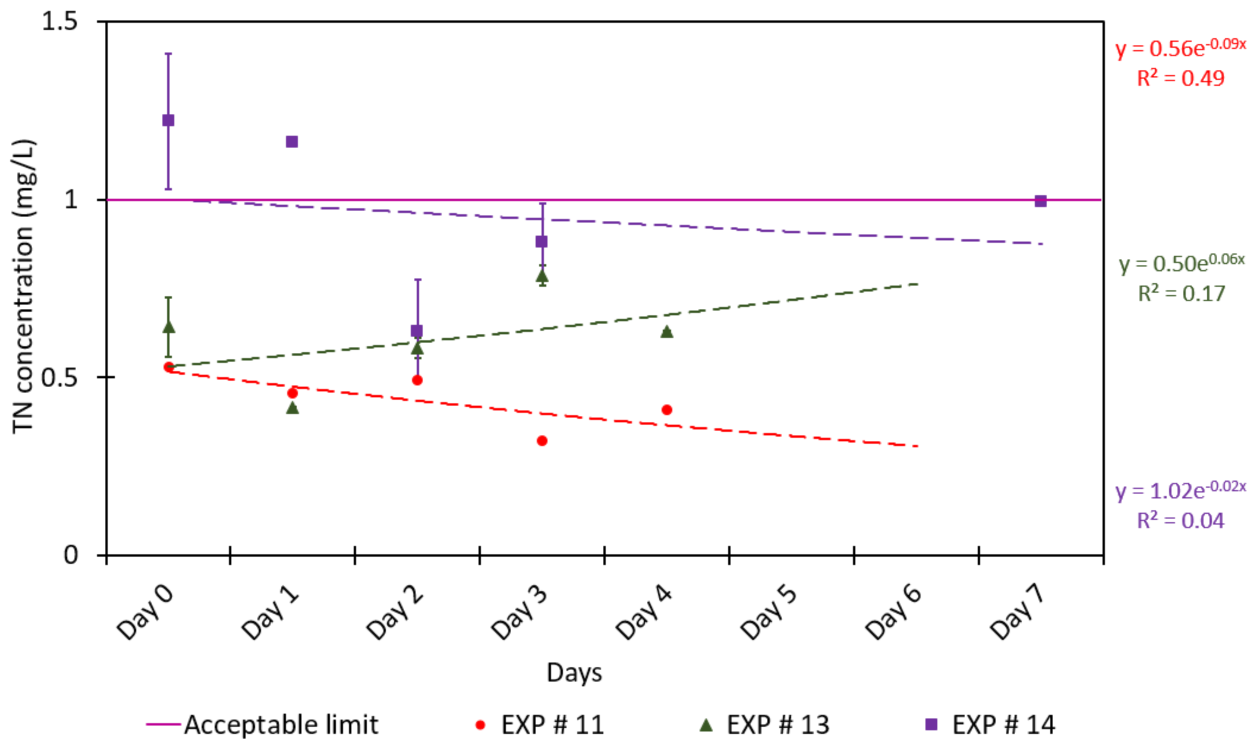


Figure 4.22 Removal trends of total nitrogen for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

Figure 4.23 shows the removal trend and R^2 value of turbidity for experiments 11, 13 and 14. As discussed in earlier section, MDDEP (2009) suggested different turbidity standards for different surface water conditions. But, Environment and Climate Change, Canada (2015) suggested that the maximum allowable turbidity value for surface water is 10 NTU. So, in this study, the maximum allowable turbidity value for surface water was considered as 10 NTU. Only in experiment 14, the initial turbidity value was higher than 10 NTU and at the end of experiment at day 7, it became almost 0. In experiment 11, the initial turbidity was 9.2 NTU and 97% of the initial turbidity was reduced at day 4 (0.31 NTU). Similar to previous section, in the case of turbidity removal, an exponential correlation with higher R^2 value had also been observed for experiments 11, 13 and 14.

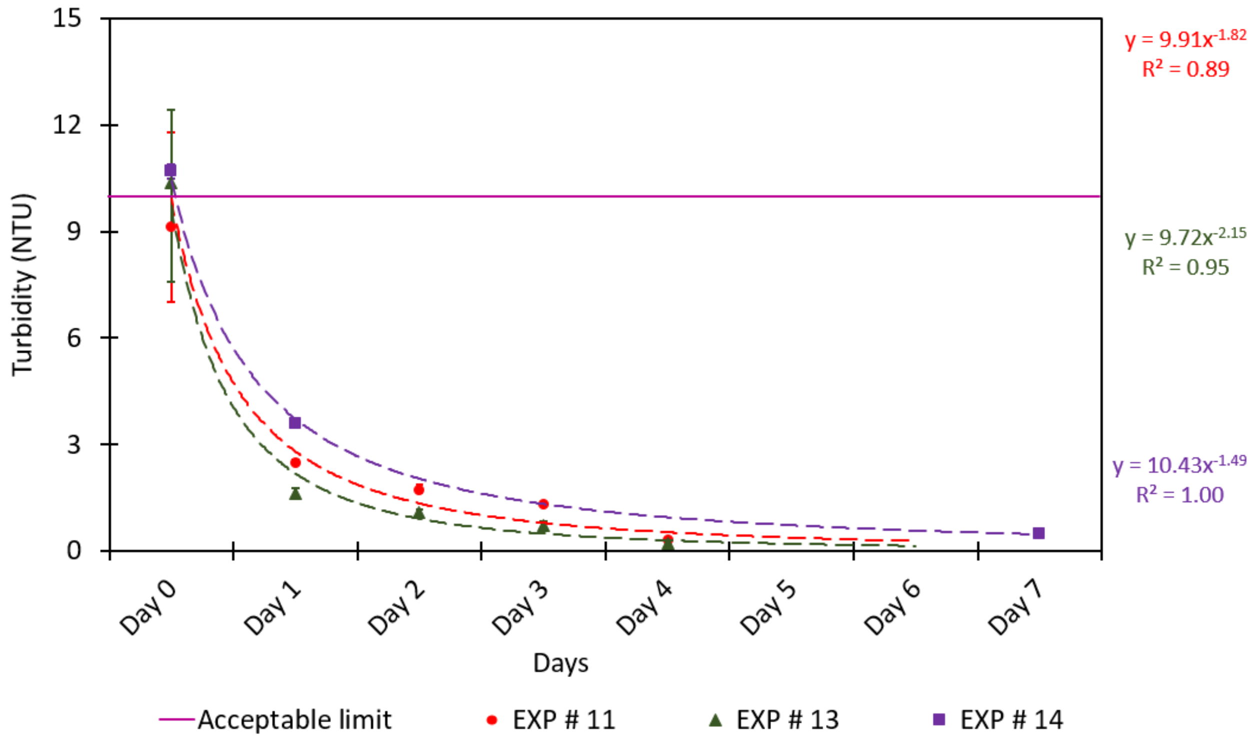


Figure 4.23 Removal trends of turbidity for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

For large algal growth in water bodies, excess amounts of total phosphorus is one of the responsible parameters. So, removing phosphorus from the water to an allowable range (0.03 mg/L) can improve the water quality and also maintain a healthy aquatic life. As in experiments 13 and 14, the final total phosphorus concentration didn't reduce to that acceptable limit, so based on removal of total phosphorus within shorter periods of time to achieve acceptable limits, the combination of geotextiles used in experiment 11, i.e., 2 layers of 110 μm at the top followed by 3 layers of 75 μm at the bottom was chosen as the best combination for the initial turbidity range of 9 to 14 NTU.

The removal patterns of nitrate, COD and total suspended solids for different days for experiment 11, 13 and 14 had been shown in Figures 4.24 to 4.26. Similar to the previous one, nitrate concentration reduced a bit and the removal rate was 26%. This filter combination removed about 84% of COD. Because of the use of smaller pore size geotextiles, i.e., 3 layers of 75 μm at the bottom, initial turbidity, and total suspended solids became almost 0 at day five. Most of the suspended solids were removed by this combination. At the end of the experiment, suspended solids concentration were reduced to 0.2 mg/L from 9.1 mg/L. The decreasing trends of total suspended solids are presented in Figure 4.26.

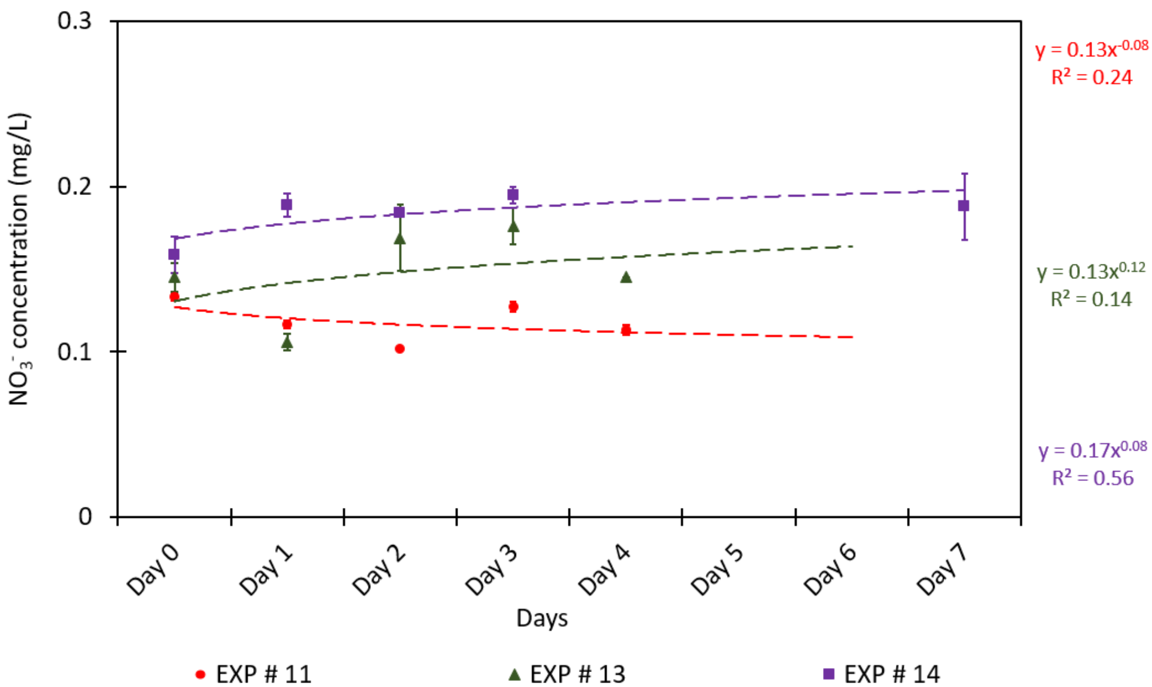


Figure 4.24 Removal trends of nitrate for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

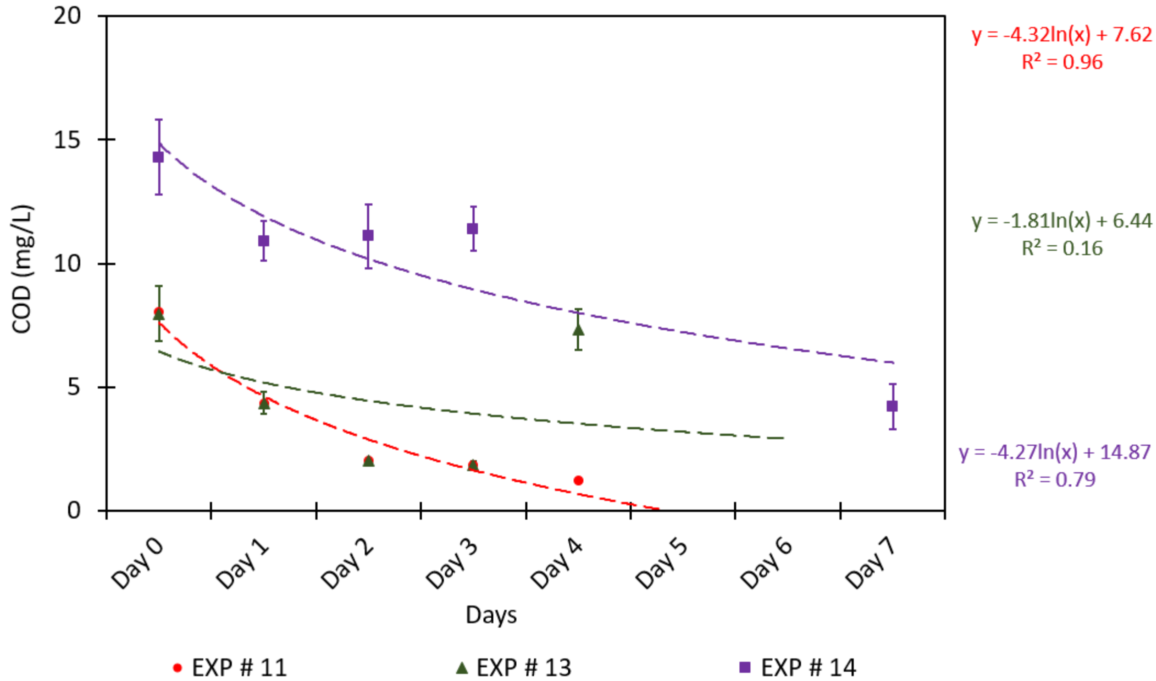


Figure 4.25 Removal trends of COD for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

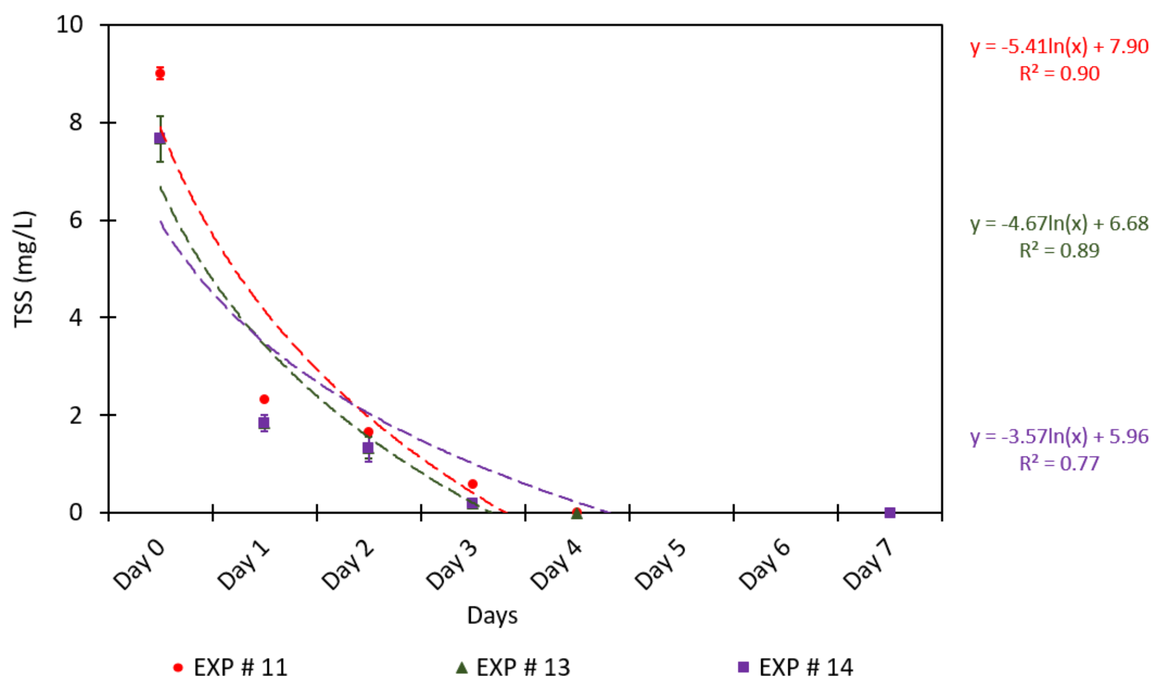


Figure 4.26 Removal trends of total suspended solids for the experiments with initial turbidities ranging from >9 to ≤ 14 NTU

From the above results, it is found that, for the initial turbidity range of 9 to 14 NTU, the geotextile combination (2 layers of 110 μm followed by 3 layers of 75 μm) used in experiment 11 showed the best results which took 3 days to reduce the water quality parameters to the acceptable limits.

Figure 4.27 shows the percentage of particles higher than 110, 90 and 75 μm at the beginning of filtration for different experiments conducted within this initial turbidity range. The minimum pore size of geotextile filters used in the experiments performed with initial turbidity ranging from 9 to 14 NTU was 75 μm. So, these filters removed the particles higher than 75 μm throughout the filtration and at the end of experiments, no particles higher than 75 μm were found. Hence, the experiment 11, which had the highest percentage of particles having size more than 75 μm (98%), removed maximum nutrients and provided maximum efficiency among all the experiments conducted within this initial turbidity range.

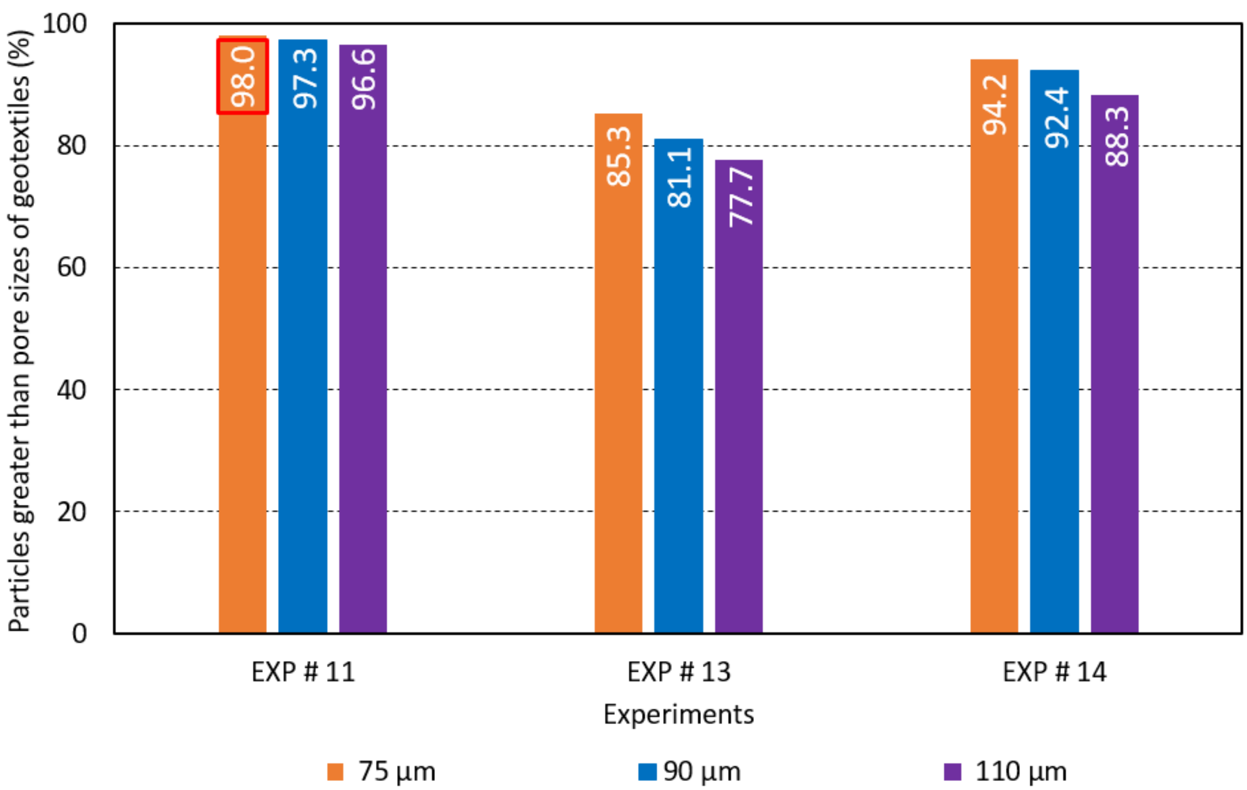


Figure 4.27 Percentage of particles higher than pore sizes of geotextiles at the beginning of filtration for different experiments with initial turbidities ranging from >9 to ≤ 14 NTU

The results for experiment 11 obtained from the sonde are presented here. For experiment 11, the concentration of chlorophyll α ranged from 3.6 to 0.7 μg/L with an average value of 2.15 μg/L. Figure 4.28 shows the decreasing trends of chlorophyll α for experiment 11. The graph was plotted with hourly data obtained from the sonde during the experiment.

Lower amounts of blue green algae in water are good for aquatic life. In this experiment, from day 2 to the end, BGA concentration remained below 500 cells/mL. Initially it was 1439 cells/mL with an average concentration of 700 cells/mL. At the end of experiment, there were no BGA cells present in the water. Figure 4.29 showed the hourly decreasing trend of BGA for experiment 11.

The average temperature and pH of experiment 11 were 24^0C and 6.11 respectively. During the experiment, the temperature and pH didn't vary very much. The variation of temperature and pH were from 26^0C to 22^0C and 6.66 to 5.56. The graphs for hourly temperature and pH with time for experiment 11 are presented in Figures 4.30 and 4.31.

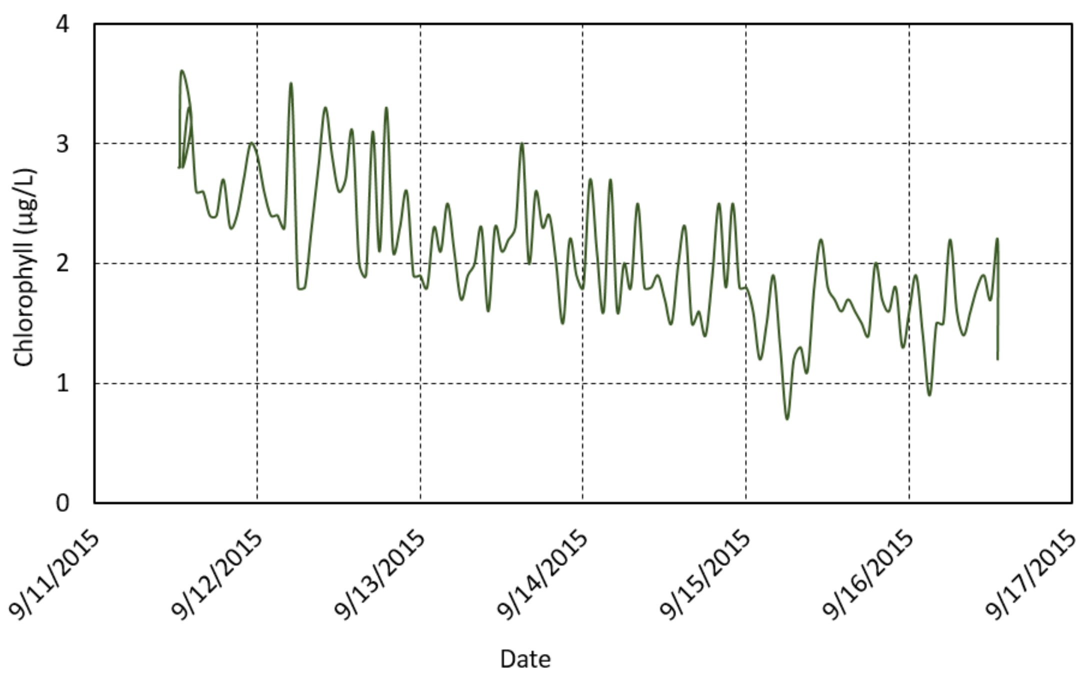


Figure 4.28 Decreasing trends of chlorophyll α for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

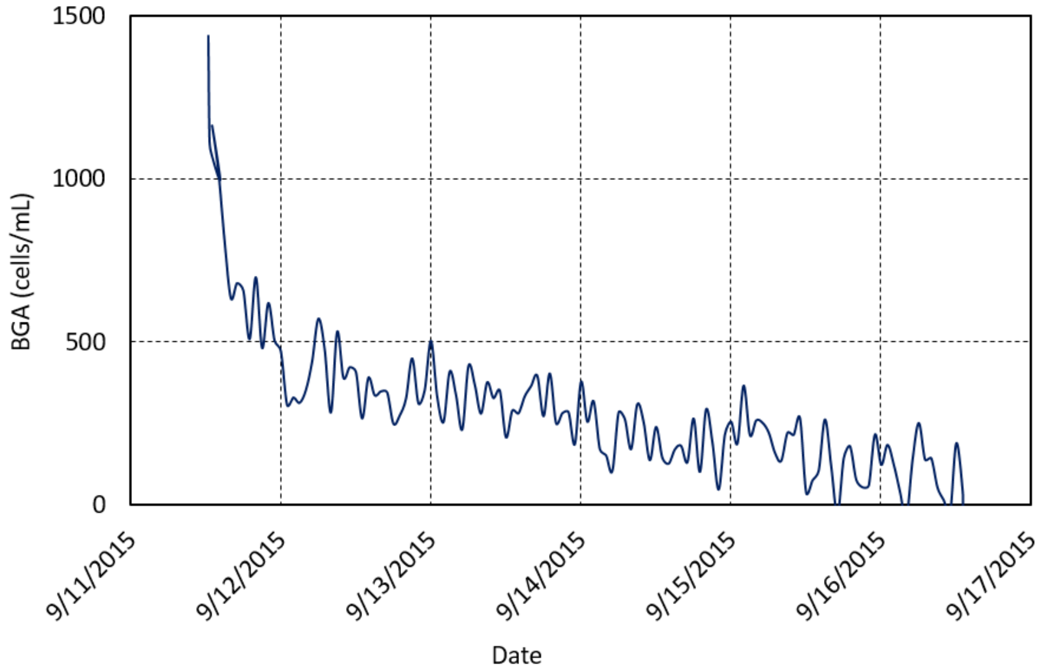


Figure 4.29 Decreasing trends of BGA for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

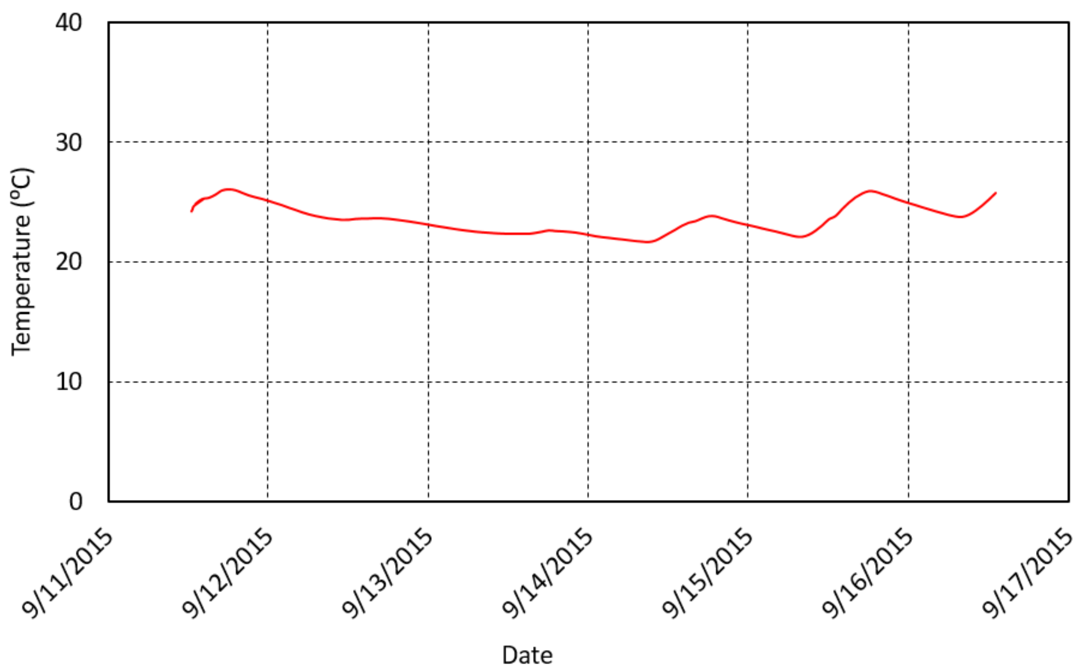


Figure 4.30 Results for water temperature variation with time for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

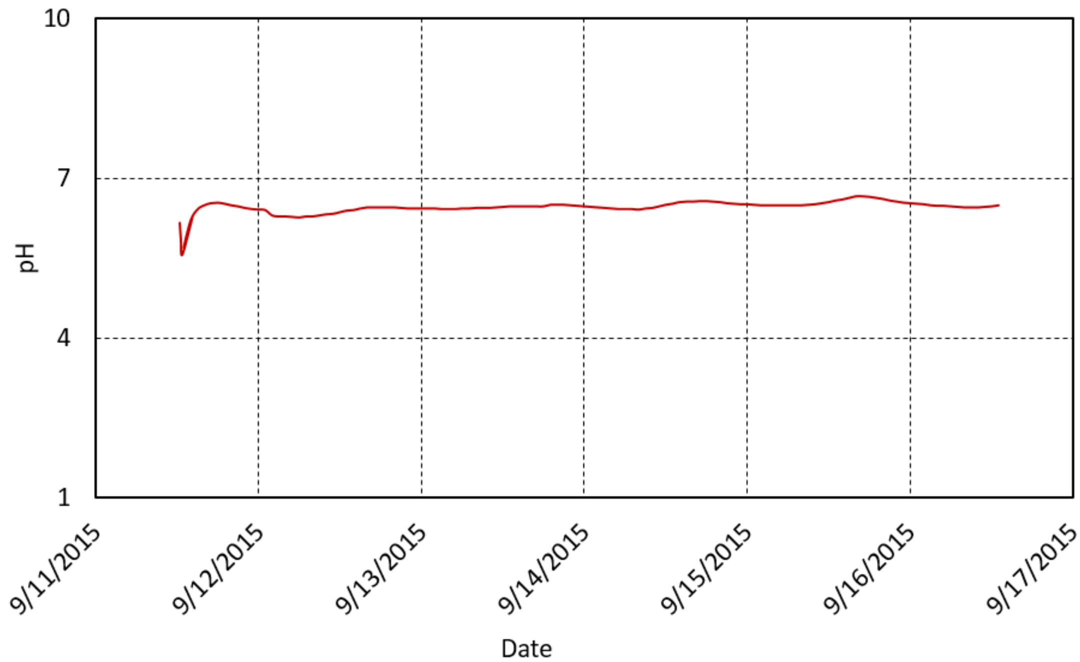


Figure 4.31 Results for variation of pH with time for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

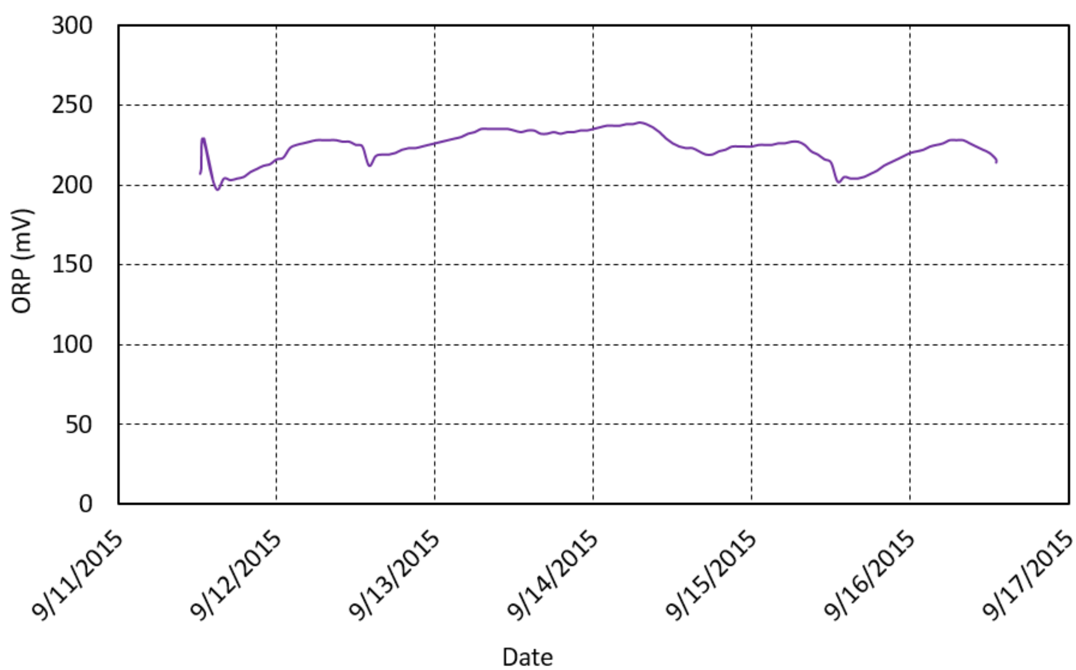


Figure 4.32 Results for variation of ORP with time for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

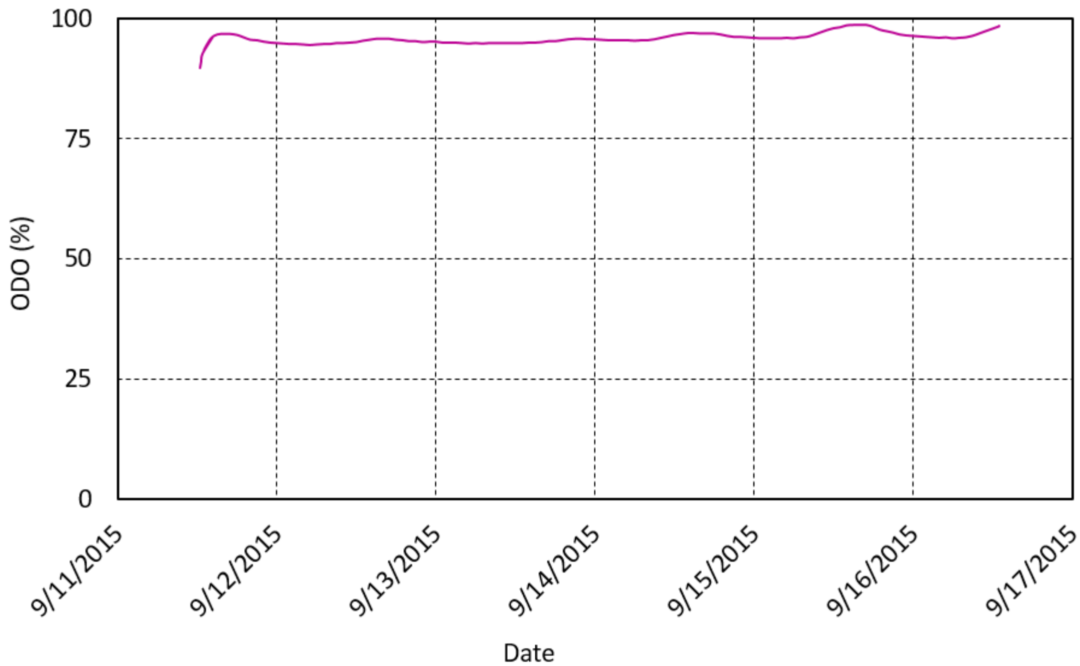


Figure 4.33 Results of variation of ODO (%) with time for the best combination (experiment 11) with initial turbidities ranging from >9 to ≤ 14 NTU

The oxygen reduction potential for experiment 11 varied from 197 mV to 239 mV with an average value of 218 mV. The graphs for hourly ORP with time for experiment 10 are presented in Figure 4.32. Figure 4.33 shows the hourly ODO % with time for experiment 11. The ODO varied from 90% to 99% with an average value of 94 % during the experiment.

4.3.3 Initial turbidity range >14 to ≤ 19 NTU

Four experiments were done in the initial turbidity range of 14 to 19 NTU. They were experiment numbers 4, 5, 7 and 9. In experiment 4, 1 layer of 110 μm at the top with 3 layers of 90 μm below were used. For the rest of the experiments, 5 layers of different combination were used.

In this category, the initial total phosphorus concentration and turbidity were above the allowable level for all the experiments. The initial COD concentration exceeded the allowable limit for all the experiments except experiment 5 while, only in experiment 9, the initial concentration of total nitrogen exceeded the allowable limit. The initial concentrations of total suspended solids, and nitrate lied within the allowable range. Therefore, the best filter combination was selected based on the removal of total phosphorus, turbidity, COD and total nitrogen within smaller periods of time to achieve acceptable limits.

Figure 4.34 shows the removal trends of total phosphorus for experiments 4, 5, 7 and 9 where the maximum initial total phosphorus concentration was 0.07 mg/L in both experiments 5 and 9 and the minimum was 0.04 mg/L in experiment 4. From Figure 4.34, the maximum allowable concentration was obtained for experiments 5 and 7 at day 2 and day 4 respectively. The same concentration was achieved at day 3 in experiment 4 but it should be noted that the initial concentration in experiment 4 was lower, 0.04 mg/L. A logarithmic correlation with higher R^2 value (more than 0.8 for most of the experiments) had been observed in case of total phosphorus removal. For experiments 5 and 7, the R^2 value was 0.97 and 0.89 respectively.

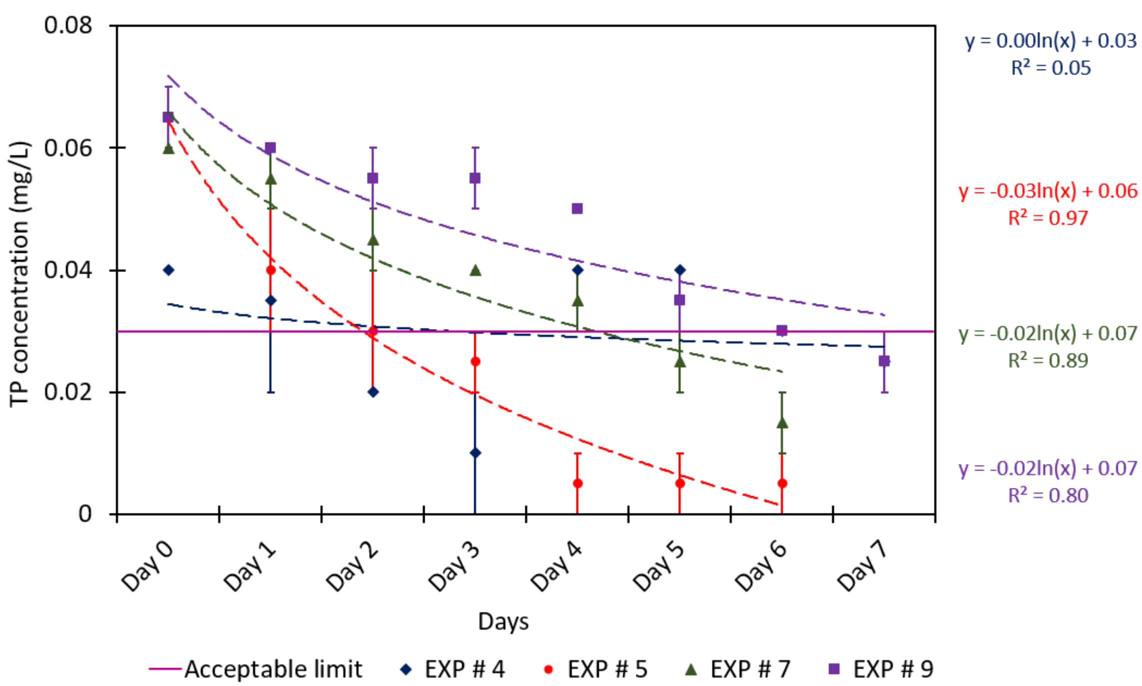


Figure 4.34 Removal trends of total phosphorus for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

As in this category, those experiments were carried out whose initial turbidity ranged from 14 to 19 NTU, so for all the experiments the initial turbidity were above 10 NTU. Figure 4.35 shows the removal trend and R^2 value of turbidity for experiment 4, 5, 7 and 9. For all the experiments, the turbidity became less than 10 NTU at day 1. A logarithmic correlation with higher R^2 value (more than 0.95) had been observed in the case of turbidity removal.

Figure 4.36 shows the removal patterns of COD and R^2 value for experiments 4, 5, 7 and 9. The initial COD concentration for experiments 4, 7 and 9 was above 20 mg/L. Only in experiment 5, COD was below that concentration. Among the experiments, at day 1 and day 2, the COD concentration reduced to 20 mg/L for experiments 4 and 7. While, for experiment 9, it took 6 days to reduce the COD concentration. Only for experiments 7 and 9, a logarithmic correlation with higher R^2 value (more than 0.85) was observed in the case of COD.

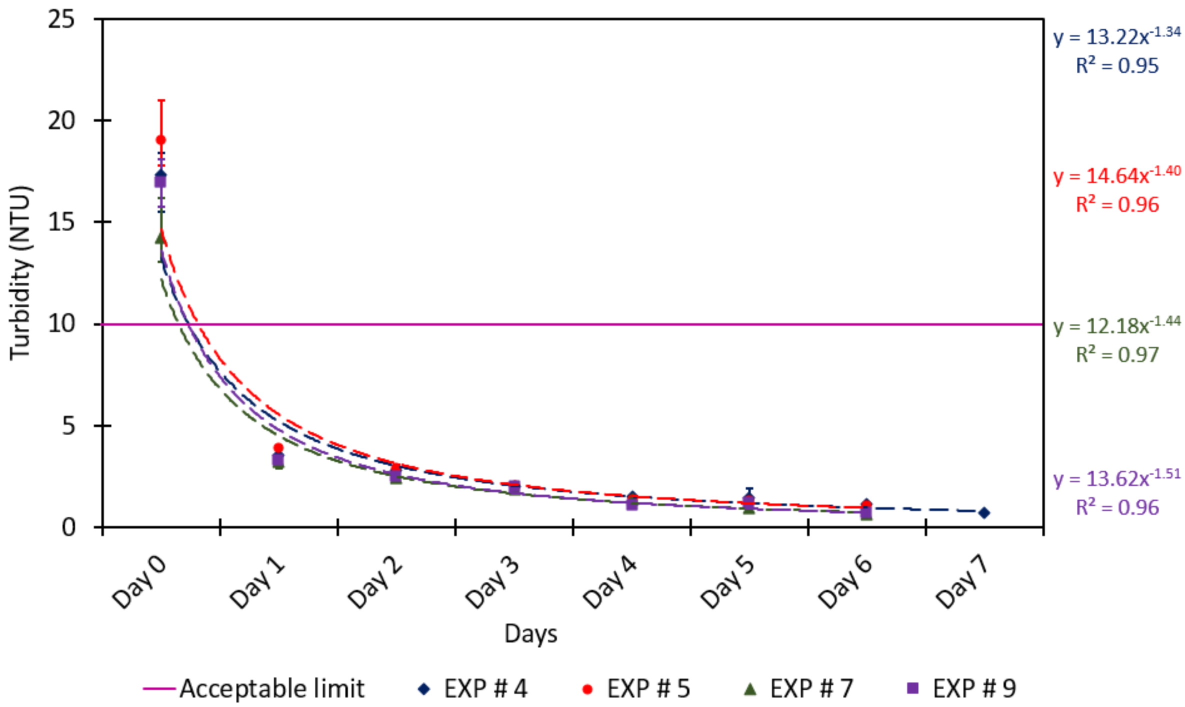


Figure 4.35 Removal trends of turbidity for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

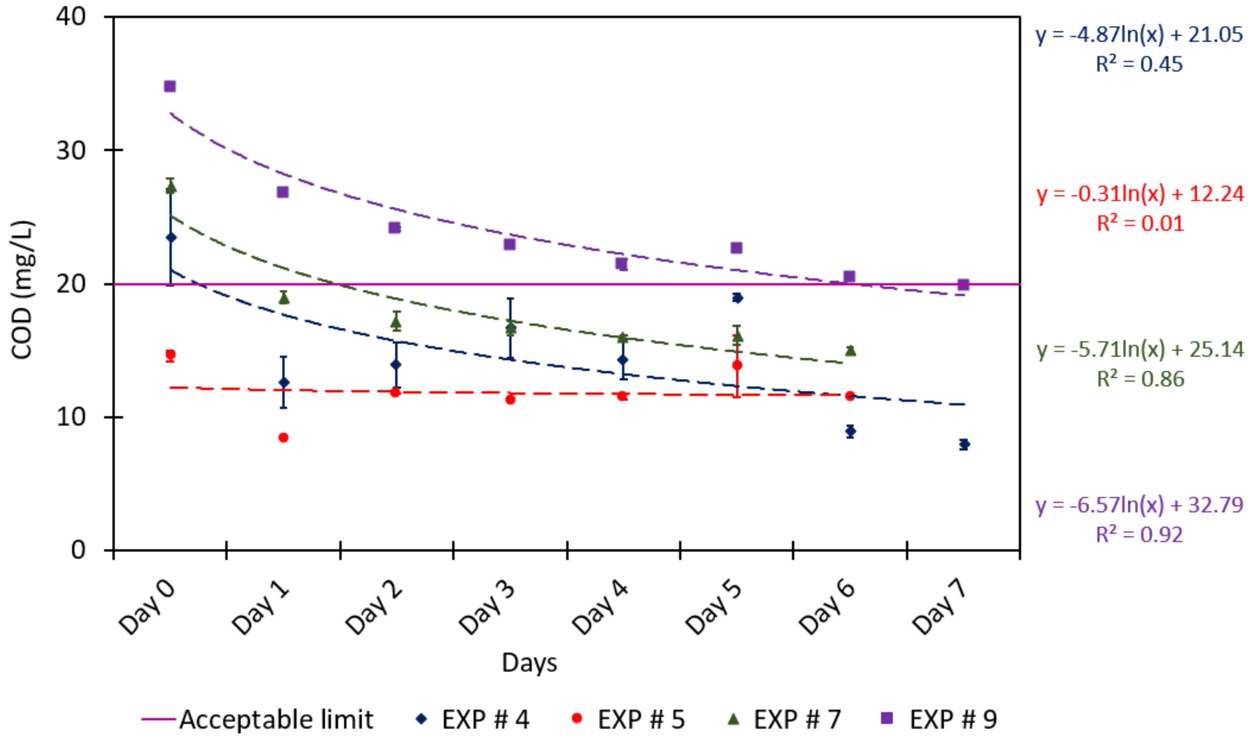


Figure 4.36 Removal trends of COD for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

From this study, it has been found that both experiments 5 and 7 worked better to remove total phosphorus and turbidity. But, experiment 5 took less time to reduce the phosphorus concentration to allowable range. Therefore, based on removal of total phosphorus within shorter period of time to achieve acceptable limits, the combination of geotextiles used in experiment 5, i.e., 1 layers of 110 µm at the top followed by 4 layers of 90 µm at the bottom had been chosen as the best combination for the initial turbidity range of 14 to 19 NTU.

The removal patterns of total nitrogen, nitrate and total suspended solids for different days for all the experiments lie within this turbidity range have been shown in Figures 4.37 to 4.39.

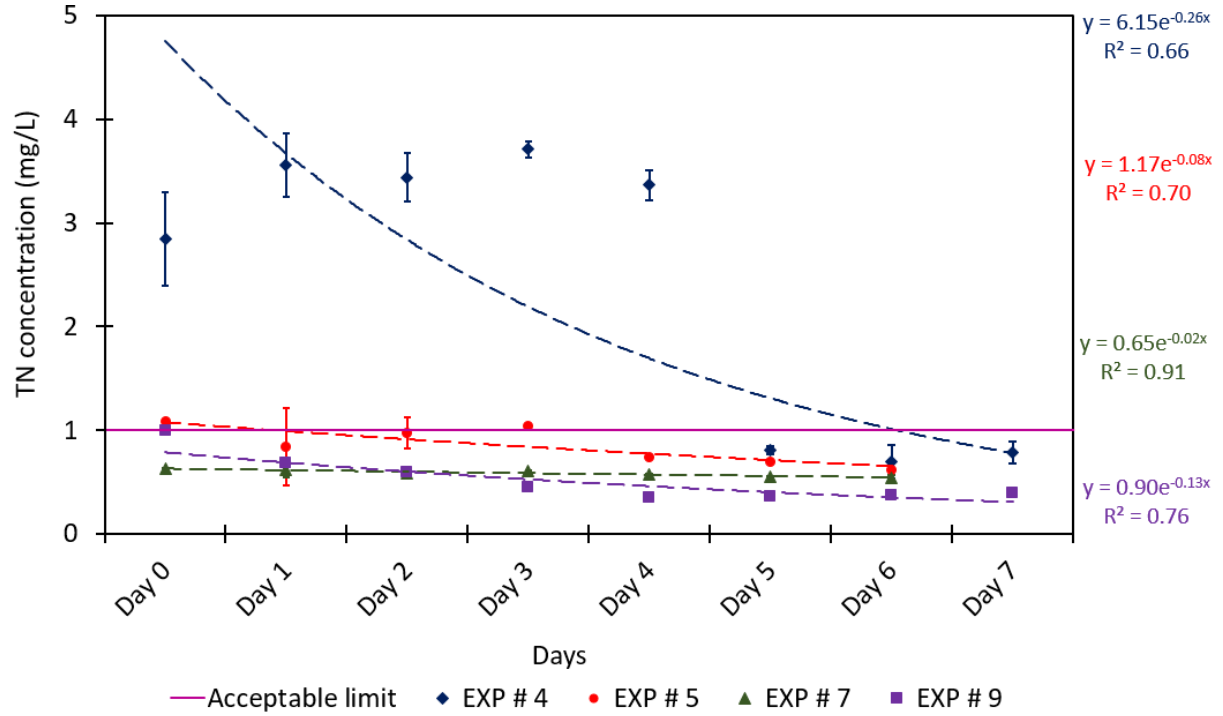


Figure 4.37 Removal trends of total nitrogen for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

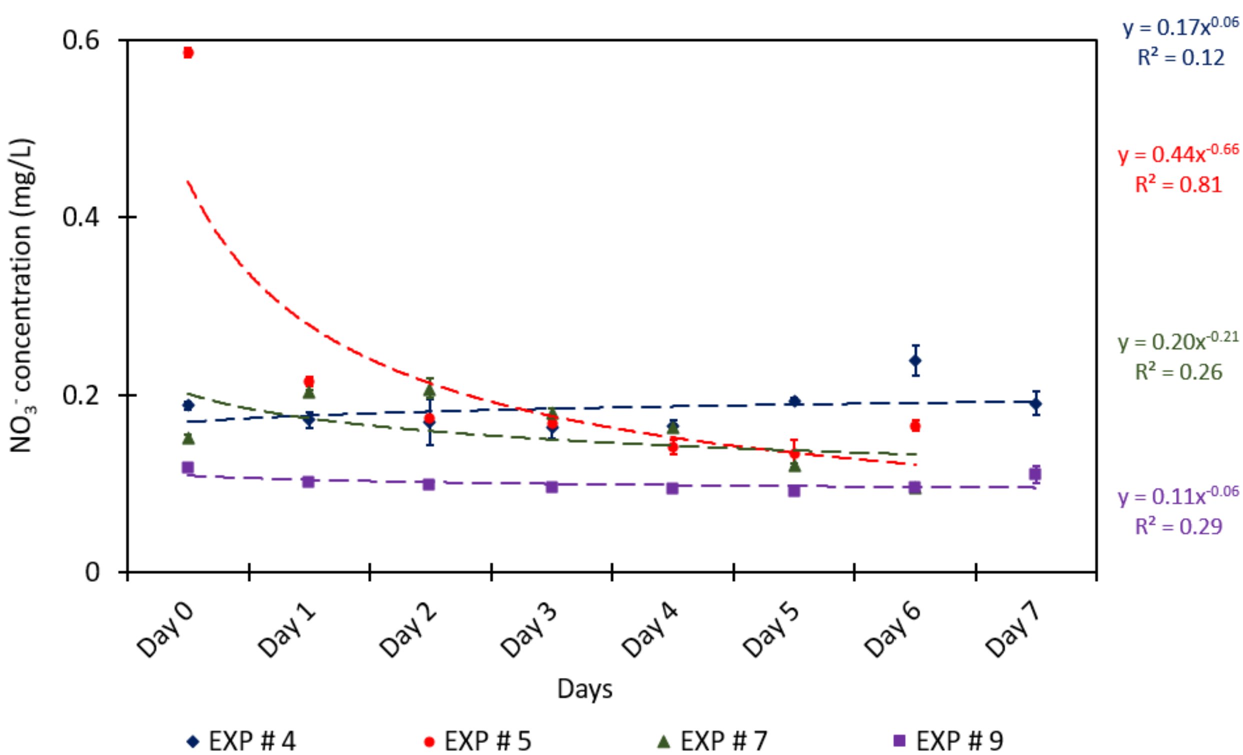


Figure 4.38 Removal trends of nitrate for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

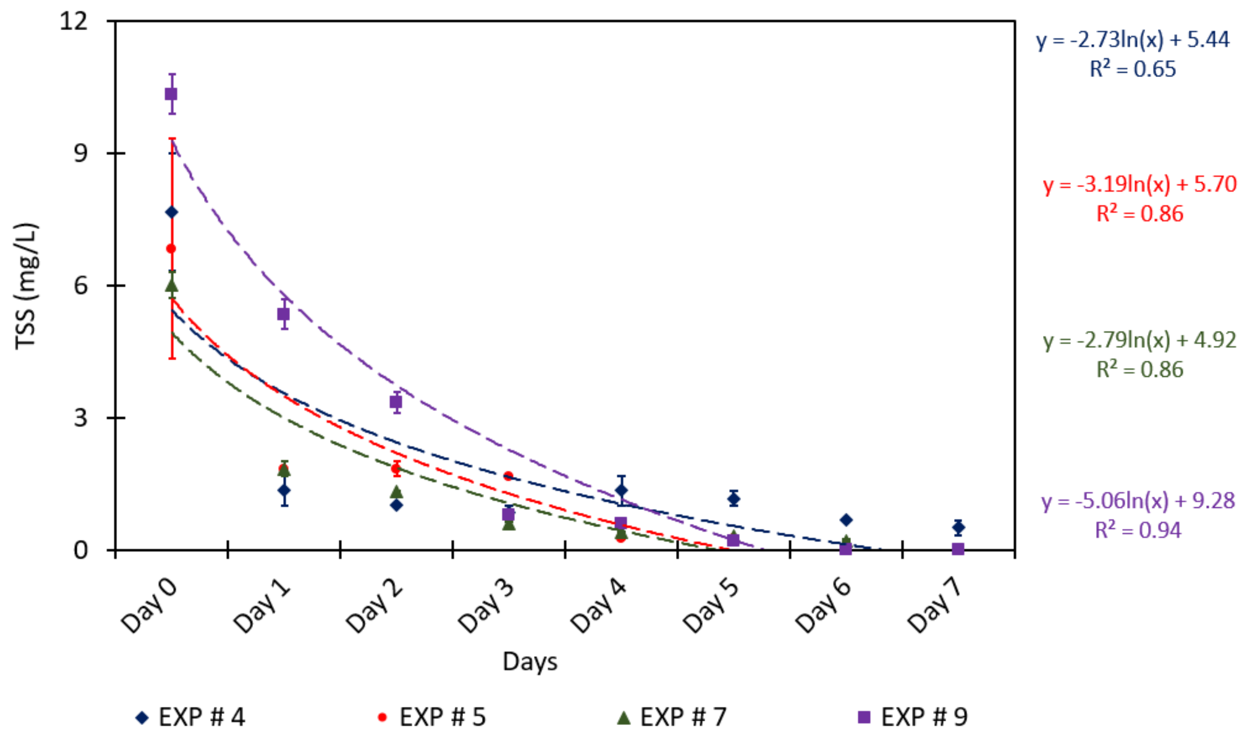


Figure 4.39 Removal trends of total suspended solids for the experiments with initial turbidities ranging from >14 to ≤ 19 NTU

Only in experiment 4, the initial total nitrogen concentration was higher than 1 mg/L which was reduced to 0.78 mg/L on the final day. For nitrate concentration, the initial concentration for experiment 5 was higher as compared to other experiments though they lied within the acceptable range. For experiment 5, the total suspended solids concentration was initially 5.33 mg/L, at day 4, it reduced to 0.2 mg/L and at the end there were no suspended solids.

Therefore, based on above discussed results of different water quality parameters, it can be said that the geotextile combination of 1 layers of 110 µm followed by 4 layers of 90 µm used in experiment 5 provide the maximum efficiency. It took 2 days to reduce the water quality parameters to the acceptable limits.

Figure 4.40 shows the percentage of particles higher than 110, 90 and 75 µm at the beginning of filtration for different experiments conducted within the initial turbidity range of 14 to 19 NTU. The minimum pore size of geotextile filters used in the experiments performed within this initial turbidity range was 90 µm. So, at the end of all experiments within this range, no particles higher than 90 µm were found as these filters removed the particles higher than 90 µm throughout the filtration duration. Hence, among all the experiments, experiment 5 contained the highest percentage of particles having size more than 90 µm (99.6%). So it removed maximum nutrients and provided maximum efficiency among all the experiments conducted within this initial turbidity range.

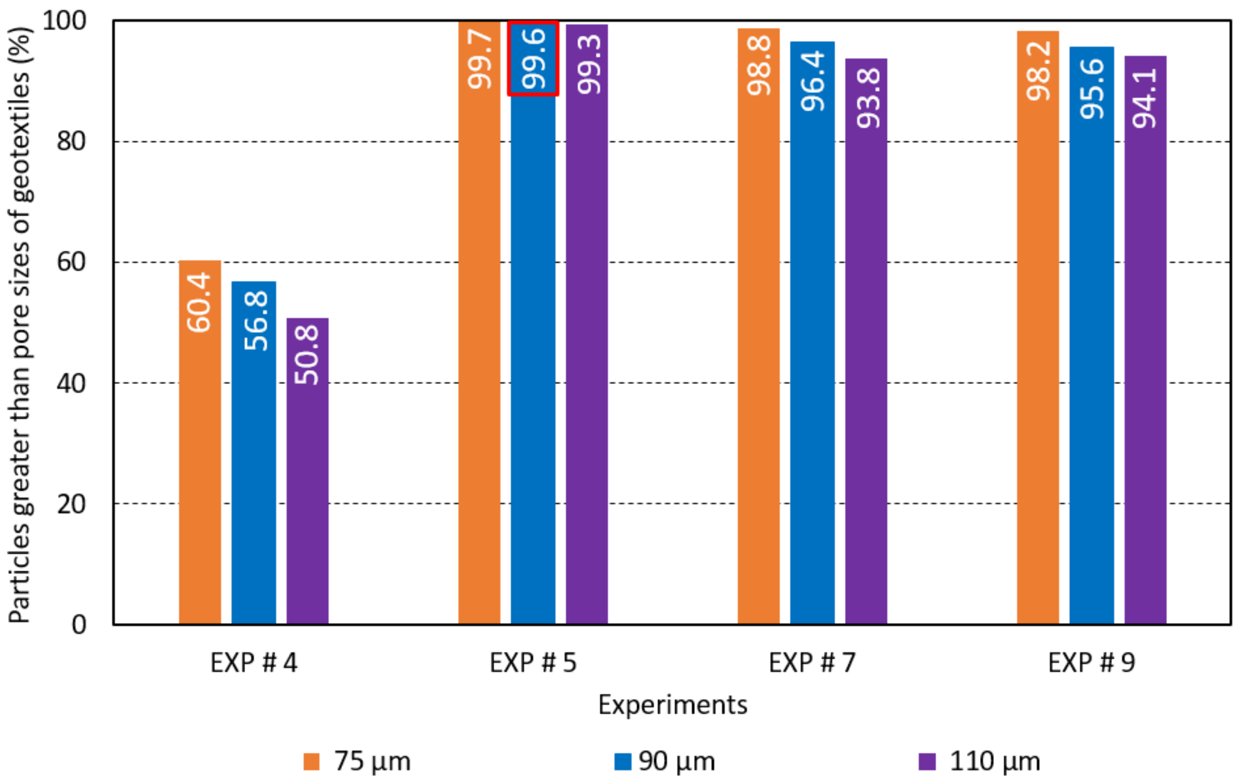


Figure 4.40 Percentage of particles higher than pore sizes of geotextiles at the beginning of filtration for different experiments conducted with initial turbidities ranging from 14 to 19 NTU

For experiment 5, initially the concentration of chlorophyll α was 6.5 µg/L and finally it reduced to 1.9 µg/L, which meant lower amount of living algae in the water. The average concentration of chlorophyll α was 3.55 µg/L. Figure 4.41 shows the decreasing trend of chlorophyll α for experiment 5. The graph was plotted with hourly data obtained from the sonde during the experiment. From the figure it was found that the chlorophyll α concentration reduced to 4 µg/L at day 1 and for the remaining time, it didn't increase but it was decreased gradually below 1 µg/L.

Initially BGA concentration was 1736 cells/mL with an average concentration of 781.5 cells/mL. But, at the end of experiment 5, there was no BGA present in the water. Figure 4.42 shows the hourly decreasing trend of BGA for experiment 5. Similar to the previous figure, the BGA concentration reduced to 500 cells/mL at day 3 and for the remaining days, it gradually decreased.

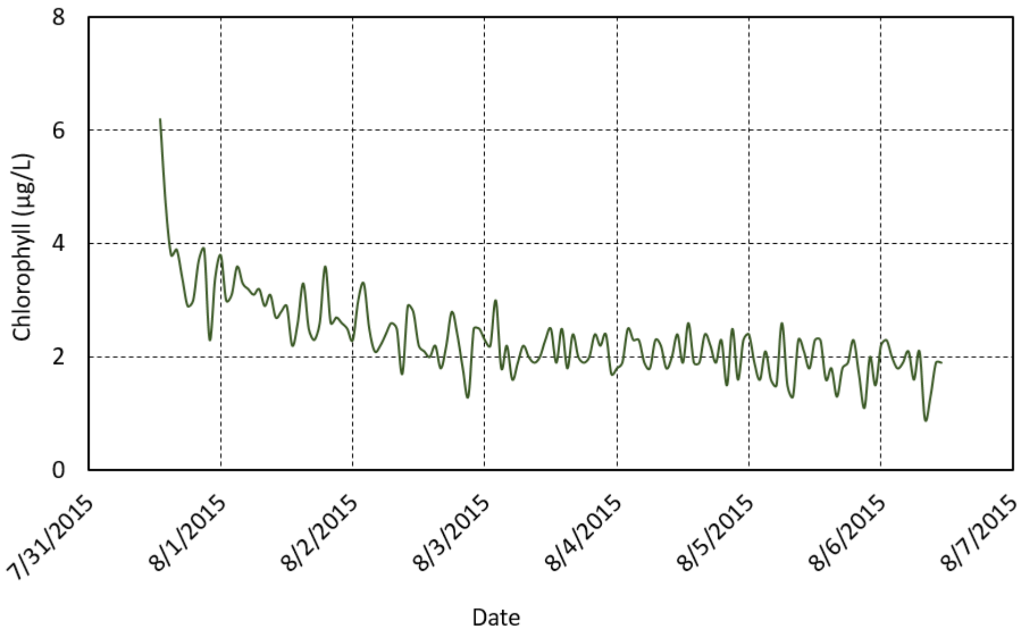


Figure 4.41 Decreasing trends of chlorophyll α for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

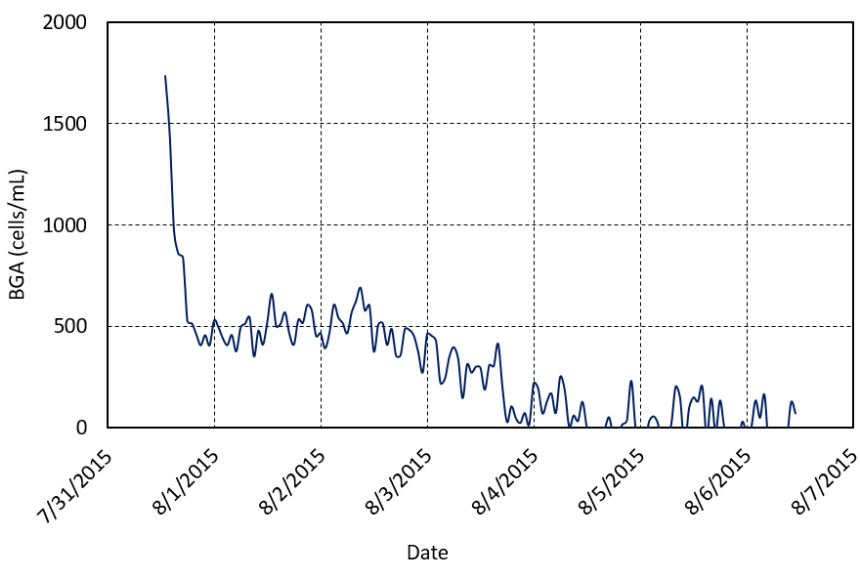


Figure 4.42 Decreasing trends of BGA for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

The temperature of experiment 5 ranged from 30^0C to 25^0C with an average temperature of 28^0C. During the experiment, pH varied from 6.71 to 6.28 with an average value of 6.5. The graphs for temperature, pH for experiment 5 are presented in Figures 4.43 and 4.44, respectively.

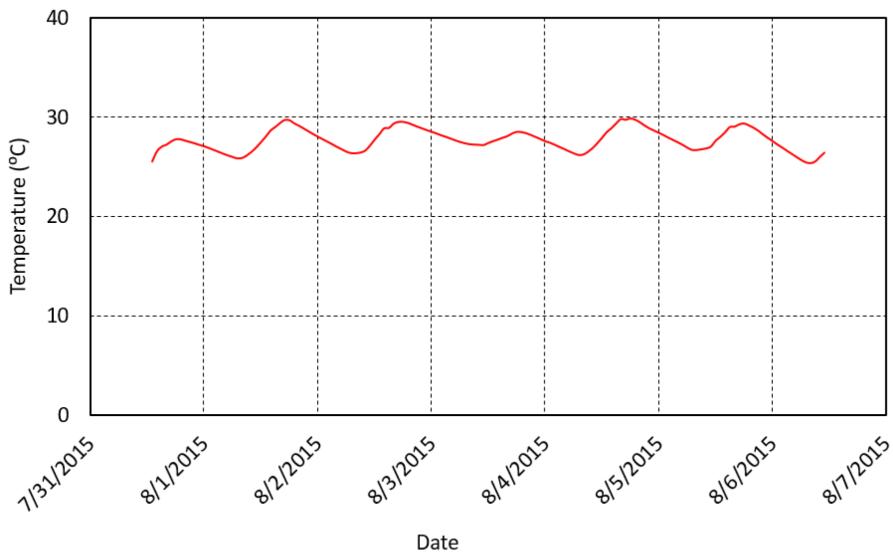


Figure 4.43 Results for water temperature variation with time for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

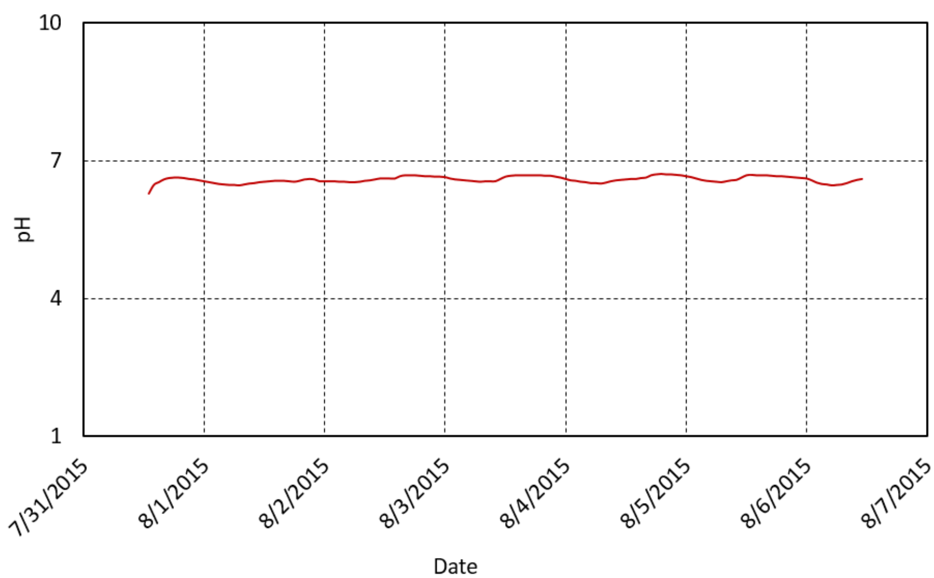


Figure 4.44 Results for variation of pH with time for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

Initially the oxygen reduction potential was 209 mV and at the end it was 276 mV, which indicated the increasing water quality with the removal of nutrients. The ODO was initially 93% and it increased to 100% at the end of experiment. The graphs for oxygen reduction potential and ODO with time for experiment 5 are presented in Figures 4.45 and 4.46, respectively.

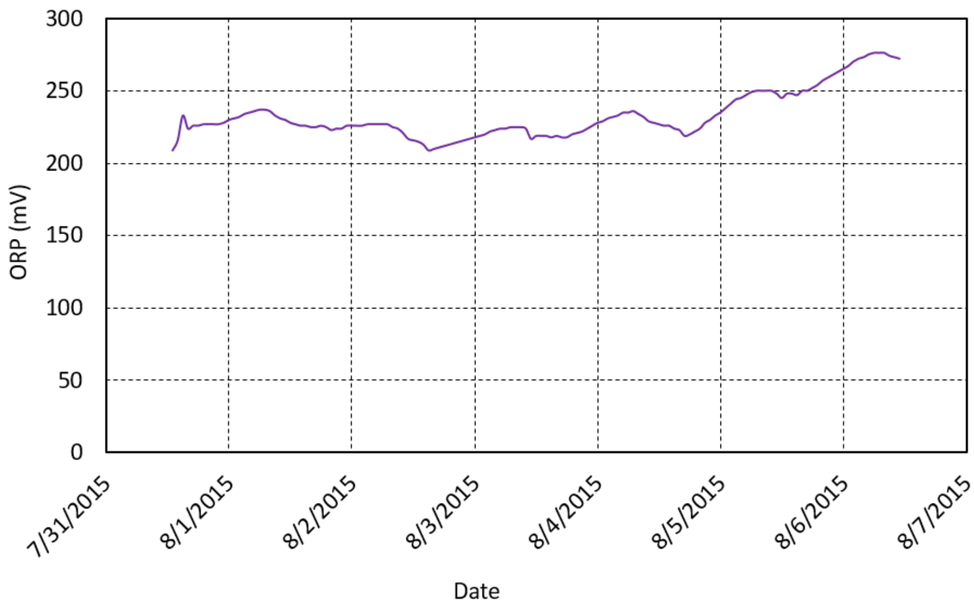


Figure 4.45 Results for variation of ORP with time for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

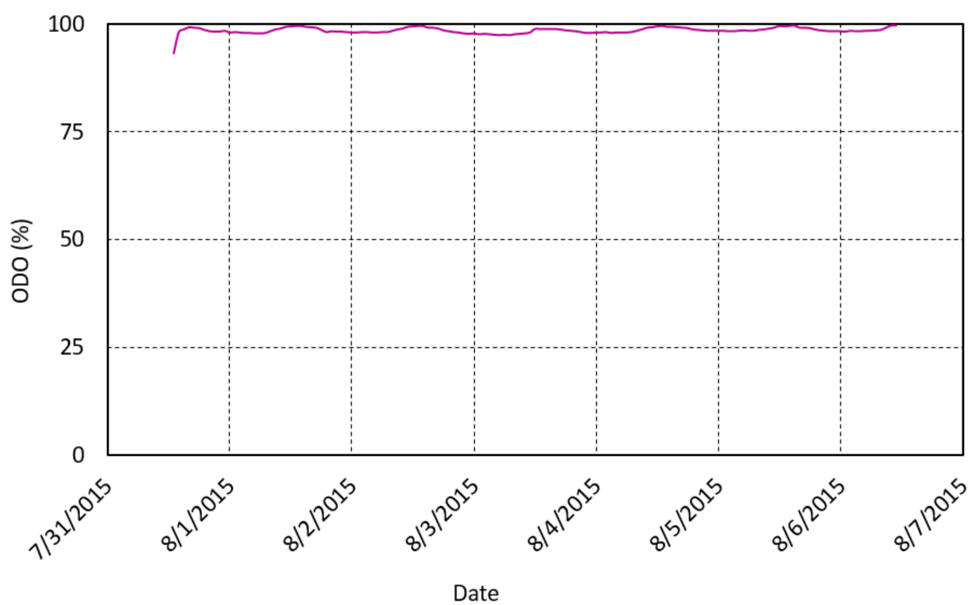


Figure 4.46 Results for variation of ODO (%) with time for the best combination (experiment 5) with initial turbidities ranging from >14 to ≤ 19 NTU

From the results of these experiments it can be said that, if the initial turbidity of water is lower, then a combination of 2 layers of 110 μm with 3 layers of 90 μm can remove nutrients but in order to get better results for water samples with higher initial turbidity, more layers of smaller pore size should be added.

4.3.4 Initial turbidity range >19 NTU

Only one experiment was carried out in this initial turbidity range to find out the efficiency of geotextiles. The initial turbidity of the experiment was 38 NTU. The maximum turbidity of Lake Caron water was 16.2 NTU. So, before starting the experiment, the sediments in the water were disturbed to get a higher turbidity value. The combination used in this experiment 6 was the same as used in experiment 5, 1 layer of 110 μm with 4 layers of 90 μm.

The total phosphorus concentration initially was 0.035 mg/L and finally it became below the acceptable range, 0.03 mg/L at day 1 and finally at day 7, it became 0.02 mg/L. As this is the higher turbidity range, the initial turbidity was 38 NTU, which was reduced to 10 NTU at day 1. Similar to the previous section, a good correlation with time to remove turbidity was found (R^2 =0.98) though the R^2 value was not good in the case of phosphorus removal. Initially the COD concentration was slightly higher than 20 mg/L which was reduced below that concentration at day 1. Total nitrogen, nitrate and total suspended solids concentration was within the acceptable range for this experiment. The removal pattern of total phosphorus, turbidity, COD, total nitrogen, nitrate and total suspended solids for different days for experiment 6 is shown in Figures 4.47 to 4.52.

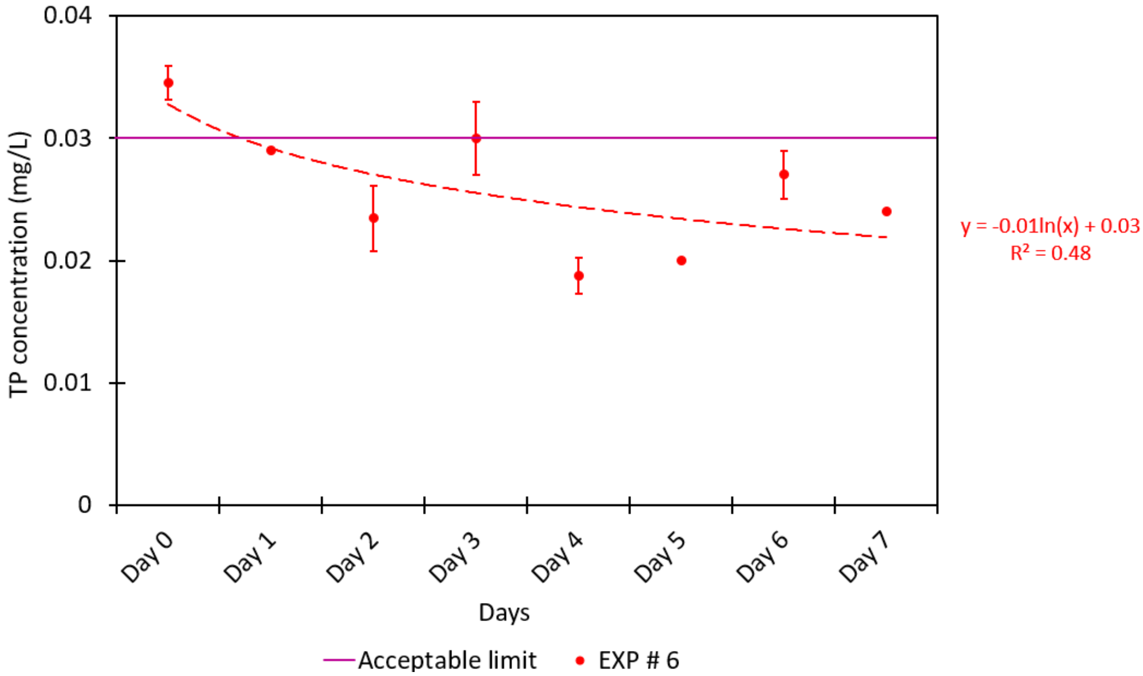


Figure 4.47 Removal trend of total phosphorus for the experiment with initial turbidity higher than 19 NTU

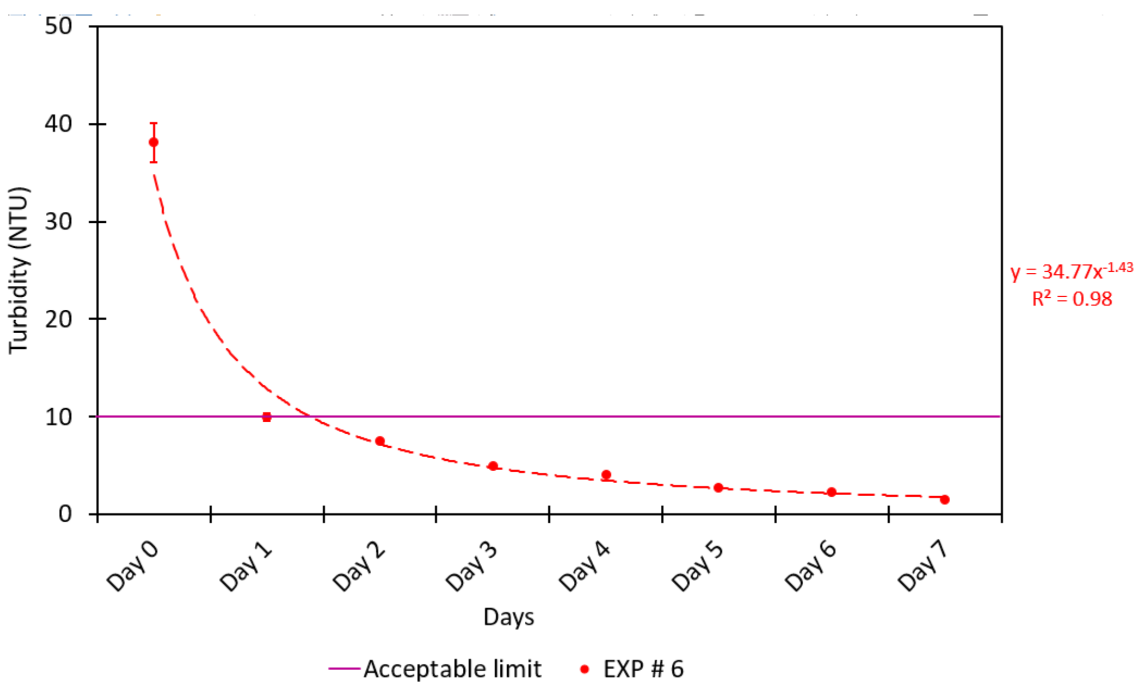


Figure 4.48 Removal trend of turbidity for the experiment with initial turbidity higher than 19 NTU

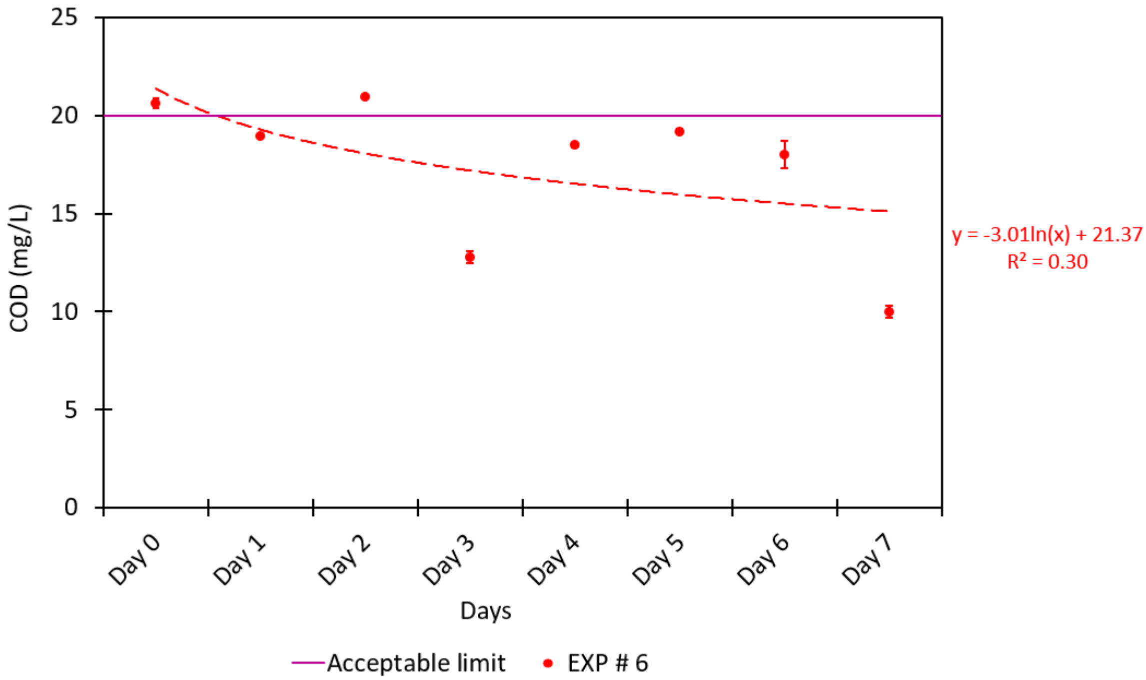


Figure 4.49 Removal trend of COD for the experiment with initial turbidity higher than 19 NTU

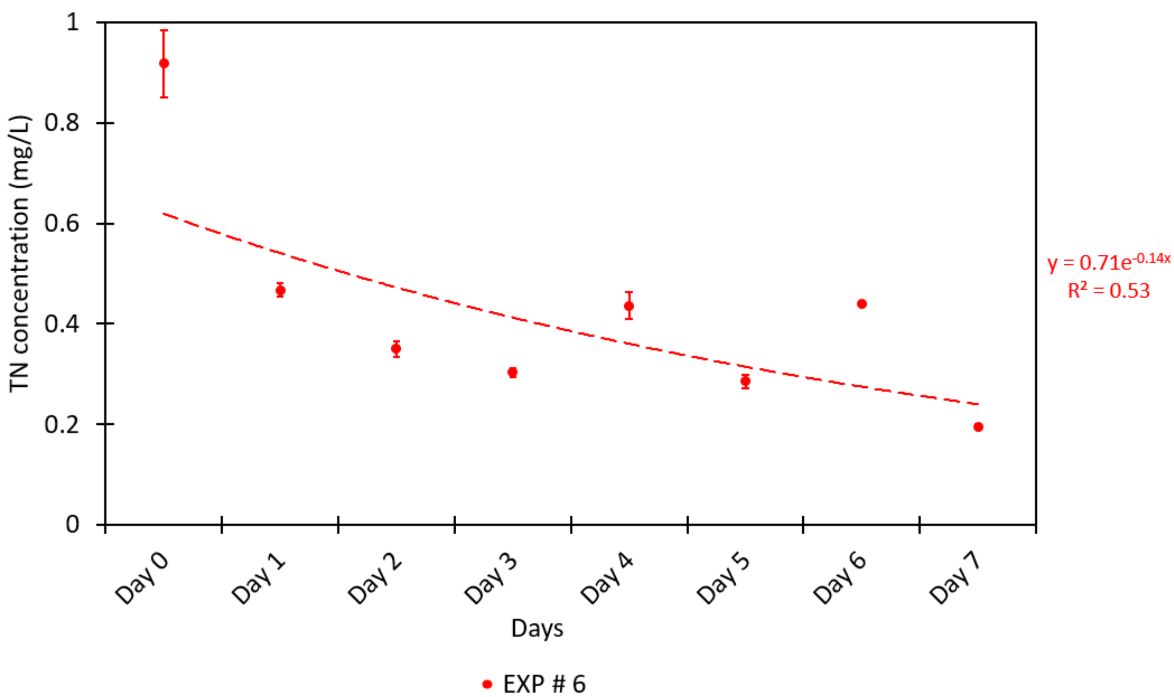


Figure 4.50 Removal trend of total nitrogen for the experiment with initial turbidity higher than 19 NTU

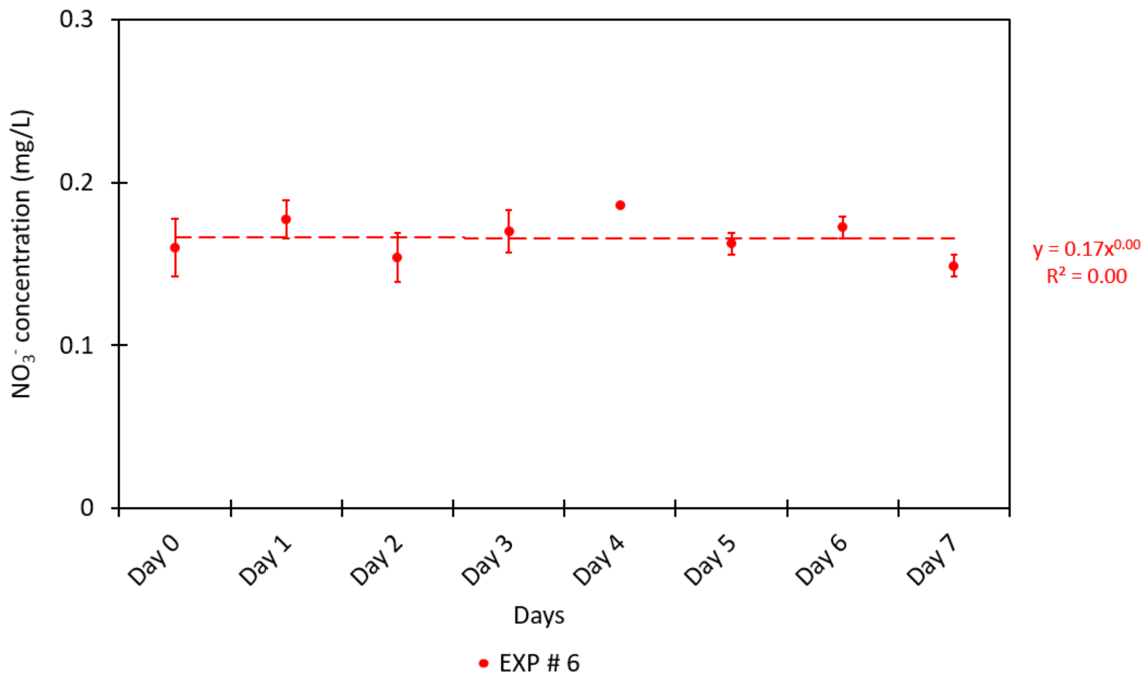


Figure 4.51 Removal trend of nitrate for the experiment with initial turbidity higher than 19 NTU

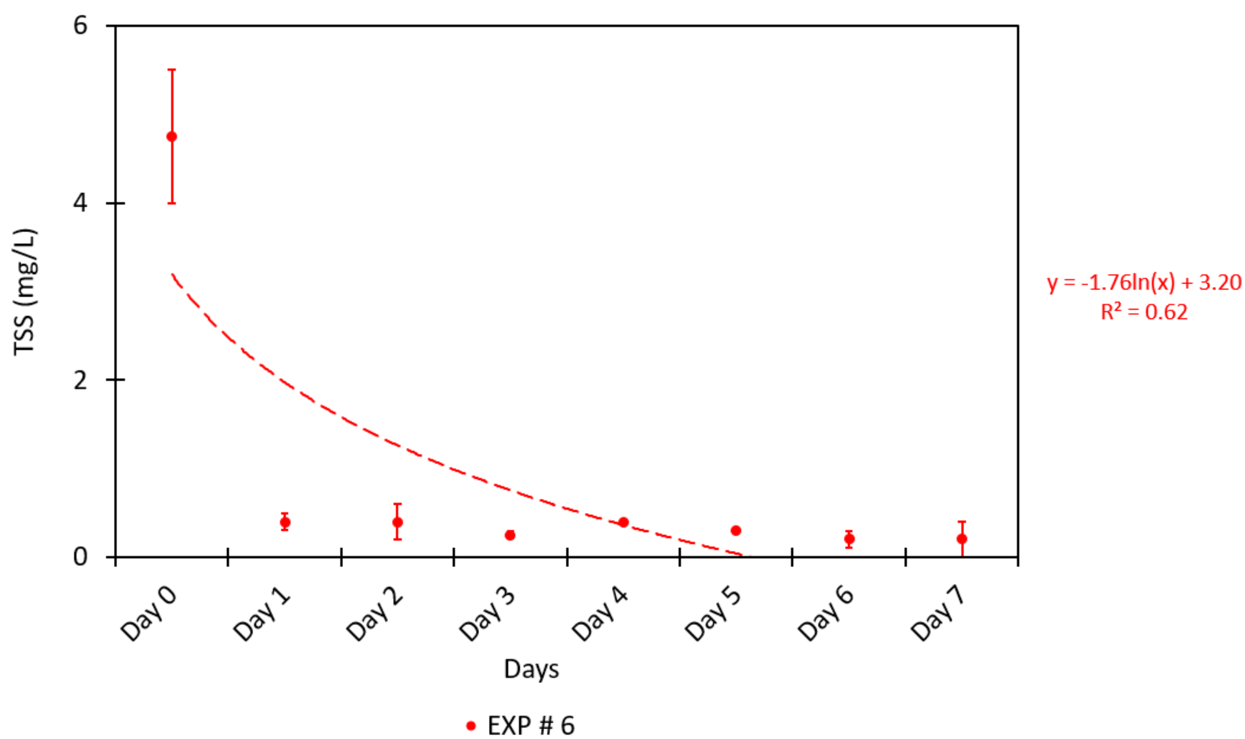


Figure 4.52 Removal trend of total suspended solids for the experiment with initial turbidity higher than 19 NTU

The results for experiment 6 obtained from the sonde are presented here. The concentration of chlorophyll α present in the water is directly proportional to the concentration of algae living in the water. For experiment 6, initially the concentration of chlorophyll α was 6.6 μg/L and finally it was reduced to 0 μg/L, which meant there was no living algae in the water. The average concentration of chlorophyll α was 3.15 μg/L. Figure 4.53 shows the decreasing trend of chlorophyll α for experiment 6. The graph was plotted with hourly data obtained from the sonde during the experiment. From the figure it was found that the chlorophyll α concentration was reduced to 2 μg/L at day 3 and for the maximum time of the remaining days of the experiment, it was less than 2 μg/L.

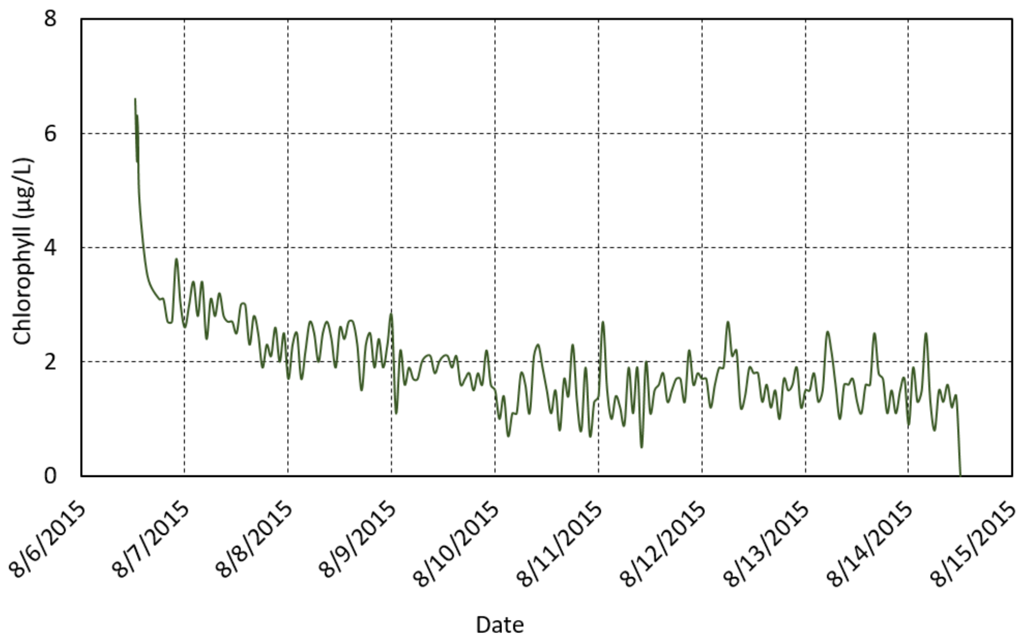


Figure 4.53 Decreasing trends of chlorophyll α for experiment 6 with initial turbidity higher than 19 NTU

The higher the nutrients, the higher the growth of blue green algae (BGA). The higher amount of blue green algae in water is not beneficial for aquatic life, because the algae consumes oxygen needed by aquatic plants and animals when it dies. At the end of experiment 6, there was no BGA in the water. The initially BGA concentration was 2379 cells/mL with an average concentration of 1174.5 cells/mL. Figure 4.54 showed the decreasing trend of BGA for experiment 6. The graph was plotted with hourly data obtained from the sonde during the experiment. Similar to the previous figure, the BGA concentration was reduced to 500 cells/mL at day 4 and for the remaining days, it was below 500 cells/mL.

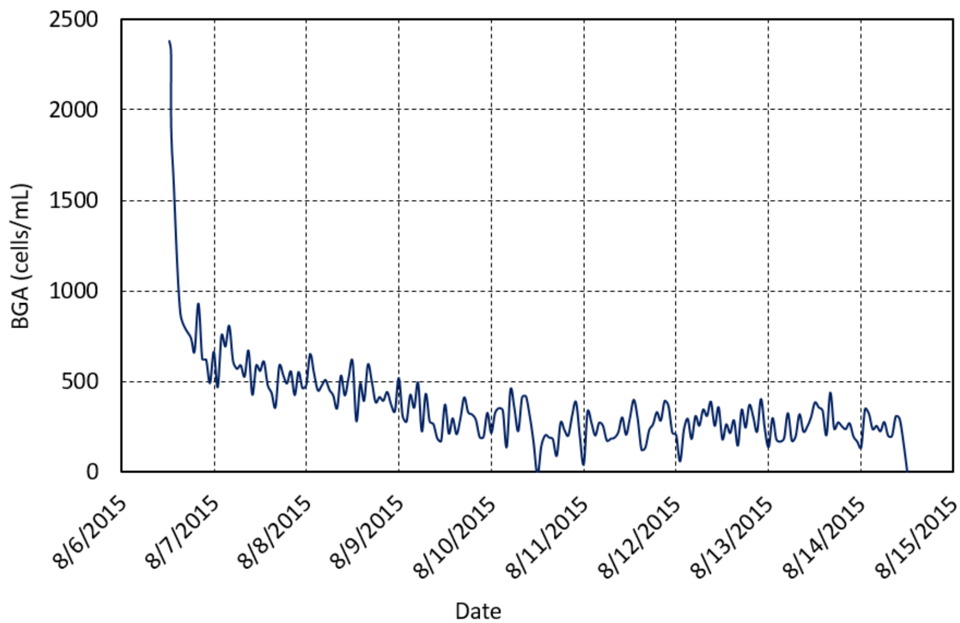


Figure 4.54 Decreasing trends of BGA for experiment 6 with initial turbidity higher than 19 NTU

The temperature of experiment 6 ranged from 31^0C to 21^0C with an average temperature of 26^0C. During the experiment, pH varied from 6.73 to 5.7 with an average value of 6.22. Initially the oxygen reduction potential was 182 mV and at the end it was 279 mV, which indicated that the water quality was increasing gradually with the removal of nutrients and chlorophyll α. The ODO was initially 92% and it increased to 100% at the end of experiment. The graphs for temperature, pH, oxygen reduction potential and ODO with time for experiment 6 are presented in Figures 4.55 to 4.58.

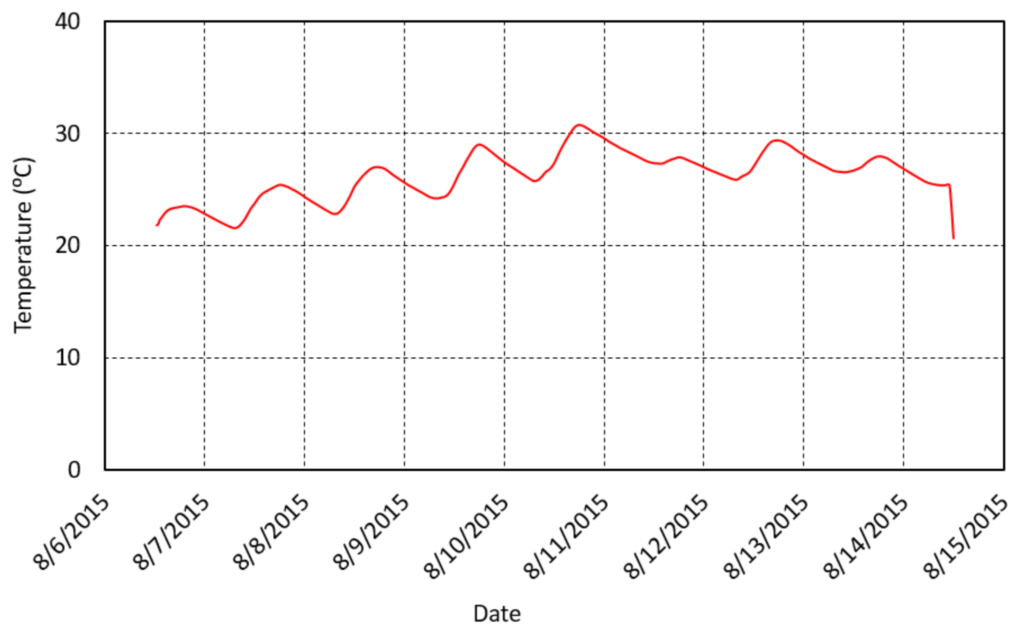


Figure 4.55 Results for water temperature variation with time for experiment 6 with initial turbidity higher than 19 NTU

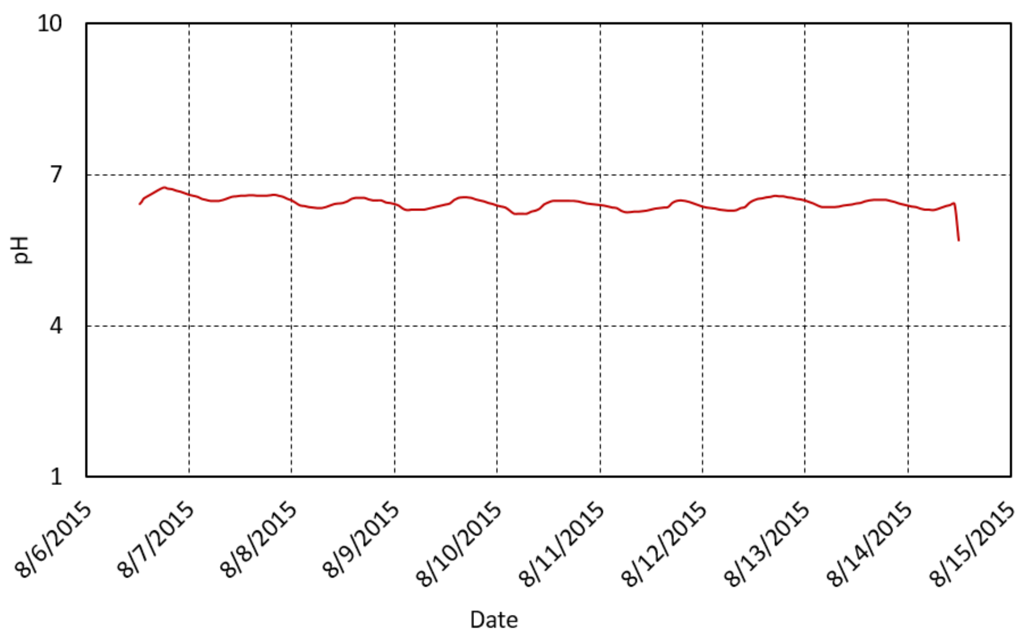


Figure 4.56 Results for variation of pH with time for experiment 6 with initial turbidity higher than 19 NTU

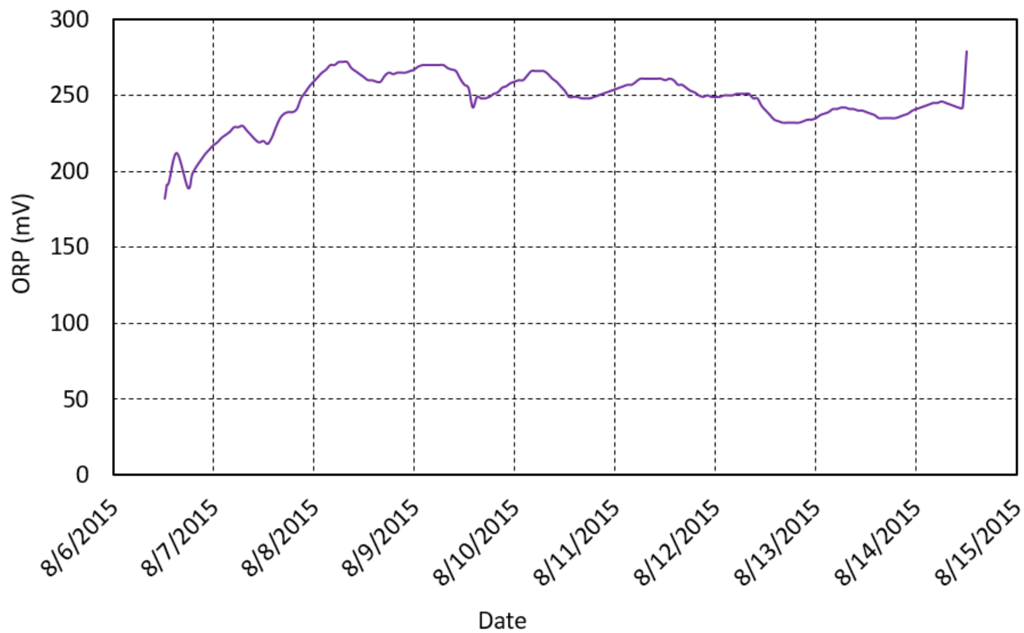


Figure 4.57 Results for variation of ORP with time for experiment 6 with initial turbidity higher than 19 NTU

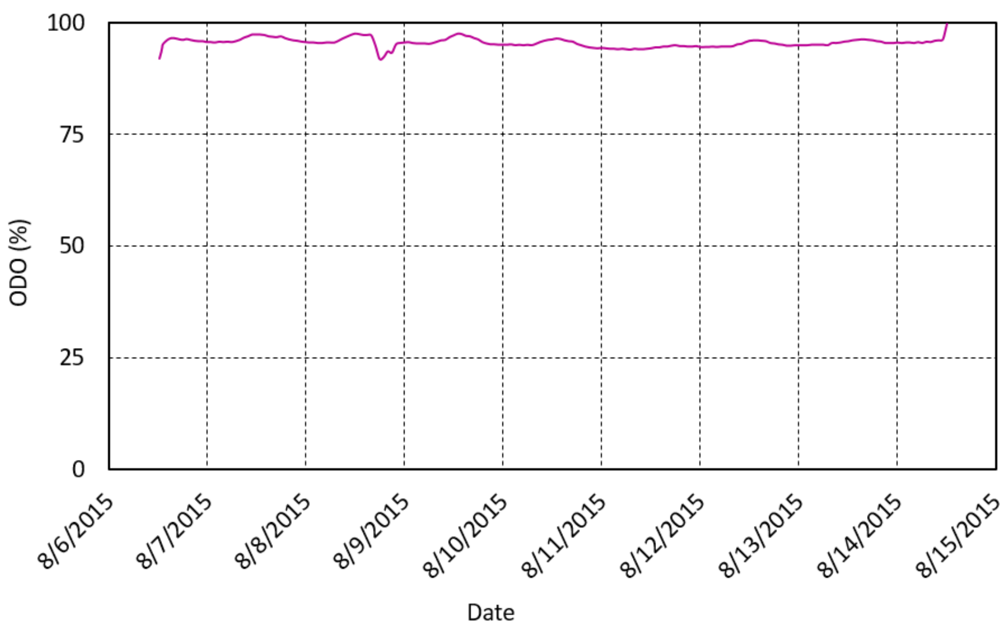
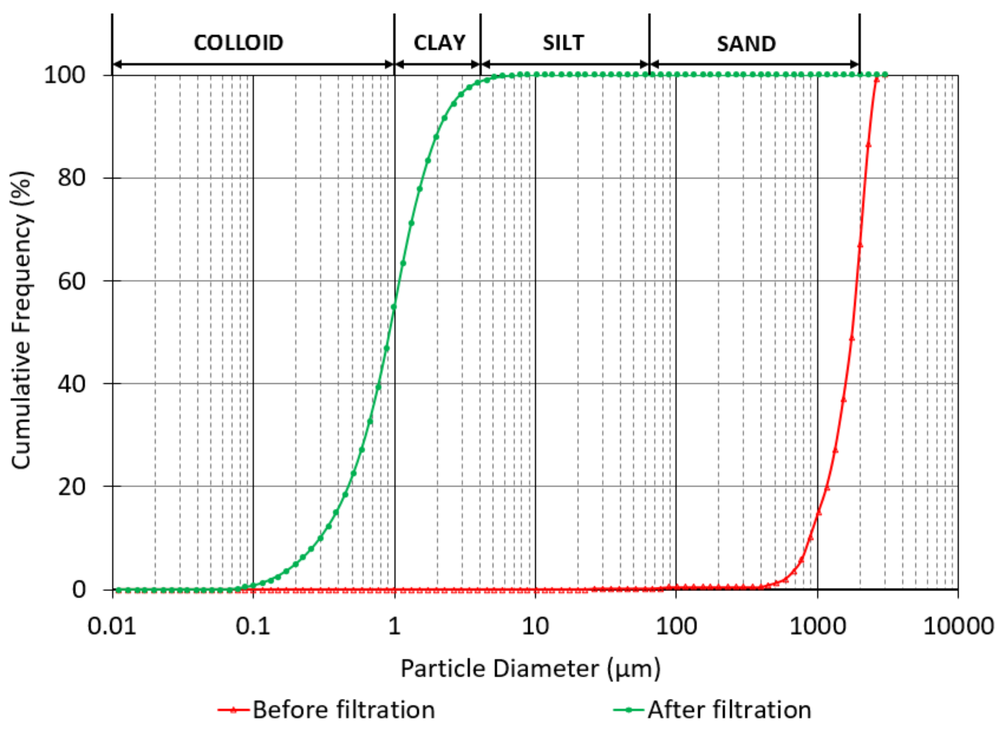


Figure 4.58 Results for variation of ODO (%) with time for experiment 6 with initial turbidity higher than 19 NTU

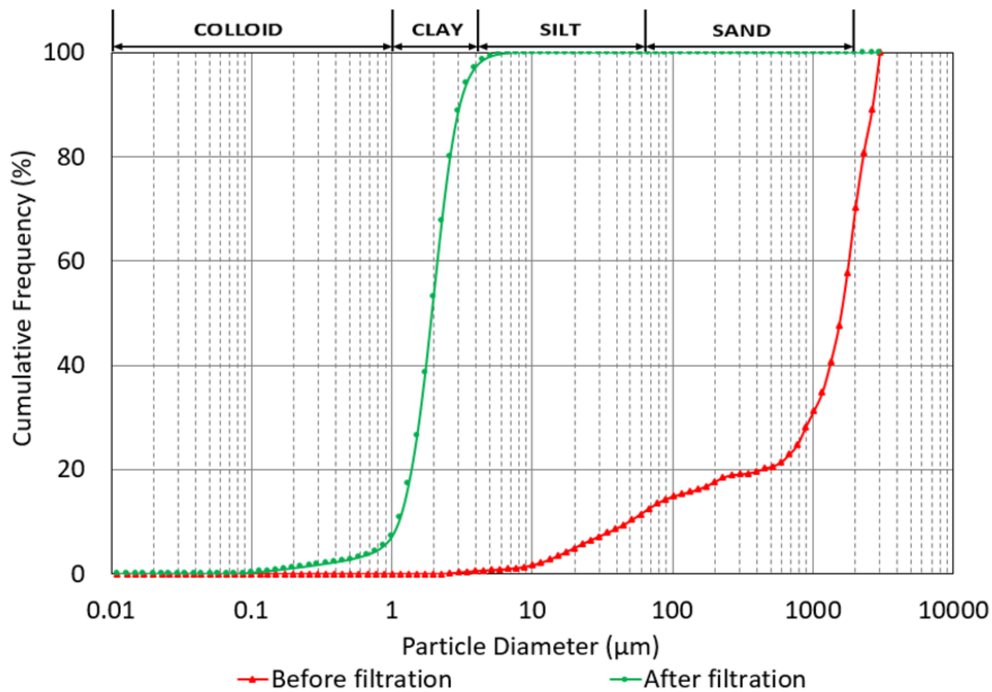
As discussed in the previous section, for higher turbidity value, the combination with more layers of smaller pore size of 90 µm filter media works better. That's why, the same combination of geo-filter media showed better results for initial turbidity range of 14 to 19 NTU and for an initial turbidity value higher than 19 NTU. It should be noted that, the geotextiles with multiple layers of 75 µm pore size clogged very quickly that the unit couldn't filter the water properly.

4.3.5 Particle size distribution

As stated earlier, most of the particles of the lake water were sand and silt. In this small scale filtration experiment, analysis of lake water samples showed the same results before starting the experiment. For example, the results of particle size before and after the filtration for experiment 5 and 6 are presented in Figure 4.59. In both experiments, the same combination of geotextiles was used, i.e., 1 layer of 110 µm with 4 layers of 90 µm at the bottom.



(a)



(b)

Figure 4.59 Particle size distribution before and after filtration for: (a) experiment 5; (b) experiment 6

It was found that, initially, in experiment 5, the range of particles size was 60.5 μm to 2000 μm (sand) while in experiment 6, the particles size varied from 4 μm to 2000 μm (both silt and sand). But, at the end of experiments, small sized particles were found in the water samples. At the end of experiment 5, 60% of the particles was found to have diameter less than 1 μm (colloidal) and for the rest 40%, diameter varied from 1 to 4 μm (clay). But, in experiment 6, 95% of the particles was found as clay with sizes varying from 1 μm to 4 μm at the end of the experiment. Though in both experiments, initially there was no clay or colloid particles but, at the end, it was found that most of the particles are colloid or clay. Because, when particles moved at very high speed, some of them broke down into new smaller particles due to collision. Also when the larger particles captured on the filters, they broke down into smaller particles due to the force of water. It should be noted that to filter all the water in the tank, there was a continuous circulation inside the tank. The durations of filtration for experiments 5 and 6 were 2 days and 1 day, respectively.

4.3.6 Correlation between geotextile pore size with particle size

Table 4.4 shows the mean (d_{50}) and average particle size of water sample before filtration for experiments 10, 11, 5 and 6 that showed the best results for initial turbidity ranging from 4 to 9 NTU, 9 to 14 NTU, 14 to 19 NTU and greater than 19 NTU, respectively. It has been found that use of more layers of smaller pore sized geotextile filters showed maximum efficiency in case of water samples having smaller particles. Among these 4 experiments, for experiment 10, the mean and average particle size were maximum and 3 layers of 90 µm geotextiles with 2 layers of 110 µm was enough to treat the water. For experiment 5 and 6, both mean and average particle size were smaller than experiment 10. In both cases 4 layers of 90 µm along with 1 layer of 110 µm worked better. The mean and average particle sizes were minimum for experiment 11 where use of further smaller sized geotextiles (75 µm) needed to use to achieve the best results.

Table 4.4 Mean particle size for the experiments with best combination of filters for different initial turbidity range

Experiment no.	**Particle size before filtration (µm)**		**Geotextiles combination**
	Average value	**Mean (d_{50}) value**	
11	1490	1556	2 x 110 µm + 3 x 75 µm
5	1691	1764	1 x 110 µm + 4 x 90 µm
6	1850	1977	1 x 110 µm + 4 x 90 µm
10	1866	2014	2 x 110 µm + 3 x 90 µm

4.3.7 Total phosphorus concentration as a function of TSS

One of the objectives of this onsite filtration experiments was to treat the water in terms of removing both total and dissolved phosphorus. For every experiment, dissolved phosphorus was also analysed along with all other analyses and no dissolved phosphorus was found. As there was no dissolved phosphorus in the lake water, so it was conceivable that removing suspended solids can accelerate the reduction of total phosphorus concentration. Bringing the results of suspended solids removal with total phosphorus removal for all the experiments into one graph makes it possible to compare and correlate the two parameters. Figure 4.60 shows the total phosphorus concentration as a function of total suspended solids. A good correlation was found between these two parameters with a regression coefficient of 0.75. The graph showed that the concentration of total phosphorus reduced with the removal of total suspended solids which indicated that most of the phosphorus content in the water was associated with suspended materials and hence removal of suspended solids significantly improved the water quality.

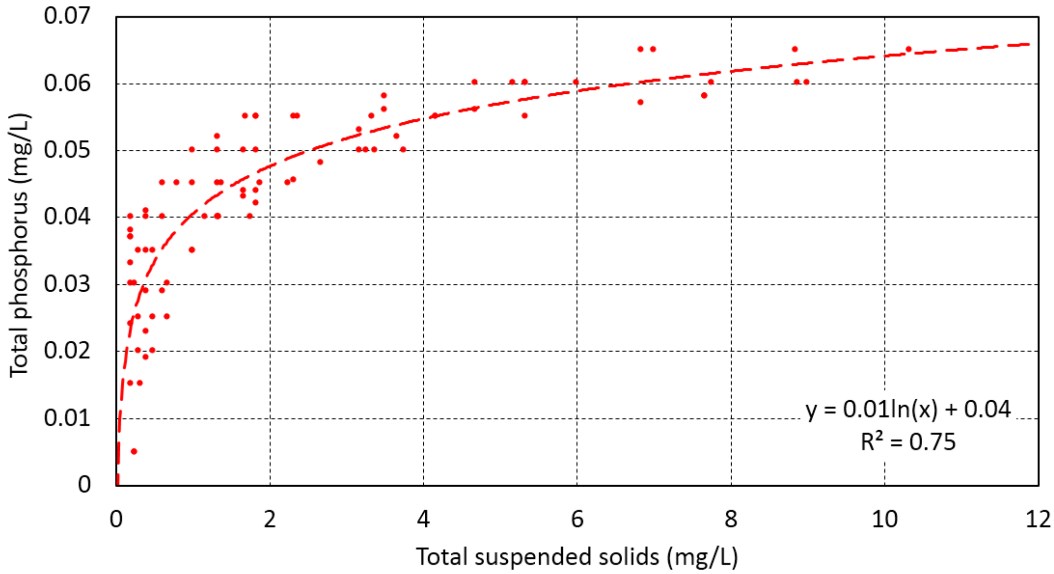


Figure 4.60 Total phosphorus as a function of total suspended solids

4.3.8 COD as a function of TSS

COD was plotted as a function of suspended solids concentration for all the experiments to find out if there is any correlation between these two parameters. Figure 4.61 showed the regression coefficient and the graph of COD as a function of total suspended solids. Similar to the previous graph, a good correlation was found between COD and total suspended solids concentration and the value of regression coefficient is 0.77. The graph justified the concept of COD reduction with the removal of total suspended solids from water.

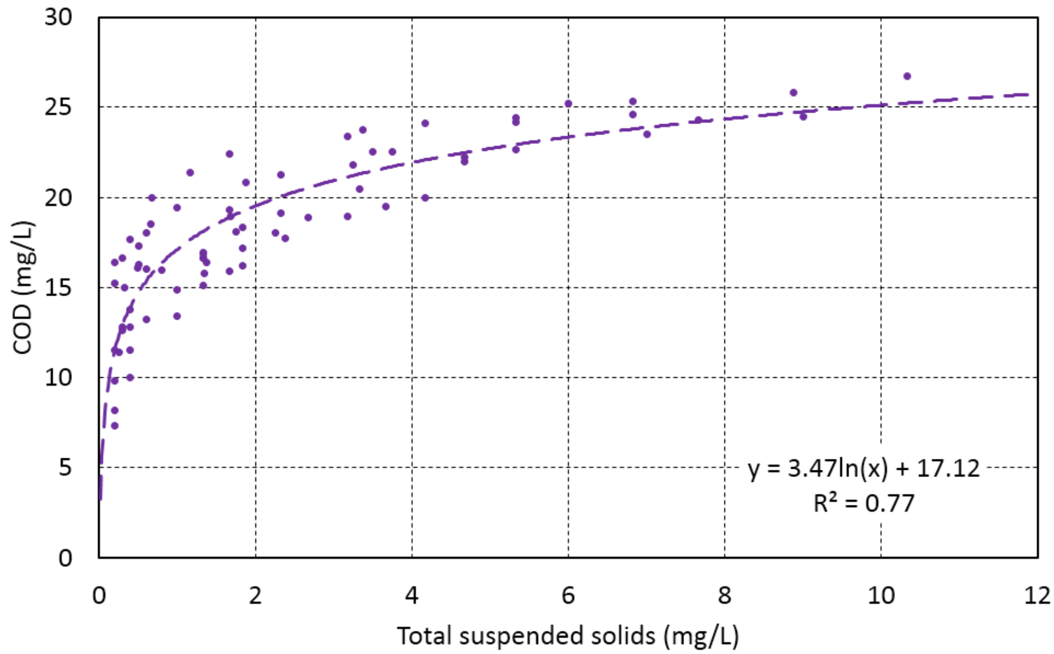


Figure 4.61 COD as a function of total suspended solids

4.3.9 Turbidity as a function of TSS

Turbidity is an important water quality parameter that indicates the clarity of water. It works as an indirect indicator of the concentration of suspended solids in the water. The higher the amount of suspended solids, the higher the turbidity value. To support this concept, turbidity values were plotted as a function of suspended solids concentration for all the experiments. Figure 4.62 shows the regression coefficient and the graph of turbidity as a function of total suspended solids. A very good correlation was found between these two parameters with a value of regression coefficient 0.80. The graph shows that the turbidity value decreased with the removal of total suspended solids.

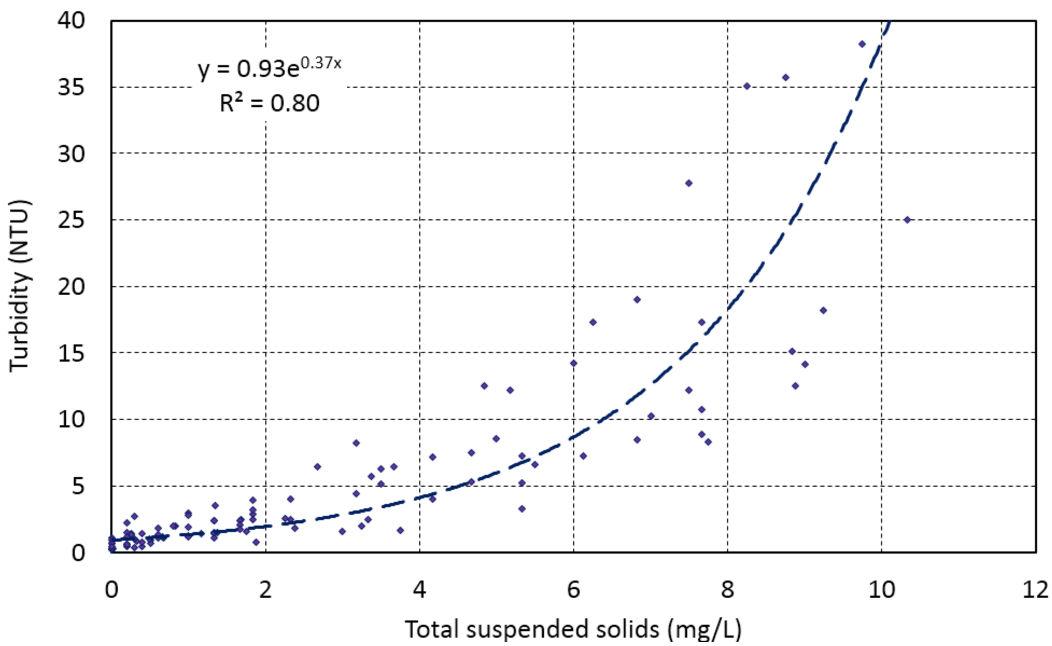


Figure 4.62 Turbidity as a function of total suspended solids

4.3.10 Flow rate vs. TSS

The flow rate of water through the geotextiles was measured every day during the experiment. It is logical that flow rate should be lower with higher value of suspended solids. To validate that perception, a graph with flow rate of water through the geotextiles with total suspended solids for all experiments was plotted into one graph. Figure 4.63 shows the graph of flow rate versus total suspended solids. These two parameters correlated with a very good regression coefficient of 0.83. The graph justified higher flow rates corresponding to lower suspended solids.

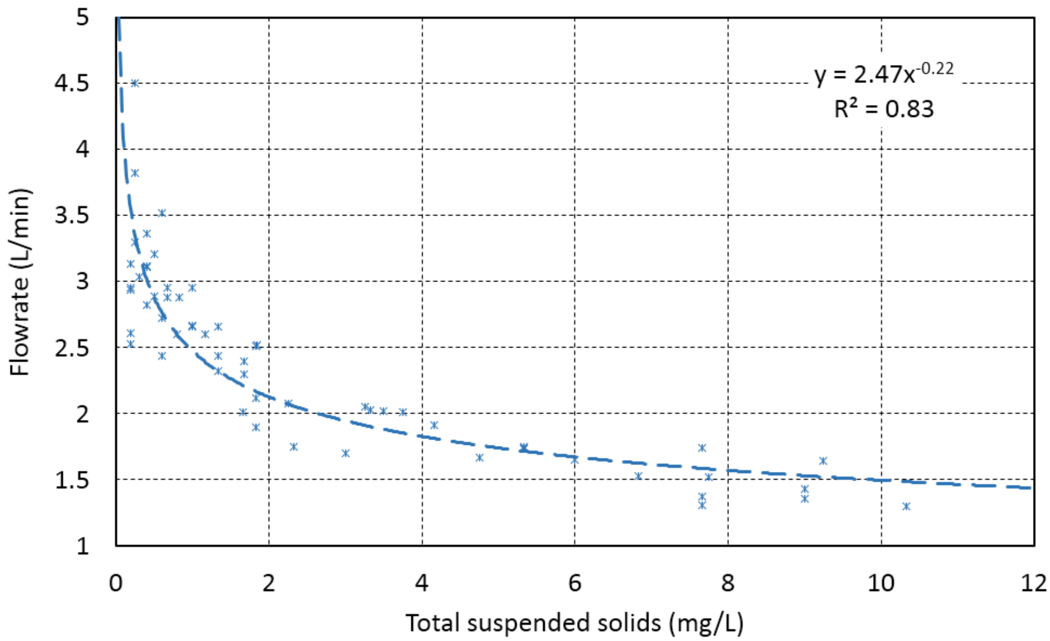


Figure 4.63 Flow rate vs. total suspended solids

4.3.11 Flow rate as a function of filter

Figure 4.64 represented the flow rate through the filter media as a function of filter for the experiments. Here, both initial and flow rates after clogging were plotted for different experiments. Experiments 1 and 11 have been exempted as they were carried out at different pump flow rates. All the experiments shown in the figure had been conducted with a pump flow rate of 7.47 L/min. In experiments 2, 3 and 4, 4 layers of geotextiles and for the rest of the experiments 5 layers of geotextiles with different combinations were used. Generally the flow rate decreased with increased number of geotextiles though the flow rate also varied with the pore size of the geotextiles filters. As shown in the figure, experiments 2, 3 and 4, which were conducted with 4 layers of geotextiles, provided higher flow rate compared to rest of the experiments where 5 layers of geotextiles had been used. Among experiments 2, 3 and 4, the flow rate in experiment 2 was higher (about 5 L/min) due to the use of larger pore sized (110 µm) geotextiles in all layers. For a combination of 1 layer of 110 µm with 3 layers of 90 µm (experiment 3 and 4), the flow rate was found about 3.7 L/min. In experiments 5, 6, 7 and 8, the combination of 1 layer of 110 µm with 4 layers of 90 µm had been used. It was found that the initial flow rate for these experiments varied from about 3 to 3.2 L/min except for experiment 6. In experiment 6, the initial turbidity was higher, above 38 NTU, and that's why, the initial flow rate was significantly low (2 L/min) as compared to other experiments with the same filter combination. The initial flow rate for experiment 9 and 10 was around 3 L/min where 2 layers of 110 µm with 3 layers of 90 µm were used as geotextile filter media. Comparatively lower initial flow rates were found for those experiments (12, 13 and 14), where 1 layer of lowest pore sized geotextiles (75 µm) was used. Experiments 12 and 13 were done with 4 layers of 110 µm and 1 layer of 75 µm sized geotextiles, and the initial flow rates were around 1.7 L/min. The initial flow rate was 1.5 L/min for experiment 14, where the combination of 3 pore size filters were used (2 layers of 110 µm, 2 layers of 90 µm and 1 layer of 75 µm). Figure 4.65 also shows that the flow rate after clogging (i.e., when the water holder of the filtration setup was fully filled with water) was almost the same for all experiments. The flow rates after clogging varied from 0.7 to 1 L/min.

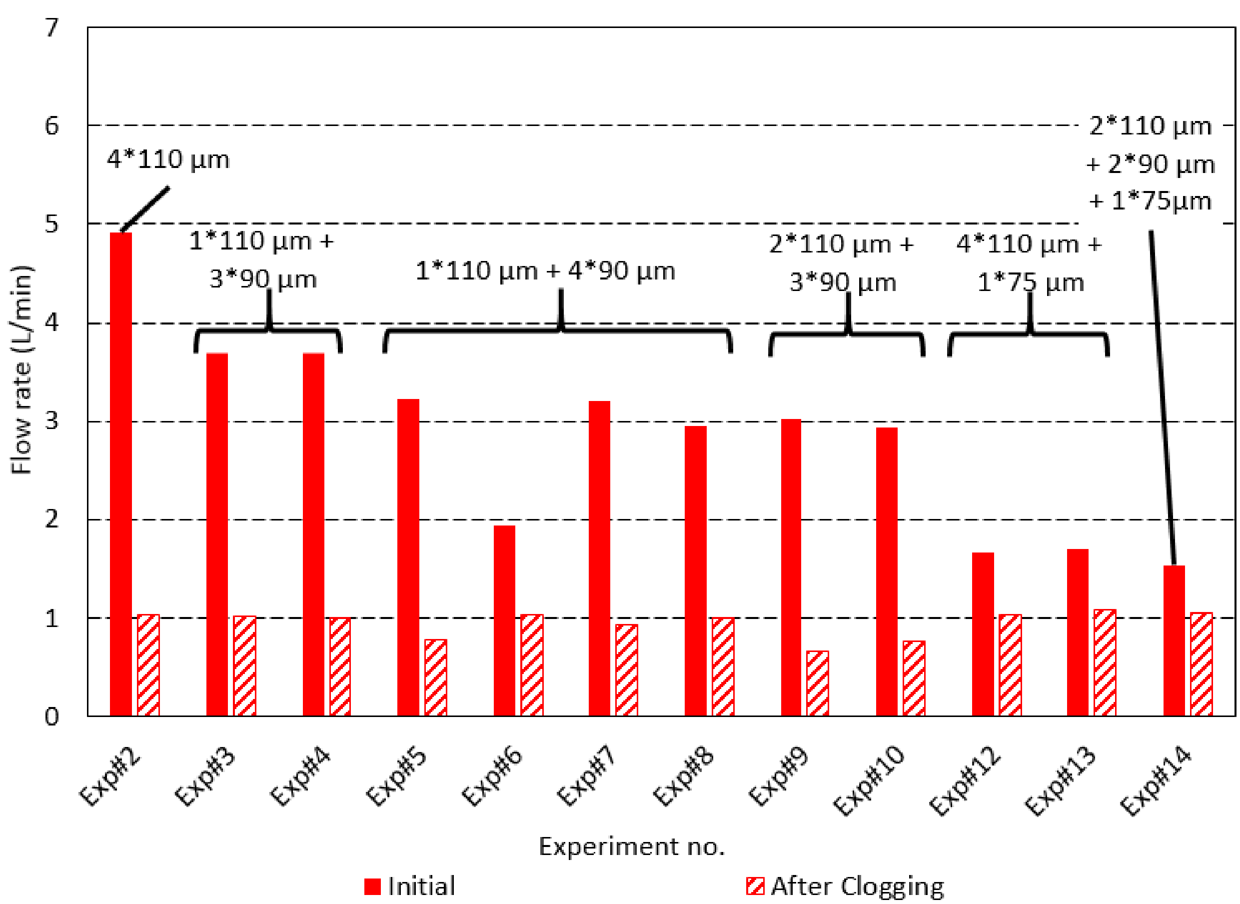


Figure 4.64 Flow rate as a function of filter

4.3.12 Clogging time vs. TSS and turbidity

Figure 4.65 shows the time geotextiles took to clog initially against initial total suspended solids, initial turbidity value of 14 experiments. As suspended particles become trapped by the geotextiles, water permeability through the geotextiles gradually decreases, and eventually it clogs. Measuring the time dependence of this clogging is necessary to predicting when a geotextile filter is no longer useful, either because of reduced throughput or reduced filtration efficiency, and should be discarded. From Figure 4.65, it can be seen that geotextiles took less time to clog with higher value of total suspended solids. A very good linear correlation was found between geotextiles clogging time with suspended solids concentration with regression coefficient of 0.81. In section 4.3.8, it was shown that turbidity value was high with higher suspended solids concentration. So it is understandable that less time will be needed for the geotextiles to clog with higher turbidity value and the graph also showed that. Though, both graphs (Figure 4.65) show the same trend, a poor regression value, i.e., 0.11 was found for the turbidity plot.

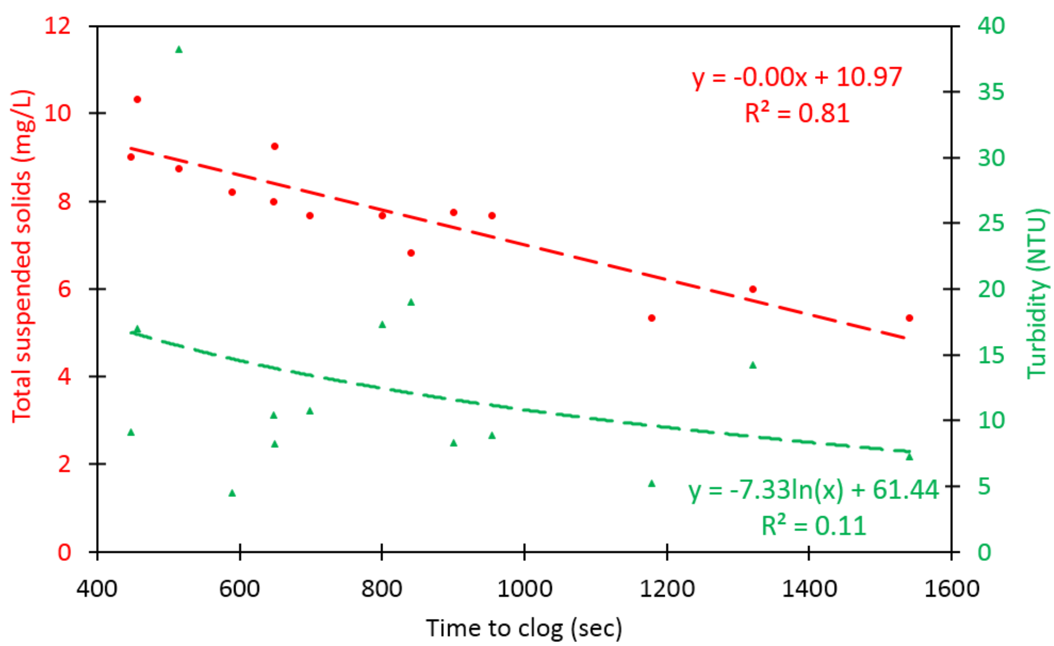


Figure 4.65 Clogging time vs. total suspended solids and turbidity

4.3.13 Results of phytoplankton analysis

Phytoplankton plays an important ecological role in aquatic ecosystems. They provide the basis for aquatic food chain: Phytoplankton → zooplankton →to feed fish populations. But, the abundance of phytoplankton destroyed the water quality. So, water samples were collected before starting the filtration and at the end of experiments for phytoplankton analysis. The analyses were done at the University of Montreal. In this section, the results of phytoplankton analysis of the experiments showing the best results for different turbidity ranges (experiments 5, 6, 10 and 11) are presented.

Tables 4.5, 4.6, 4.7 and 4.8 show the results of phytoplankton analysis for experiments 10, 11, 5 and 6 respectively. From the table it has been found that at the end of filtration, lots of phytoplankton species were removed. Quantities of some species had been increased and a few new species were developed throughout the filtration. Though there is no specified limit for toxic phytoplankton in recreational water, they become hazard and nuisance in water bodies when concentrate at the water surface in blooms (Ministry of National Health & Welfare, 1992). In a closed water body like a lake, cyanobacteria proliferate intensively by using the light and nutrients and create a visible discoloration known as cyanobacterial blooms (Chorus and Bartram, 1999; Falconer, 2005). Some cyanobacteria species produce a group of toxins named Microcystins (Butler et al., 2009). According to Health & Welfare Canada (2012), the recommended guideline value for total mycrocystins in recreational waters is less than 20 µg/L. The most common toxin-producing genera in fresh water are *Anabaena, Aphanizomenon*, *Cylindrospermopsis*, *Microcystis*, *Nodularia* and *Planktothrix* (Health & Welfare Canada, 2012). Among them, cyanotoxins from *Aphanizomenon*, *Cylindrospermopsis*, and *Microcystis* genera were found in the water samples from Lake Caron. More than 90% of the cyanobacteria was removed for all four experiments. For experiment 10, the concentration of cyanobacteria was 5976 µg/L and 88 µg/L before and after the filtration, resulting in 99% reduction. More than 99% of the cyanobacteria was removed in experiment 11, where the initial and final concentration of cyanobacteria was 6110 µg/L and 38 µg/L, respectively. Similarly, 98% and 91% of the cyanobacteria were removed in experiment 5 (initial concentration 1195 µg/L and final concentration 25 µg/L) and 6 (1865 µg/L and 166 µg/L), respectively.

Table 4.5 Results of phytoplankton analysis for experiment 10

Class	Phylum (Common name)	Name	Concentration (µg/L)	
			Before filtration	**After filtration**
Bacillariophyceae	Bacillariophyta (diatoms)	*Achnanthidium minutissimum*	9.28	0.21
		Eunotia pectinalis	4.84	0
		Navicula cryptonella	1.78	0
		Nitzschia acicularis	0.89	0
Bicosecophyceae	Bacillariophyta (diatoms)	*Bicosoeca lacustris*	0	0.06
Chlorophyceae	Chlorophyta (green algae)	*Ankyra judayi*	10.61	0
		Chlamydomonas sagittula	10.31	1.03
		Sphaerocystis schroeteri	326.81	0.66
		Coelastrum pulchrum	6.90	0
		Dispora crucigenioides cf	0.78	0
		Resting spore of Sphaerocystis schroeteri	11.83	0
		Scenedesmus quadricauda	2.32	0
		Chloromonas frigida	0	0.78
		Acutodesmus incrassatulus	0	0.14
Choanoflagellatea	Choanozoa (golden-brown algae)	*Salpingoeca frequentissima*	16.50	0
Chrysophyceae	Ochrophyta (golden-brown algae)	*Chromulina mikroplankton*	2.75	1.18
		Chrysosphaerella longispina	56.56	0
		Dinobryon bavaricum	202.54	0
		Ochromonas sphagnalis	2.32	0
		Dinobryon divergens	13.13	0
		Ochromonas globosa	0	0.37
Coccolithophyceae	Haptophyta (haptophytes)	*Chrysochromulina parva*	23.63	3.38
Conjugatophyceae (Zygnematophyceae)	Charophyta (green algae)	*Staurodesmus incus*	340.29	0
		Arthrodesmus Ralfsii latiuscula	4.20	0
Coscinodiscophyceae	Bacillariophyta (diatoms)	*Aulacoseira granulata*	40.24	0
Cryptophyceae	Cryptophyta (cryptomonads)	*Komma caudata*	10.44	0
		Cryptomonas erosa	375.32	66.29
		Cryptomonas ovata	346.45	2.54
		Rhodomonas lacustris nannoplanctica	50.52	0
		Cryptomonas borealis	87.18	0
		Cryptomonas pyrenoidifera	8.94	0
		Cryptomonas gracilis	0.75	0

Cyanophyceae	Cyanobacteria (blue-green algae)	*Aphanothece bachmannii*	4.71	0.99
		Chroococcus minimus	4.60	1.15
		Microcystis aeruginosa	5953.42	85.93
		Chroococcus prescottii	5.32	0
		Cylindrospermum stagnale	7.68	0
Dinophyceae	Miozoa (dinoflagellates)	*Ceratium hirundinella*	107.80	0
		Gymnodinium varians	0	0.78
Euglenophyceae	Euglenophyta (euglenoids)	*Euglena viridis*	19.21	0
Synurophyceae	Ochrophyta (golden-brown algae)	*Mallomonas akrokomos*	102.91	0
		Synura uvella	318.17	0
		Mallomonas ploesslii	4.66	0
Trebouxiophyceae	Chlorophyte (green algae)	*Botryococcus braunii*	1187.84	0
		Oocystis solitaria	26.51	1.66
		Oocystis submarina variabilis	0.50	0
		Crucigenia tetrapedia	0	0.47

Table 4.6 Results of phytoplankton analysis for experiment 11

Class	**Phylum (Common name)**	**Name**	**Concentration (µg/L)**	
			Before filtration	**After filtration**
Bicosecophyceae	Bacillariophyta (diatoms)	*Bicosoeca lacustris*	0	0.06
Chlorophyceae	Chlorophyta (green algae)	*Ankyra judayi*	71.59	0
		Chloromonas frigida	14.14	0.13
		Chlamydomonas sagittula	0.25	0
		Sphaerocystis schroeteri	25.87	0.44
Chrysophyceae	Ochrophyta (golden-brown algae)	*Chromulina mikroplankton*	3.14	0.39
		Chrysosphaerella longispina	452.51	0
		Ochromonas globosa	21.21	0
		Chromulina pseudonebulosa	0.10	0
		Dinobryon bavaricum	8.69	0
		Chromulina elegans	0	0.05
		Ochromonas sphagnalis	0	0.02
		Pseudokephyrion sp cf	0	0.16
Coccolithophyceae	Haptophyta (haptophytes)	*Chrysochromulina parva*	60.77	0.03

Coscinodiscophyceae	Bacillariophyta (diatoms)	*Aulacoseira granulata*	36.67	0
Cryptophyceae	Cryptophyta (cryptomonads)	*Rhodomonas lacustris nannoplanctica*	173.23	0
		Komma caudata	0.73	0
		Chroomonas nordstedtii	5.96	0
		Cryptomonas borealis	36.73	0
		Cryptomonas erosa	59.61	0
		Cryptomonas pyrenoidifera	3.35	0
		Cryptomonas gracilis	1.40	0
		Cryptomonas ovata	66.94	0
Cyanophyceae	Cyanobacteria (blue-green algae)	*Aphanothece bachmannii*	15.08	0.71
		Chroococcus minimus	7.67	0.01
		Microcystis aeruginosa	6063.90	36.83
		Chroococcus prescottii	8.28	0
		Woronichinia naegeliana	14.90	0
Euglenophyceae	Euglenophyta (euglenoids)	*Euglena viridis*	1443.55	9.31
Fragilariophyceae	Bacillariophyta (diatoms)	*Asterionella formosa*	38.42	0
		Tabellaria fenestrata	166.02	0
		Fragilaria capucina	0	4.86
Synurophyceae	Ochrophyta (golden-brown algae)	*Mallomonas akrokomos*	2.98	0
		Mallomonas majorensis	2.65	0
		Synura uvella	13.25	0
Trebouxiophyceae	Chlorophyte (green algae)	*Botryococcus braunii*	2036.29	0
Xanthophyceae	Orchophyta (golden-brown algae)	*Stipitococcus apiculatus*	7.04	0

Table 4.7 Results of phytoplankton analysis for experiment 5

Class	**Phylum (Common name)**	**Name**	**Concentration (µg/L)**	
			Before filtration	**After filtration**
Bacillariophyceae	Bacillariophyta (diatoms)	*Nitzschia acicularis*	42.20	0
		Achnanthidium minutissimum	0.30	0.12
		Pinnularia biceps	5.34	0
Bicosecophyceae	Bacillariophyta (diatoms)	*Bicosoeca lacustris*	0	0.80

Chlorophyceae	Chlorophyta (green algae)	*Chloromonas frigida*	14.73	0.43
		Sphaerocystis schroeteri	589.20	0
		Ankyra judayi	0.70	0
		Carteria multifilis	2.98	0
		Chlamydomonas pseudopertyi	5.96	0.75
		Pediastrum duplex	4.22	0
		Resting spore of Sphaerocystis schroeteri	10.43	0
		Scenedesmus quadricauda	4.14	0
		Chlamydomonas gracilis	0	0.70
		Scenedesmus brevispina	0	0.32
Chrysophyceae	Ochrophyta (golden-brown algae)	*Chromulina mikroplankton*	1.57	0
		Ochromonas sphagnalis	6.96	1.16
		Dinobryon divergens	16.76	0
Coccolithophyceae	Haptophyta (haptophytes)	*Chrysochromulina parva*	40.51	0
Conjugatophyceae (Zygnematophyceae)	Charophyta (green algae)	*Mougeotia elegantula*	1.03	0
		Staurastrum longipes	8.61	0
Coscinodiscophyceae	Bacillariophyta (diatoms)	*Aulacoseira granulata*	81.49	0
Cryptophyceae	Cryptophyta (cryptomonads)	*Komma caudata*	62.64	0
		Cryptomonas pyrenoidifera	107.38	0
		Cryptomonas borealis	44.71	0
		Cryptomonas erosa	73.45	0
		Cryptomonas ovata	34.44	0
		Rhodomonas lacustris nannoplanctica	0.89	0
		Cryptaulax vulgaris	0	0.28
Cyanophyceae	Cyanobacteria (blue-green algae)	*Dolichospermum flos-aquae*	259.84	2.54
		Aphanothece bachmannii	10.56	1.37
		Chroococcus minimus	5.37	0
		Chroococcus prescottii	452.51	0
		Microcystis aeruginosa	466.45	21.48
		Pseudanabaena limnetica	0.19	0
Euglenophyceae	Euglenophyta (euglenoids)	*Phacus monilatus suecicus*	14.35	0
Fragilariophyceae	Bacillariophyta (diatoms)	*Tabellaria fenestrata*	225.06	0
		Fragilaria capucina	1.48	0
Klebsormidiophyceae	Charophyta (green algae)	*Elakatothrix gelatinosa*	0.84	0
Synurophyceae	Ochrophyta (golden-brown algae)	*Synura uvella*	65.20	0
Trebouxiophyceae	Chlorophyte (green algae)	*Botryococcus braunii*	1357.53	0
		Dictyosphaerium ehrenbergianum	1.49	0
		Oocystis solitaria	2.05	0
		Crucigenia tetrapedia	0	0.24

Table 4.8 Results of phytoplankton analysis for experiment 6

Class	Phylum (Common name)	Name	Concentration (µg/L)	
			Before filtration	After filtration
Bacillariophyceae	Bacillariophyta (diatoms)	*Amphora ovalis*	16.01	0
		Frustulia saxonica	15.81	0
		Nitzschia acicularis	0.74	0
		Pinnularia viridis	0	140.41
Bicosecophyceae	Bacillariophyta (diatoms)	*Bicosoeca lacustris*	4.47	0
Chlorophyceae	Chlorophyta (green algae)	*Sphaerocystis schroeteri*	357.94	1100.67
		Oedogonium sp male filament	37.27	0
		Pediastrum duplex	5.06	116.61
		Stauridium tetras	0.28	0
		Resting spore of Sphaerocystis schroeteri	40.75	9.47
		Scenedesmus quadricauda	7.95	5.22
		Scenedesmus serratus	0.63	0
		Chlamydomonas sagittula	0	4.71
		Characium westianum	0	1.29
		Chloromonas frigida	0	0.58
Chrysophyceae	Ochrophyta (golden-brown algae)	*Chromulina mikroplankton*	0.39	0
		Ochromonas sphagnalis	2.32	0
		Dinobryon divergens	95.56	0
Coccolithophyceae	Haptophyta (haptophytes)	*Chrysochromulina parva*	13.50	6.75
Conjugatophyceae (Zygnematophyceae)	Charophyta (green algae)	*Closterium venus*	8.28	0
		Mougeotia sp	20.70	0
		Staurastrum longipes	25.83	292.74
Coscinodiscophyceae	Bacillariophyta (diatoms)	*Aulacoseira granulata*	388.44	8933.52
		Aulacoseira granulata angustissima	0	31.30
Cryptophyceae	Cryptophyta (cryptomonads)	*Komma caudata*	41.76	0
		Cryptomonas ovata	273.83	0
		Rhodomonas lacustris nannoplanctica	151.57	0
		Chroomonas nordstedtii	2.24	0
		Cryptomonas borealis	48.43	0
		Cryptomonas erosa	7.54	0
		Cryptomonas pyrenoidifera	23.84	0

Cyanophyceae	Cyanobacteria (blue-green algae)	*Dolichospermum flos-aquae*	202.10	0
		Aphanothece bachmannii	9.90	5.37
		Chroococcus minimus	6.14	4.60
		Chroococcus prescottii	84.85	69.81
		Microcystis aeruginosa	1515.97	49.10
		Cylindrospermum stagnale	45.93	0
		Woronichinia naegeliana	0	36.09
		Pseudanabaena limnetica	0.25	1.26
Dinophyceae	Miozoa (dinoflagellates)	*Ceratium hirundinella*	0	220.77
Euglenophyceae	Euglenophyta (euglenoids)	*Colacium vesiculosum*	2.65	7.54
		Phacus monilatus suecicus	14.35	0
		Trachelomonas hispida	12.14	0
		Trachelomonas lacustris ovalis	4.28	0
Fragilariophyceae	Bacillariophyta (diatoms)	*Fragilaria capucina*	1.78	1.98
		Asterionella formosa	0	675.18
		Fragilaria acus	0	4.40
		Ulnaria ulna	0	17.79
		Tabellaria fenestrata	0	58.11
Klebsormidiophyceae	Charophyta (green algae)	*Elakatothrix gelatinosa*	0.23	0
Synurophyceae	Ochrophyta (golden-brown algae)	*Synura uvella*	433.07	16.56
		Mallomonas caudata cf	0	206.97
Trebouxiophyceae	Chlorophyte (green algae)	*Botryococcus braunii*	3054.44	6448.26
		Nephrocytium limneticum	18.63	0
		Nephrocytium lunatum	1.81	6.46
		Dictyosphaerium ehrenbergianum	0	5.43
		Oocystis solitaria	0	21.86

4.3.14 Best geotextile combinations for different initial conditions

Figure 4.66 shows the best geotextiles combinations for different initial turbidity range at a glance. Figure also shows the required duration of filtration to achieve the optimum results for these best combinations. As shown in the figure, the required filtration duration was less for higher initial turbidity value. This happened because, as for higher initial turbidity, more layers of smaller pore sized geotextiles was used, which accelerated the filtration and hence reduced the nutrients quickly.

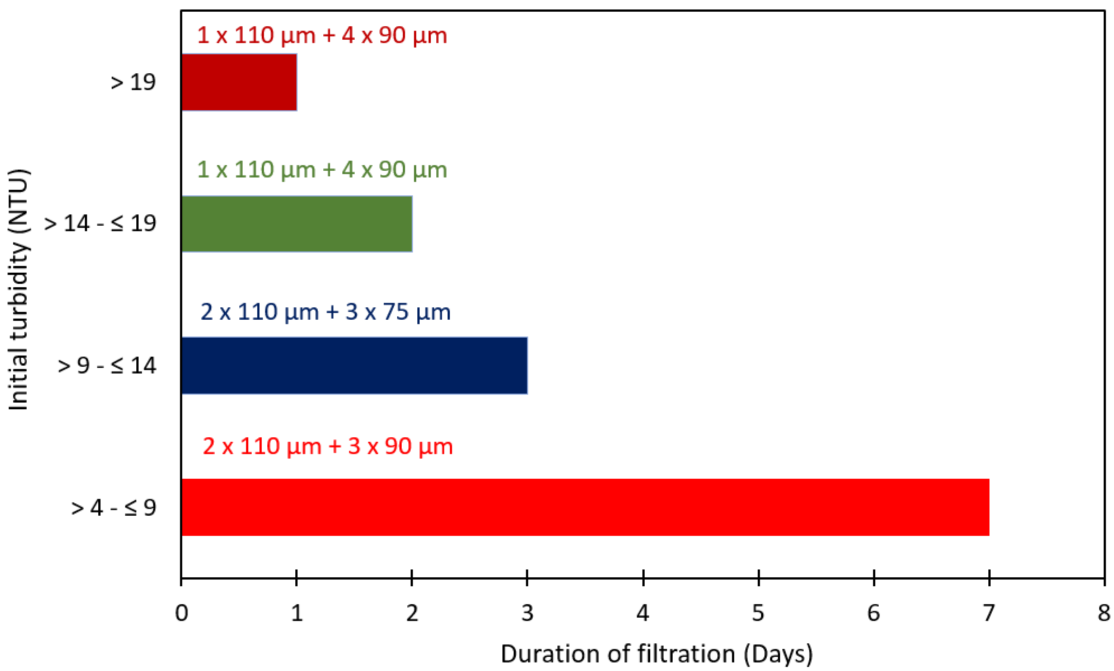


Figure 4.66 Best geotextile combinations for different ranges of initial turbidities

4.3.15 Potential implementation

In this study, a small scale filtration unit was developed to remove nutrients and suspended particles from a eutrophic lake water samples by using geotextiles as a filter media. The study was successful in designing an efficient, environmentally friendly, easily produced and easily implemented filtration technique to treat surface water bodies. The system eliminated toxin producing cyanobacteria; removed turbidity, total suspended solids, phosphorus and had a strong potential to remove other common surface pollutants. Suspended solids removal improved the water quality as strong correlations were found among suspended solids with total phosphorus, COD and turbidity.

Some conventional filtration technique for example rapid sand filtration can also remove the suspended solids from the water and the technique is very common in water treatment. It has some drawbacks such as higher maintenance cost, supervision is required, backwashing, it cannot remove smaller sized particles, the requirement for chemicals etc. Filtration using geotextiles is free from all these drawbacks. Further the conventional filtration methods may not be feasible for surface water bodies used for recreational purposes. As a result, the filtration technique used in this study (filter unit and geotextiles as a filter media) can be a potential technique to treat recreational water bodies.

This filtration method improved the lake water quality without using chemicals, so this method didn't create any environmental impact. It can successfully be used as a portable water purification system for elimination of toxin producing cyanobacteria and treatment in larger water body even in remote locations. This study enabled not only the design of filtration systems for different cases, but also provided guidelines for full scale implementation.

Further development of this filtration technique is required for large scale implementation. This will take several different paths. As the initial work, i.e., laboratory and on site experiments showed promising results, so the next step pilot experiment should be conducted to further evaluate the filtration technique. To do so, this filtration unit or a larger version of it can be tested in a small portion of the lake. Based on the pilot experimental results, information for full scale implementation will be developed.

For commercialization of successful filtration technique additional work must be done to ensure quality control and consistent manufacturing of the filtration unit and the geotextiles. Further filter studies, manufacturing and improvements will enable the development of a self-sustaining and scalable filtration unit that is capable of treating surface water bodies without affecting the environment.

In the following section, guidelines have been provided to upgrade and design the filtration unit for full scale implementation based on the current study:

Depending on the turbidity of the water body, the geotextiles combination can be selected from this study. A larger sized filtration unit than that used in this study should be chosen when applied to the entire lake. Though larger sized filtration units will reduce the filtration duration and number of units, an excessive larger size should be avoided in order to handle the unit properly. The number and size of the filtration units and duration of filtration can be calculated based on the volume of the water contained in the contaminated water body. A sample calculation for Lac Caron is shown in the following as an example.

Lake water sampling analysis for two years showed that the average turbidity of lake water varied from 2 to 9 NTU. Onsite small scale experiments results showed that a filtration unit having diameter 0.2 m and height 0.25 m was capable of treating 300 L (0.3 m^3) of water with initial turbidity ranging from 4 to 9 NTU in 7 days.

The total volume of lake water = 48400 m^3

1 filtration unit can treat 0.3 m^3 of water in 7 days

So, 1 filtration unit can treat 48400 m^3 of water in = $\frac{7*48400}{0.3}$ m^3 = 1129333 days

Now, if the filtration is conducted for 3 months (90 days) for the entire lake, the total number of units required = $\frac{1129333}{90}$ = 12548 nos.

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

Then, the total volume for 12548 nos. of filtration units is = (12548 * 0.00785) m^3 = 98.5 m^3

The ratio of diameter (d) and height (h) of the unit used for small scale experiment is

$$\frac{d}{h} = \frac{0.2}{0.25} = 0.8$$

$$\rightarrow h = \frac{d}{0.8}$$

For full scale experiments, it is necessary to use larger sized filter units, otherwise the required numbers of filtration units will be very high.

Assuming the diameter (d) of the larger filtration unit = 1.2 m

So, the height (h) of the larger filtration = 1.2/0.8 m = 1.5 m

And, the volume of the larger filtration unit = $\pi \frac{1.2^2}{4}$*1.5 m^3 = 1.7 m^3

Therefore, the required number of filtration units = $\frac{98.5}{1.7}$ = 58.

Therefore, to treat the entire lake water, filtration may be conducted for 90 days with 58 nos. of filtration units having diameter 1.2 m and height 1.5 m.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The sample analyses of different water quality parameters of Lake Caron undoubtedly demonstrate that the water body was in an eutrophic stage. Every year, during summer the lake showed an extreme blue-green algal bloom. The water samples collected from lake showed higher values compared to the allowable concentrations for aquatic life in terms of total phosphorus and chlorophyll α concentration. So, it was necessary to treat the lake water to return it to mesotrophic from eutrophic stage.

But, to treat the polluted water, it was not necessary to remove all the nutrients from the water. As removing all nutrients from the water would impede the growth of aquatic organisms, (i.e., algae, phytoplankton, zooplankton etc.) that were the primary food producers supporting the entire aquatic ecosystem. That's why, the water quality standard had been developed to protect aquatic ecosystems. It was required to maintain all the water quality parameters within the acceptable ranges in order to protect the aquatic life. Acceptable limits for different water quality parameters to protect aquatic life had been discussed earlier.

So, the main objective of the study was to reduce the concentration of phosphorus, nitrogen, nitrate, total suspended solids, and turbidity of the Lake Caron water to the acceptable limit to maintain a healthy aquatic life. A small scale field experiment beside Lake Caron using a filtration technique was conducted with the objectives to evaluate the effectiveness of non-woven geotextiles in reducing the nutrients and suspended solids to improve the lake water quality. The results from the filtration unit showed that geotextiles can work as an effective filter media to treat a eutrophic lake water in terms of removing total suspended solids, turbidity, phosphorus and other nutrients. Custom made geotextiles with different materials and three apparent opening size had been tested as filter media. The geotextiles are TE-GTX300, TE-GTN300, TE-GTN350 and TE-GTN340 and the three apparent opening sizes were 110 µm, 90 µm and 75 µm. A total of 14 experiments were carried out using different combinations of geotextiles to find out the best combination providing maximum efficiency in removing nutrients and suspended solids to maximum allowable limits within shorter period of time. On average, the experiment duration was 7 days. The results showed that for different initial turbidity ranges, different combinations work better.

- Filtration with 2 layers of 110 µm (TE-GTX300) followed by 3 layers of 90 µm (TE-GTN350) geotextiles for 7 days was capable of improving the water quality to the acceptable level for an initial turbidity range of 4 to 9 NTU. This combination reduced the total phosphorus and COD concentration below the acceptable limits at day 7 and day 1 respectively. All other water quality parameters of that experiment were below the acceptable limits initially.

- For an initial turbidity range of 9 to 14 NTU, filtration with a filter media consisting of 2 layers of 110 µm (TE-GTX300) and 3 layers of 75 µm (TE-GTN340) geotextiles for 3 days was sufficient to achieve the water quality parameters within the acceptable limits. The total phosphorus concentration became 0.03 mg/L, i.e., maximum allowable limit suggested by MDDEP, at day 3, and all other parameters were within the admissible ranges at the beginning of the experiment.

- The combination of 1 layer of 110 µm (TE-GTX300) with 4 layers of 90 µm (TE-GTN300) showed best results for an initial turbidity range of 14 to 19 NTU and higher than 19 NTU. Filtration using this combination for 2 days improved the water quality and reduced the quality parameters to the acceptable level for both turbidity ranges. In both cases, the initial total phosphorus concentration was reduced below the allowable limit at day 2 and day 1 respectively. All other water quality parameters that were initially above the acceptable limits became within the permissible level at 2nd day of the filtration.

From the results of the experiments, it can be concluded that if the initial turbidity of water was lower, i.e., 14 NTU, the combination of 2 layers of 110 µm with 3 layers of 90 µm worked efficiently to remove suspended solids and nutrients, but for water samples with higher initial turbidity, i.e., higher than 14 NTU, combination with more layers of smaller pore size of 90 μm geotextiles worked better. It should be noted that, the geotextiles with 75 μm pore size clogged very quickly that the unit couldn't filter the water properly. So it is recommended not to use geotextiles with 75 μm apparent opening size for an initial turbidity value higher than 14 NTU.

From the particle size distribution analysis, it was found that, the geotextiles removed all sand sized particles. Because, when particles moved at very high speed, some of them broke down into new smaller particles due to collision. Also when the larger particles captured on the filters, they broke down into smaller particles due to the force of water. That's why at the end, there were only colloids or clay particles present in the water. As there was no dissolved phosphorus in the water sample, so removal of suspended particles eventually removed the contaminants from the water. It was also observed that the use of more layers of smaller pore sized geotextile filters showed maximum efficiency in case of water samples having smaller particles.

It was found that the lake water didn't have any dissolved phosphorus. So, the concentration of total phosphorus reduced with the removal of total suspended solids which indicated that most of the phosphorus content in the water was associated with suspended materials and hence removal of suspended solids significantly improve the water quality. A good correlation was found between these two parameters with a regression coefficient of 0.75.

A similar trend was found between COD and total suspended solids concentration and the value of regression coefficient is 0.77. The correlation justified the concept of COD reduction with the removal of total suspended solids from water. A very good correlation was found between these turbidity and total suspended solids with regression coefficient of 0.80, which indicated that the higher the amount of suspended solids, the higher the turbidity value.

The flow rate of water through the geotextiles with total suspended solids justified higher flow rate corresponding to lower suspended solids. These two parameters correlated each other with a very good regression coefficient of 0.83.

Flow rate depended not only on the number of filter layers but also on the pore size of the filter. Usually, initial flow rate decreased with increased number of filter layers and decreased pore size of the filter media. But, the flow rate after clogging (i.e., when the water holder of the filtration setup was fully filled with water) was almost same for all the experiments.

Suspended particles become trapped by the geotextiles, water permeability through the geotextiles gradually decreases, and eventually it clogs. Measuring the time dependence of this clogging is necessary to predicting when a geo filter is no longer useful, either because of reduced throughput or reduced filtration efficiency, and should be discarded. It was found that geotextiles take less time to clog with higher value of total suspended solids and turbidity. Though a very good linear correlation is found between geotextiles clogging time with suspended solids concentration (regression coefficient of 0.81) but a poor regression value (0.11) is found for the turbidity plot.

Both phytoplankton and zooplankton play an important ecological role in aquatic ecosystems. It was found that with the removal of nutrients, a number of phytoplankton species specially toxin producing cyanobacteria were removed. In all cases, the removal percentage of cyanobacteria was more than 90%. However, the concentration of some species was increased and a few new species were grown during the filtration.

5.2 RECOMMENDATIONS FOR FUTURE WORK

The study of filtration was a small scale field experiment and can be employed in the case of Lake Caron. Use of geotextiles as filter media in filtration to clean the water can be the safest way to treat water. Therefore a larger scale, in situ test should be performed to obtain more realistic data for scale up and future implementation.

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