The Use of Geotextiles for the Treatment of Surface Water

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Abstract

The Use of Geotextiles for the Treatment of Surface Water

Ehsan Moslemizadeh

Various substances have been discharged into water areas from the shore and rivers through human activity. Suspended solids (SS) are examples of such substances. SS have the potential to adsorb various substances such as heavy metals and nutrients. In addition, SS which exist in the water as contaminated SS, form contaminated sediments by sedimentation. These contaminated sediments will influence human health through the food chain. Eutrophication is also one of the biggest environmental problems caused by organic matter and nutrients residing in enclosed water areas. Therefore, removal of the substances such as SS, and decreasing the amount of chemical oxygen demand (COD) present in the water and organic matter play an important role in environmental treatment.

In this study, laboratory filtration tests were performed to develop a technique for water treatment. A non-woven filter was used as the filter medium. The pore size and the thickness of the filter are 150 μm and 0.2 cm, respectively. The results showed that SS were removed to levels of 2 mg/L or less by filtration. A SS removal efficiency of 84.3% was obtained. By filtration, COD was also removed. The results revealed that there is a linear relationship with the regression coefficient (R^2) of 0.6 to 0.9 between the elimination of SS and COD. In addition, dissolved COD results also showed a decreasing trend through the filtration process. Therefore, SS removal improved the quality of water in terms of COD.

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List of Abbreviations

USEPA	United States Environmental Protection Agency
ASTM	American Society for Testing and Materials
CCME	Canadian Council of the Environment
PAH	Polycyclic aromatic hydrocarbons
NTU	Nephelometric Turbidity Units
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
OCP	Organochlorine pesticides
GPS	Global Positioning System
WHO	World Health Organization
PCB	Polychlorinated biphenyls
POM	Particulate organic matter
DOM	Dissolved organic matter
AOS	Apparent Opening Size
TOC	Total Organic Carbon
RO	Reverse Osmosis
DO	Dissolved Oxygen
SS	Suspended Solids
NF	Nanofiltration
MF	Microfiltration
UF	Ultrafiltration

1 Introduction

Water reservoirs across countries have been designed and created for different purposes. The source of water for these reservoirs is precipitation and rivers; which then will form larger rivers and finally reach a sea or an ocean, or will end at a lake or a pond. Over the centuries, human use of rivers and lakes has increased steadily. Not only the quantity of water but also its quality is a concern. Unfortunately, in today's world, the quality of water is highly threatened. One of the major factors affecting the quality of water is inappropriate waste disposal in areas which indirectly affects human life. In addition, the presence of fertilizers (such as phosphates and nitrites), pesticides, and herbicides in the surface water is not only harmful for humans; it also has many negative effects on the aquatic ecosystem. It's important to know the exact concentration of contaminants in order to find the best way for their elimination. Nowadays many forms of legislation have been introduced to save the environment.

Suspended solids are the major source of the sediments at the bottom of lakes and ponds. They can absorb several types of contamination such as nutrients, and heavy metals. Removal of contaminants such as contaminated suspended solids (SS), particulate and dissolved chemical oxygen demand (COD) will improve the water quality. Filtration is one of the well-known techniques available for the removal of SS. The basis of filtration in treating the contaminated water is its separation ability. This special property makes it easy to remove pollution by removing particles larger than the filter media pore size.

The main objective of this research was to determine the capacity of a filtration system to remove suspended solids from a type of surface water by using geotextiles as the filter medium. In order to achieve this goal, laboratory filtration tests were performed. The filter medium used for this purpose was a non-woven geotextile material. The pore size of the filter, which is mainly known as Apparent Opening Size (AOS), was selected based on the size distribution of the SS. It was found out that using a continuous filtration system, suspended solids were trapped on the filter within the first hours of filtration process and upon their accumulation on the top of filter medium, and a cake was formed. As water passed through this newly formed medium the contaminants were removed. This method can be employed for several surface water bodies such as inlets, lakes, ponds, and bays. Remediation can be done by removing suspended solids and other water contaminants associated with SS. The efficiency of the filtration system for removing other contaminants, such as total and dissolved COD was also studied. As a result of this research, in-situ treatment systems can be developed to remove contaminants from surface waters such as rivers, lakes, and ponds using geotextile media.

This thesis consists of seven chapters. They are namely as follows:

1. Introduction

   In this section some general information about the background effects and the reasons are discussed. The thesis topic has been introduced in addition to a general overview of the problem.

2. Literature review

   Some similar work in this field is discussed in this section. They have been categorized regarding their similarity and relevant information used in this project. It also includes a short and brief history about filtration.

3. Materials and methods

   All the materials and methods which were used to accomplish this project are described in this part.

4. Results and discussion

   In this section results are presented in the form of graphs and tables and the discussion has been made for the different trends and explanation of the results.

5. Conclusions

   This chapter consists of the conclusions of this work.

6. Future work

   Suggestions of possible future work are made in this chapter.

7. References

   References are presented in the last part of the thesis.

2 Literature review

Natural lakes and streams are habitats for living substances such as microorganisms. They include gases, organic, and inorganic material. Suspended solids (SS) present in the water body have a significant effect on water quality issues. Suspended solids are of concern in water quality indices due to their ability to transport pollutants (Droppo and Stone 1996, 1994). SS have the potential to adsorb various substances such as heavy metals and nutrients (Fukue et al. 2007). In addition, SS that exist in the water as contaminated SS, form contaminated sediments by sedimentation. These contaminated sediments will influence human health through the food chain. Some examples of contaminated sediments properties are listed below as follows:

1. Beeton et al. (1979) has stated that the major fractions of contaminated compounds are always deposited in the sediments in the lakes, seas and oceans.
2. Studies have shown that contaminated sediments did not remain in the place they first sank. They have been distributed to other places over time (Larsson 1983)
3. The transportation of PCB's from sediments to water has been studied by Larsson (1985).

An experiment was performed in Kasaoka Bay in Japan by using a purification vessel which contained 38 filters units with a total area of 205 m^2 (Fukue et al.

2006). The results showed that the suspended solids could be reduced from 30 mg/L to 2 mg/L or less.

SS is more referred to as particulate substances which can be removed by filters. The higher the amount of this substance in the water the higher the decrease in quality such as reduced transparency. However, removal of dissolved matter is harder than particulates and they are not visible unless colored. The technology for removing dissolved materials is by using filters with smaller pore size (0.45 μm). There are some other techniques especially in wastewater treatment such as coagulation and flocculation.

Organic matter has also the potential to adsorb various substances. Organic matter in water can be classified into particulate and dissolved organic matter. The particulate organic matter itself is SS, but the dissolved organic matter can be defined as SS, when they are adsorbed by suspended solids. Tebbut (1998) mentioned adsorption as the effective method for removing dissolved organics. Moreover by knowing the adsorbing potential of SS removing these materials from water area will also remove other contaminations such as heavy metals and nutrients as well as COD and some dissolved material. It was noted by Fukue et al. (2007) that there is a strong direct relationship between removal of heavy metal and removal of SS in the water.

A report by World Health Organization (1999) states that in the Asia Pacific Region, 54% of lakes are eutrophic, the proportions for Europe, Africa, North America and South America are 53%, 28%, 48% and 41% respectively (World

Lake Database 2002) The eutrophication may cause algae blooms of organisms such as cyanobacteria. The cyanobacteria which are known to produce toxins can cause the death of aquatic biota and can also harm human health through drinking water (Carpenter et al. 1998). Blooms of cyanobacteria, or blue-green algae, are a symptom of eutrophication. Algal problems will occur by having phosphorous concentrations equal or above 50 ppb (Masters 1998). The release of toxin by cyanobacteria increases when they die as there is now no cell wall to inhibit its release. Organic matter is one of the important factors for occurrence of eutrophication. It can affect eutrophication by several mechanisms.

2.1 Quality indices of lakes

The quality of water is the suitability of water to sustain the condition of usability and to be used in different processes regarding water distribution plans. The Canadian Council of the Environment (CCME) has established a water quality index (WQI). They have provided an equation which uses the mean of three items to define on a scale of 100 whether the lake is in good condition or not. Equation 2-1 is used for calculating this index.

$$Index = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right] \qquad (2\text{-}1)$$

Calculation of this index is based on defining the three parameters; F_1, F_2, and F_3. Where:

- F_1: number of parameters that are not obedient to the water quality guidelines. (Scope). This can be expressed as a percentage.

$$F_1 = \left(\frac{failed\ units}{total\ units}\right) \times 100 \tag{2-2}$$

- F_2: the number of times in which analytical results do not abide by the guidelines (frequency).

$$F_2 = \left(\frac{failed\ results}{total\ results}\right) \times 100 \tag{2-3}$$

- F_3: the difference between the values obtained analytically which are not obeying the guideline and the values in the guideline (amplitude). F_3, as an asymptotic function, will present the normalized sum of excursions in relation to the guidelines. This value varies from 0 to 100.

$$F_3 = \left(\frac{normalized\ sum\ of\ excursions}{0.01 \times normalized\ sum\ of\ excursions + 0.01}\right) \tag{2-5}$$

"Normalized sum of excursions" can be obtained by:

$$normalized\ sum\ of\ excursions = \frac{\sum excursion_i}{total\ number\ of\ results} \tag{2-6}$$

Finally for the "excursion" calculation, there are two conditions in which excursion differs

- If the results shouldn't exceed the guideline:

$$excursion = \left(\frac{failed\ test\ result}{guidline}\right) - 1 \tag{2-7}$$

- If the results are not under the range of guideline recommendations then

$$excursion = \left(\frac{guidline}{failed\ test\ result}\right) - 1 \tag{2-8}$$

- If according to the guideline the result is expected to be zero:

$$excursion = failed\ test\ result \tag{2-9}$$

According to the above calculation, the final result is a number between 0 and 100 which can be classified from poor to excellent quality according to Table 2-1.

Table 2-1 Categorization of different quality index values (Canadian Council of Ministers of the Environment Water Quality 1999)

Quality	Value
Excellent	95.0 – 100
Good	80.0 - 94.9
Fair	65.0 - 79.9
Marginal	45.0 - 64.9
Poor	0.0 - 44.9

A series of data sets in relation to geographical and climatology of each province has been published. According to those data sets and above calculations, the turbidity of lakes in the province of Quebec should be below 10 Nephlometric turbidity units (NTU) (Canadian Council of Ministers of the Environment Water Quality 1999). In the following sections most of the contaminants threatening water quality will be discussed.

2.2 Causes of the contamination

Another reason which makes the natural water resources vulnerable is the overuse of water due to high-human activity these days. Disposal of the wastes in inappropriate regions has threatened the environment which indirectly will affect human life in the future. Many lakes and rivers have lost their purities by improper disposal of waste or discharge of untreated industrial waste directly in water resources.

Degradation of different water bodies by human waste disposal or different industrial activities can seriously harm aquatic life. In recent years there is increasing concern about the dwindling of useable water resources. Increasing rates of eutrophication of natural waters, due to human activities are a well-known problem these days. Research has been conducted to determine the cause of algae presence in water, its extent of growth, and the effect of their decomposing behaviour on water quality (Tebbutt 1998).

In this research filtration is evaluated in order to find the best and the most efficient method for in-situ filtration of water. The total and dissolved COD, the concentration of organic contents, and the total suspended solids are the performance-indicators. For that purpose a laboratory scale filtration system was set up.

2.3 Organic matter

Organic matter can be a substance which once had life and was capable of decaying or itself is a product of decay process. The content of organic carbon is important for crop production; both in land and water. In the marine environment, they play an important role in the ecology systems with providing energy, food, and vitamin for bacteria, plants and animals. Organic matter has the potential to adsorb on to various substances as well as SS, and the ability of adsorption is higher than inorganic matter. Generally speaking, based on their solubility, organic matter in water can be classified into two main groups; particulate organic matter (POM) and dissolved organic matter (DOM). Based on the definition of Thurman (1985), DOM corresponds to that portion of organic carbon in aquatic solution that can pass through a 0.45 μm silver or glass fiber filter. The part of organic compounds that remains on the filter is to be called POM. Tebbut (1998) mentioned POM can be considered as a type of SS.

Riley (1975) has stated the effect of DOM on the food chain by the mechanism of absorbance. He also indicated that part of the POM occurring in the water has been formed by sedimentation of DOM. Interaction between land and water in soil and aquatic environment, result in sorption, desorption, accumulation, and transportation of pollutants between two phases of liquid and solid. According to Volk et al. (1997) DOM can be removed by biodegradation.

Four main sources of organic matter in the aquatic environment have been introduced by Stumm (1970):

- Organic matter from land (soil) will be transported to water by wind and small streams that join others.
- Production from decaying of dead organisms. This method depends on two mechanisms which have to act simultaneously; autolysis and bacterial action.
- Excretion by plants i.e. algae. Algae provides large amounts of photosynthesized compounds, directly to the water
- Excretion of aquatic animals i.e. zooplankton may be an important source of dissolved organic matter.

Organic matter in the soil has been formed from plants and animals, weathered materials, and degraded products i.e. corps of animals and micro-organisms, biomass from green plants, and secretion from plant roots in the ground (Koerdel et al. 1997). In the rivers, because of the interaction that occurs between water and soil, there is organic matter degraded in both aquatic and ground environment. According to Koedrel (1997) there are three major components of organic matter identified in the fresh water system environment.

- The refractory allochthonous material
- The relatively labile autochthonous contribution

- Anthropogenic input to the river.

Burton and Liss (1976) have summarized the concentration of organic carbon in different parts of the aquatic environment as shown in Table 2-1.

Table 2-1 - Concentration of organic carbon in different water body systems (Burton and Liss 1976)

Organic carbon (mg/L)	River	Estuary	Coastal sea	Open sea		Sewage
				Surface	Deep	
dissolved	10-20	1-5	1-5	1-1.5	0.5-0.8	100
particulate	5-10	0.5-5	0.01-1.0	0.01-1.0	0.003-0.01	200
Total	15-30	1-10	1-2.5	1-2.5	0.5-0.8	300

The total content of organic material is also expressed as the content of the total organic carbon (TOC) which is the total content of organic bonded carbon. TOC is measured as a unit of carbon from total substances, opposing the content of total organic material (OM), which is measured as a unit of volume (Koerdel et al. 1997).

Scientists have defined natural organic materials (NOM) in the water, weathered material or degraded products of plants and animals which mostly contain carbon, but not carbon dioxide (CO_2), carbonate (CO_3^{2-}), carbide, and metal cyanides (CN^-) (Koerdel et al. 1997). As above, degradation compounds can be categorized into two main groups; biopolymers, and geopolymers (humic substances). According to their solubility in different pH, humic substances themselves can be divided into three groups;

- Humic acids which are soluble in bases but will precipitate in acids,

- Fulvic acid which are soluble in both acids and bases.
- Humins which are not soluble in acids neither in bases.

The structure of humic substances is mostly related to the biological source. Humic substances in the nature are present as colloids (Ziechmann 1960). Volk et al. (1997) studied that beside humic substances, carbohydrates, and amino acids are the major components of organic matter in the stream. It was also found in the same study that humic substances are the major component of biodegradable dissolved organic carbon that can be affected by seasonal changes.

Wedephol (1969) also suggested another grouping for organic matter based on the geochemical point of view. In this method organic matter can be divided into four different subdivisions according to their behavior upon receiving treatment by different solvents:

- Bitumen which is extractable by organic solvents such as benzene
- Kerogen which is bitumen free (insoluble organic matter)
- Humic acid extractability when treated by a weak alkali solution
- Components of the original mass after extraction procedure was done as described above. Those materials are described as residual organic matter.

2.3.1 Organic contaminants

Carbon molecules are the basic element in the structure of the organic chemical contaminants. The source of their release in the water is industrial plants, agricultural fields, municipal wastewater (CCME 1999). The organic compounds, such as alkylated and chlorinated benzenes, which have been discharged from chemical and industrial plants are the major contaminants subjecting rivers pollution and subsequently have an impact on the quality of water (Schwarzenbach et al. 1983). Nowadays utilization of some of them has been banned, however others have long lasting life and they do exist in the environment. One of the examples of this kind of organics is polychlorinated biphenyls (PCBs). The application of PCBs was in electrical equipment, heat transferring systems, and some industrial products. Being exposed to PCBs can cause health affected (USEPA 1997). Another example of organic chemicals is carcinogenic such as polycyclic aromatic hydrocarbons (PAHs). The majorities of these compounds is produced during combustion and mostly are found in wood-treating products (USEPA 1997). There are also some studies done by several scientists on the effect of organic contaminants in the environment (Wei et al. 2008). Their study was mostly focused on organochlorine pesticides (OCPs).

The presence of organic matter in the water can also affect metal behavior in the environment. NOM present in the terrestrial and aquatic phase of the environment which can influence the behavior of contaminants in the water. According to Shuman and Cromer (1979) NOM can affect metal chemical state and availability in natural water. From the biological point of view they will also mask metal toxicity to phytoplankton, increase their solubility, and act as metal buffers.

2.4 Eutrophication

Eutrophication is one of the biggest problems for water area. It is caused by the excessive and uncontrolled input of nitrogen and phosphorous in the aquasystem. It is the natural response to the state of increasing chemical nutrients in the water basin. It is important to know that in some cases P is the primary cause of the eutrophication. For others it might be N, and for the rest both (Carpenter et al.1998). Eutrophication may cause algae blooms. It has several negative effects on the water body system. Perhaps the most important and most obvious visible result is the increased rate of algal and aquatic plant growth. The negative point in this section is its interference with fishery practices and of course bad visual effects. Oxygen shortages as the result of excessive decaying plants will cause fish kills. It has been noted that eutrophication can adversely affect fish feeding habits and subsequently their meat quality (Seehausen et al. 1997). They have mentioned the aquatic light condition affected by the immoderate growth of plants can distress fish.

The decreases in oxygen levels also cause a reduction in water quality. This sudden decrease in water quality will threaten fish and other animal populations and humans through the food chain. This is commonly the result of a direct release of agricultural waste into the water system, although it can occur naturally when there is high concentration of nutrients present in the area.

Growth of aquatic vegetation and reproduction of phytoplankton is the known effect of this phenomenon which interferes with the natural functioning of ecosystems. The color of the water will then change to a greenish blue.

The excessive growth of algae (algal bloom) may limit the sunlight available for bottom organisms. The problem is well known in the shoreline areas of lakes; where green looking aquatic plants exist. Aquatic plants in general can be categorized in two main groups: Those which can move and the others that are attached to the ground. Eutrophication is the increase on nutrients in ecosystems that can lead to increased amounts of phytoplankton per unit volume of water and excessive growth of aquatic plants (Chin 2006). The increase in the population of aquatic plants can cause several effects according to Thomann (1987) as follows:

1. Visual effects by the appearance of algal colony, decaying of algal clumps, and discoloration of the water. Also the presence of unpleasant smells and odors.
2. A large decrease in the amount of dissolved oxygen (DO) at night can cause the death of desirable fish species.
3. Presence of phytoplankton settling at the bottom of the water body system can result in the contamination of sediments
4. Appearance of some kinds of phytoplankton that require silica (formerly known as diatoms) which may result in the clogging of water treatment

facilities; i.e. filtration. Also it will increase the frequency of filter backwashing.

5. Extensive growth can result in interference with channel navigation and carrying capacity.

Removal of nutrients can prevent eutrophication from occurring. Van der Molen et al. (1998) reported the decrease of eutrophication by using filtration and removing dissolved material.

The presence of organic matter in the water body system is vital for the ecosystem cycle, but at the same time being unrestrained is considered as contamination.

2.5 Algae

Algae are not plants as they are simpler in structure. They are like plants because they are photosynthetic. Algae are mostly multi-cellular. They consume inorganic compounds such as carbon dioxide, ammonia, nitrate, and phosphate to synthesize new algal cells and to produce oxygen. Water quality will become worse when there is lack of sunlight. It will mostly occur at depth. Algae will then consume oxygen so that in water containing algae, there will be a significant variation in DO; super saturation in the day, and too much depletion at night. Algae may be green, blue-green, brown, or yellow (Boyd 1982).

Algae and bacteria growing in the same habitat do not interfere with each other and do not compete for food; instead they have a symbiotic relationship in which the algae consume the end products of bacterial decomposition of organic matter. Algae then produce oxygen to maintain an aerobic condition. Algae are very important in the aquatic environment, particularly in standing or slowly moving bodies. In these environments where water contain nutrients (nitrogen, and phosphorus), phosphorus usually is the critical element. Most of the algae are able to fix nitrogen in the atmosphere. It was reported by Hofman et al. (1998) that they were able to remove phosphorus, suspended solids and turbidity with the help of filtration.

Tebbutt (1998) stated that blue-green algae which mostly are in shallow lakes, can survive in small concentrations of phosphates. This very special kind of algae also releases toxins which can be fatal. Skin irritations and many gastrointestinal problems are reported as the result of blue-green toxicity in drinking water. However blue-green algae are commonly known as cyanobacteria, and they are not considered as the general types of algae blooms that have been discussed in this section. In the coming section, suspended solids are going to be discussed as important and well-known contaminants in the water body systems.

2.6 Suspended solids

There are two main types of materials present in the water with respect to their size; particulate and dissolved. The scale for this categorization is the 0.45 μm pore size glass fiber. Particles that can pass are called dissolved and those which remain on top of the filter are particulate. Suspended solids are one of the natural forms of particulate matter in the water. Measuring SS in surface water has become one of the most important ways of determining water quality. This analysis was developed first for characterization of wastewaters, but since it is inexpensive and easy to use, it has been accepted for regular purposes in the lab (Glysson et al. 2000). Measuring the suspended solid is a technique to measure the concentration of particulate matter in the water. This method is filtering a known volume of water containing the solids through a pre-weighted filter which will hold the solids above it (USEPA 1998). Dissolved solids are those materials which are dissolved in water such as calcium, magnesium, sodium, and also small amounts of organic matter that are soluble in water (Hemond and Fechner – Levy 2000).

It was noted by Fukue et al. (2007) that there is a strong relationship between chemical oxygen demand (COD) and SS in the water. The adsorbing potential of suspended solids can be taken into account. Removing these materials from water area will also remove other contaminations such as heavy metals and nutrients as well as COD and some dissolved material. Therefore, removing suspended solids is important for treating water in areas such as lakes and ponds. Filtration is one of the well-known techniques which are available for removing SS from water area. In this study, the objective is to develop a technique for treatment of surface water by removing the contaminants with in-situ filtration, laboratory filtration tests were performed. Particulate matter has been known to be the cause of water quality decrease (Mulliss et al. 1996). The way that sediments enter the reservoir and the different methods of their settlement affects the characteristics of the particulate and dissolved solids (Eisma 1993). Contaminated sediments are harmful to human health through the food chain (Fukue et al. 2007). Suspended sediments are responsible for environmental damage such as fish gill irritation and transportation of adsorbed contaminant (Davies-Colley and Smith 2001). Suspended solids presented in the water cause water to have cloudiness appearance. The intensity of this cloudiness is called turbidity.

2.7 Turbidity

This parameter is mostly related to suspended material in the water system. Turbidity is the cloudiness caused by particle matters. Some particles have larger sizes and heavier weights than others and thus they can settle faster than smaller and lighter particles (USEPA 2005). The increase of suspended solids may result in light closures. The decrease in the clarity of water subsequently will cause the environment to be unsuitable for organisms. The impact of sediments is mostly related to sunlight and visual range reduction which causes photosynthesis problems. Nephelometric turbidity as an index of light spreading by suspended solids has been widely used (Davies-Colley and Smith 2001).

2.8 Cyanobacteria

Cyanobacteria are known to produce toxins that can cause the death of aquatic biota and can also influence human health through drinking water. This very special bacteria is well-known as blue-green algae. Growth is highly related to the nutrient concentration in water body. Cyanobacteria have attracted the attention of environmental and health agencies all around the world. There are several reports on animal and human poisoning due to polluted water consumption resulted by the activities of this very special kind bacteria (Sivonen et. al. 1990).

Cyanobacterial toxins are now becoming concerns of many professionals and cases of animal and human poisonings have risen (Codd 2000; Codd et al. 2005; Mohamad and Shehri 2007). All these problems have made cyanobacterial contamination an important issue for water quality over the past decade.

2.9 Dissolved Oxygen

Oxygen is known to be the most important element in controlling water. The presence of O_2 is vital for maintaining high forms of biological life. The first parameter subjected to change after receiving a pollutant is oxygen. When an organic substance enters a stream, microorganisms start to digest this substance. This reaction is below:

$$Organic\ matter + O_2 + nutrients \xrightarrow{microorganisms} CO_2 + H_2\,O + stable\ products$$

This reaction is known as oxidation. It consumes oxygen and can lead to depletion (Kiely 1997). Due to the chemical characteristics of oxygen and water, it is slightly soluble in water. Clean surface water is highly saturated with dissolved oxygen (DO), but it will decrease rapidly in the presence of pollutants.

Tebbutt (1998) recommended that for maintaining aquatic life, a concentration of 2 mg/L of DO is the minimal requirement for small reservoirs and about 5 mg/L for larger scale ones.

Chin (2006) indicates that depletion of DO in lakes and reservoirs at the lower depths can cause iron and manganese to become dissolved, and this can cause severe changes in taste and odor. Another possible reason for taste changes is the release of anoxic and/or anaerobic decay products in the water such as hydrogen sulfide. Oxygen solubility is related to the environmental conditions. According to the USGS (2006), the solubility of oxygen decreases by pressure depression or temperature increases. In shallow surface water though there is not much change in pressure, and therefore temperature is the main influence. In order to control this vulnerability, it is necessary to measure the amount of oxygen at every stage for a better understanding of the water quality condition.

2.10 Oxygen demand

Indication of the organic content in water or wastewater is by measuring the amount of oxygen which is required to oxidize it. There are two main methods for measuring the oxygen demand in water body system:

- Biochemical Oxygen Demand – a measure of oxygen required by microorganisms for degradation.
- Chemical Oxygen Demand – chemical oxidation by using oxidizing agents in an acidic environment.

As the results are faster for the COD test than the BOD, it is preferable in lab scale experiments. Organic matter can be determined directly as Total Organic Carbon (TOC). Chin (2006) has stated that comparison of BOD and COD results can help in identifying toxicity and to indicate the presence of biologically resistant substances. This is regularly done. For example, if the ratio of BOD to COD is about 1:2. The organic matter is considered quite biodegradable.

BOD is related to biodegradable compounds and it is the quantities of these substances which can be oxidized by bacteria. The amount of oxygen required for this is called BOD. Aerobic bacteria use dissolved oxygen for biodegradation

COD is the amount of oxygen consumed when materials in water are oxidized by a strong oxidizing chemical agent. Chin (2006) stated that this oxidizing procedure results in oxidation of almost all organic compounds that are not available for immediate consumption. According to literature (Luck 1999), COD results are higher than BOD. In the COD test procedure, organics will react with chemical agents in a high temperature. However the procedure is faster than the BOD test. Testing BOD takes five days, but a normal COD test is done in two hours. This feature makes COD advantageous over the BOD test for monitoring organic content. Organics are subject to reaction with a boiling mixture of chromic and sulfuric acid which is to be prepared under special conditions. Furthermore, organic matter presented in surface water can be used as the indication of pollution level of the water body (WQM 1999). It has been stated by Boyd (1982) that the density of plankton and turbidity are the major cause of oxygen consumption and subsequently increasing of oxygen demand in enclosed water areas. This happens because of the organic material decomposition by microorganisms. The relationship between organic matter concentration and the depth of the reservoir is direct. Samples taken from the surface of water tend to have a lower COD concentration in comparison to COD from the same point at a greater depth (Dixit et al. 2007). This is probably because of aeration at the water surface.

COD is a commonly used method in labs which gives the equivalent value of the amount of oxygen which is needed to oxidize all the organic matter in water samples to CO_2 and water. All these reactions take place in a vial using a strong chemical oxidizing agent in an acidic medium after preparation. Most of the COD measuring kits in today's market use the same technique. They used to use potassium permanganate ($KMnO_4$) as the strong oxidizing agent for many years, but since its effectiveness varied widely from time to time and also it was not able to oxidize all organic material completely, it has been substituted with another substance potassium dichromate ($K_2Cr_2O_7$), as it is more effective and inexpensive. The capability of oxidizing almost all of the organic compounds, make this the indicator to measure COD.

The following unbalanced equation shows the reaction of potassium dichromate with organic matter (Eykholt and Fritschel 2000):

$$C_nH_aO_bN_c + d\ Cr_2O_7 + (8d+c)\ H^+ \rightarrow 2dCr^{3+} + nCO_2\uparrow + c\ NH_4^+ + \frac{a+8d-3c}{2} H_2O$$

And if $d = \frac{2n}{3} + \frac{a}{6} + \frac{b}{3} - \frac{c}{2}$, and n=3, a=6, b=3, c=2 then:

$3Cr_2O_7^{2-} + C_3H_6O_3N_2 + 26H^+ \rightarrow 6Cr^{3+} + 3CO_2\uparrow + 2NH_4^+ + 12H_2O$

2.11 Heavy metals

Metals naturally are present in water bodies, but man's industrial activities have increased contamination. This kind of contamination threatened water, soil, and air. This is to be a health concern since many metals are identified as toxic. Having the specific gravity greater than 5 g/cm^3, they will be categorized as heavy metals (Neely 1979). Metals such as copper, zinc, nickel, and lead are examples of heavy metals. According to the United Nation Environmental Program, most common metal pollutants present in the environment are chromium, copper, lead, nickel, zinc, arsenic, mercury, and cadmium. Heavy metals are also key components of biomolecules, such as most of the enzymes, thus they are required to be taken in the daily diet in small amounts. Moreover, if ingested above the recommended range they can act as toxic due to severe effects. It has been stated by Mulligan (1998) that metals such as zinc, copper, and nickel can affect skin, respiratory and gastric systems. Some heavy metals, such as cadmium, mercury, and lead even at very low concentrations can be toxic. According to CCME standards (1999), chromium, copper, and lead are among those heavy metals which are the concern of Canadian drinking water suppliers. There are currently several ongoing efforts made by investigators to monitor and trace the distribution and concentration of metals in water, soil, sediments, and in the air (Pligirim and Schoreder 1997).

2.11.1 Copper

Having the atomic number of 29, copper is well known for its excellent electricity conductivity. It has a reddish-brown appearance and tightly bound to organic matter. Moreover, degradation of organic matter can release copper to the environment (Mulligan 1998). Copper is mostly present in the water in the form of soluble salts. The concentration of copper salts in natural surface water has been reported to be 0.00083 mg/L to 0.105 mg/L (Faust and Aly 1999). WHO has published an international drinking water standard in which the acceptable concentration of copper is 1 to 1.5 mg/L (WHO 1993). This limit is different from European standards which recommends water used in a distribution system, the copper concentration level should be less than 0.05 mg/L.

2.11.2 Zinc

Zinc is a bluish-white metal that has an atomic number of 30. It can affect the taste of water adversely. Like other metals, extensive exposure to it can cause problems. Respiratory problems have been reported from high concentrations of zinc chloride ($ZnCl_2$) (Faust and Aly 1998) from 600 to 2000 mg/L) will lead to poisoning (Mulligan 1998).

2.11.3 Nickel

It is a silvery-white metal. Nickel compounds are found in most of the mines and the majority of nickel salts are soluble water. Nickel chloride ($NiCl_2$) is the most soluble form in water. The natural concentration of nickel in the water and streams has been reported from the minimum of 0 µg/L to the maximum of 71 µg/L (Faust and Aly, 1998). Sediments in the river can adsorb nickel compounds and transport them (Fukue et al.1997).

2.11.4 Lead

Lead appears as brownish-white or grey. Its atomic number is 82 and according to Mulligan (1998), galena ore (PbS) is the main source of lead extraction. Lead concentration in surface waters has been reported from 0.001 mg/L to 0.89 mg/L (Faust and Aly 1998).

2.12 Surface Water Treatment

2.12.1 Methods for suspended solids removal from water

The in situ treatment and remediation of large reservoirs are limited. However, fixed facilities are used such as treatment plants. Measuring suspended solid concentration is the most accurate way for finding the total amount of suspended solids. This method has been derived from wastewater sampling, but nowadays is widely being used and accepted for regular water treatment purposes. Because of the low price it also can be used in labs. The general techniques for removing suspended solids are:

- Screening (filtration)
- Flotation
- Sedimentation

There are also several techniques such as booms, pumping of toxins and absorbents, which are used to treat contaminated surface water streams that are spilled from agricultural field, marine, domestic, and industrial plants. It should be noted that these techniques are mostly applied for controlling chemical spills such as oil (Yong et al. 2007).

2.12.2 Filtration history

Filtration is a physico-mechanical method used in water and wastewater treatment systems. Mechanical separation as it is called in the literature is one of the most common techniques in industry for particle separation. In the liquid phase they include filtration and sedimentation processes (Purchas and Sutherland 2002). Filtration is the removal of suspended solids by passing the liquid containing solids through the porous media. In water treatment, for producing high quality water, a combination of several other methods with filtration will be taken into account. In water treatment plants filtration will be mixed with coagulation, flocculation and sedimentation processes, lime or lime-soda ash softening with sedimentation. Filtration technologies can be classified as depth filtration and surface filtration. It is believed that it goes back more than 4000 years. The first trial in water treatment goes back to 2000 BC. Basic purifying methods such as boiling or placing hot metals in water, and passing that water through sand media or charcoal filters were the first registered methods in the history.

The first filtration experiment is registered under the name of Sir Francis Bacon In 1627. Within a hundred years, sand filtration was the preferred method for water purification purposes. During those times, Robert Thom, a Scottish scientist, was the first publisher of this method. He also designed the first citywide municipal water treatment in Scotland. Later on in the nineteenth century, American scientists successfully designed a rapid sand filtration system which was able to clean a jet stream (Baker et al. 1981). Combination of this method with chlorination reduces bacterial colonies causing different common water diseases (i.e. chorea, typhoid, and dysentery). In the United Kingdom, the Metropolis Water Act of 1852 required all water supplies in London to be upgraded to slow sand filtration plants (Binnie et al. 2002). By the beginning of 1985, installing a water filtration plant to provide clean water became the law (Outwater 1996).

2.12.3 Filtration methodology

The main purpose in filtration is to remove non-settleable solids. It can also remove suspended solids, some microorganisms, and bacteria. Reducing the turbidity by the result of removing suspended solids and subsequently improving water physical appearance are well-known. Finlay (1979) named several factors affecting the filtration process. They are as follows:

- Filter opening size: determines the particle matter that can be trapped by the filter.
- Grain size and shape: angular shape grains are known to have higher efficiency in filtration removal rate. The existence of particles categorized as large grain size increase filtration efficiency.

- Chemical properties of water and particles: to help the adsorption capacity, chemical may be added to the filter.
- Filtration velocity: increasing the discharge or velocity above the filter decreases filtration efficiency.

2.12.4 Filtration types

Filtration technology can be classified in to two main types; depth filtration and surface filtration. However there are some other kinds which are mostly used for special water quality purposes such as purification, desalination, ion separation in drinkable water treatment systems, medical and pharmaceutical purposes, chemical, and food processing technologies. In those situations, where there is the necessity of producing water free of all possible substances, membrane filtration is used. The more sensitive the work becomes, the more expensive the cost of operation and maintenance. In all kind of membrane filtration methods, there is a need for a driving force which circulates the flow in the system. Membrane fibers have found immediate application in the field of water treatment and microbiological studies. All of them follow the same filtration concept:

- Microfiltration (MF): (in comparison to the other membrane filtration methods) is the process with the largest pores and highest fluxes. Membrane pore size ranges from 0.1 to 10 micrometers. It has the ability to remove major pathogens and large bacteria. It has been increasingly used for drinking water treatment purposes. It is not possible to remove organics with MF unless they are particulates and considered to take part in turbidity measurement.

Moreover a membrane is mostly symmetric. (Schafer 2001, Belfort et al. 1994).

- Ultrafiltration: using smaller pore size compared to MF, it needs hydrostatic pressure to flow water through the filter. Usage of this method has been confined to industrial usage since its efficiency in removing dissolved organic carbon has been reported to be 26-37% in long term operation (Gimbel et al. 1993). UF pore shapes are mostly asymmetric due to their small sizes (Schafer 2001).
- Nanofiltration: has been developed recently and is suitable for low levels of dissolved solid solutions. Its application has been reported mostly on surface and groundwater with the purpose of removing nuisance substances. Its main contribution is in desalination, but also has been proven in removing natural and synthetic organic matter (Letterman 1999).
- Reverse osmosis (RO): needs pressure to force the solution through a membrane filter that takes the solute on one side and allows clean solvent to pass to the other side. Its application is in water and wastewater purification, dialysis, and food industry (Pierzynski et al. 2005). It is very costly for both operating and capital costs. For instance in residential usage for each 5 liters of clean water output, the input should be around 15 liters. RO has the smallest membrane opening size among the other methods (Figure 2-1). It can particularly remove substances smaller than 1 nm and bigger than 0.1 nm.

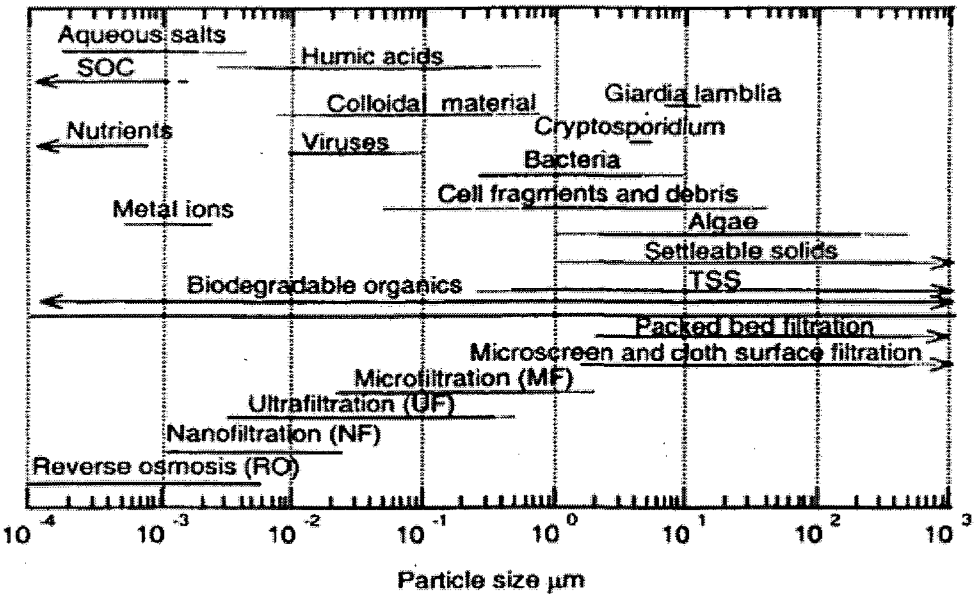


Figure 2-1 Different membranes and their removal ability with particle size ranges (Levine et al. 1985)

2.12.4.1 Depth filtration

The concept of depth filtration is completely different from surface filtration, so is its filter material. The basic principle of depth filtration is the same regardless of type of technology used (Caliskaner et al. 1999). Particle removal is achieved by passing water through a filter installed at the bed, composed of an incompressible granular media. As the flow passes through the filter bed, trapped particles are transported to the surface of the filter media where they are then removed by various mechanisms such as straining by mechanical instruments, flocculation, or adhesion (Tchobanglous et al. 1991).

2.12.4.2 Surface filtration

Surface filtration is the most common type of filtration which removes substances with the help of the filter media. The removal mechanism is at the surface of the filter where particles bigger than the pore size, are subject to being trapped and separated from the system. The technical term of AOS (apparent opening size) is used for the pore size of the filter. Efficiency of this method is highly related to AOS and the particle size in the water body system. Scientists have recommended that for the most efficient direct filtration, turbidity should be below 5 NTU (The American Water Works Association Filtration Committee, 1980).

2.12.5 Slow sand filtration

Slow sand filtration (SSF) is the oldest method of producing potable water. It mainly works through forming a biofilm in the top millimeters of sand layers which consists of several types of microorganisms such as bacteria and protozoa as well as some special kinds of aquatic insects (Campos et al. 2006). In this method is another kind of filtration for particles larger than 15 µm and the turbidity below 50 NTU. Application of this method is limited by pore blockage. Hence the need for large volumes of water for backwashing makes it costly (Swanson 1997). According to the USEPA (1997), SSF has shown a removal efficiency of 90 to 99.99 percent of virus removal.

2.12.6 Geomembranes

Geomembranes are mostly used for soil improvement purposes. They have been recommended for several geotechnical projects such as soil movement prevention, and soil reinforcement. Moreover they have been used in water-earth related projects such as channel dredging operations; however using geomembranes as filter media is limited. Geotextiles consist of permeable textiles that are available in two major forms (LaGrega et al. 2001):

- Woven: are fabrics which have measurable opening sizes and have a visible geometrical shape pattern
- Non-woven: are materials which have been formed by randomly placed fabric string or threads and mostly do not have visible pattern as the woven kind (Koerner 2005).

They have been used successfully as the replacement of granular filters for filtration in almost all drainage applications (Christopher and Fischer 1992). Designing a filter with geotextile is similar to graded granular soil. However it is more complex than soil as a geotextile has the compressible filaments as Christopher and Fischer (1992) stated. They also recommend that for thicker material, as for needled punched nonwoven, a high porosity can be specified as the clogging resistance. According to Luettich et al. (1992) in designing geotextile filters, two main requirements should be met:

1. The filter must retain soil and solid particles. In order to do this, the pore size of the filter should be smaller than the soil grains

2. The filter's permeability must be high enough to allow the water flow to pass through it.

He has also suggested some precautions in order to prevent clogging. They are as follows:

- Using the largest opening size that satisfies the retention at the same time.
- Porosity for nonwoven geotextiles should be the largest possible, and not less than 30%
- Use the largest percent open area for woven geotextiles. This value shouldn't be less than 4%.

2.13 Problem of Des Hurons river

The Des Huron River is one of the tributaries of the Chambly basin. It is a river of importance in the territory since it drains 82% of its watershed. It has a very tortuous route and its banks are eroded. The land attached to the river's bank is fairly shared between natural and residential areas. At several places, banks were dug at the base or affected by a failure in the upper portion of the bank. This problem of erosion represents an important input of sediment in the river. The main problem of des Hurons river is the high concentration of suspended solids as the result of agricultural runoff discharge originated from corn and soya fields into the river. The analysis of heavy metal concentration also shows the adverse effect of nearby industry on the river.

2.14 Summary

There are several different available surface water treatment techniques applicable to the des Hurons river pollution condition. They are mostly expensive and need the involvement of huge operations and construction designs. As mentioned so far, most of the contamination present in water causing problems can be linked to the SS fraction. Moreover algal blooms as well as several kinds of microorganisms are all part of the suspended material. In-situ filtration seems to be the easiest, inexpensive, and reliable technology for treating surface water through SS reduction. The application of In-situ filtration technology will also decrease treatment costs of water plants used as the source for potable water.

3 Materials and Methods

3.1 Sampling

3.1.1 Sampling site

Among different areas where it was possible to take samples, the des Hurons River matches all the criteria, Accessible sampling points and high concentrations of SS and COD were its noticeable characteristics. This river is one of the sub branches joining the basin of Chambly, located at about 40 km south east of Island of Montreal Island. Figure 3-1 shows the locations of the basin and the island of Montreal.

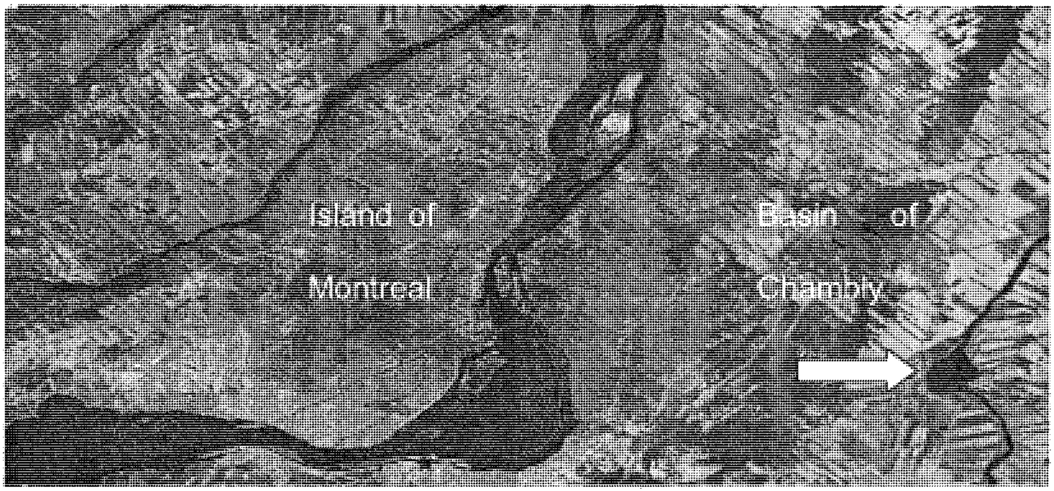


Figure 3-1 Basin of Chambly

Chambly is a city with about 26000 residences. It is located in the municipality of Vallée-du-Richelieu and it is administrated by the Montérégie. The des Hurons has a turbidity that was noticeably high. This river is known to be the subject of industrial and agricultural waste disposal from farms located at both banks. The river flows into the Basin of Chambly.

There were 7 points chosen for sampling. Selection of those stations was mostly based on their suitability for measuring and taking samples in all weather conditions. These points were sampled twice in 2007, once in the middle of the summer and once at the end of the autumn. Geographical positions of the stations were measured with a TomTom® GO 720 Car navigation GPS instrument and the data is as shown in Table 3-1.

Table 3-1 GPS values for sampling points

Station	North	West
A	45° 27' 35.41"	73° 15' 24.23"
B	45° 28' 48.57"	73° 13' 50.58"
C	45° 29' 26.58"	73° 11' 8.31"
D	45° 29' 45.45"	73° 9' 21.28"
E	45° 30' 53.89"	73° 8' 1.51"
F	45° 35' 0.56"	73° 5' 37.08"
G	45° 34' 40.74"	73° 5' 44.15"

The positions of sampling points on the river are shown in Figure 3-2. Samples were taken manually, in plastic bottles and then they were transferred to the lab for analysis. Sampling methodology was made according to the ASTM standard method ASTM D3370-82. Samples were from the surface or a depth of 10 cm. Four 20 liter containers were rinsed with the stream water, shaken and emptied. After that procedure they were ready for sampling.

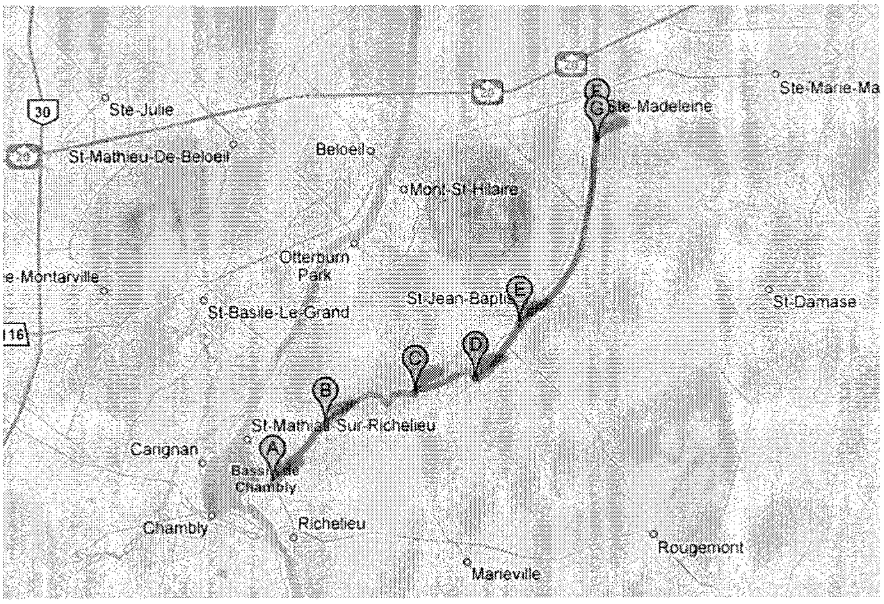


Figure 3-2 Sampling positions on the map

One of the factors related to suspended solids which can be measured at the site is turbidity. These suspended solids can be also invisible to the naked eye, but in the case of the des Huron's river the state of being muddy was high enough for bare eye in-situ diagnostics. A LaMotte 2020 portable turbidity meter was used to measure turbidity at the site. The detection limit was 0.05 NTU. Water samples were taken and shaken thoroughly before reading and for the second time when they are filled with sample water they were installed on the designated slot for reading turbidity value. After each measurement, the sample bottles were washed with distilled water to make sure there would be no residue in the bottles. Before each measurement, the calibration was made with the standard solutions present in the package. In the LaMotte 2020 box, there were three standard solutions for making the calibration. The concentrations were as follows: 0 for blank, 1, and 10 NTU. The detection limit for this instrument was 0.05 NTU. Figure 3-3 shows this instrument.

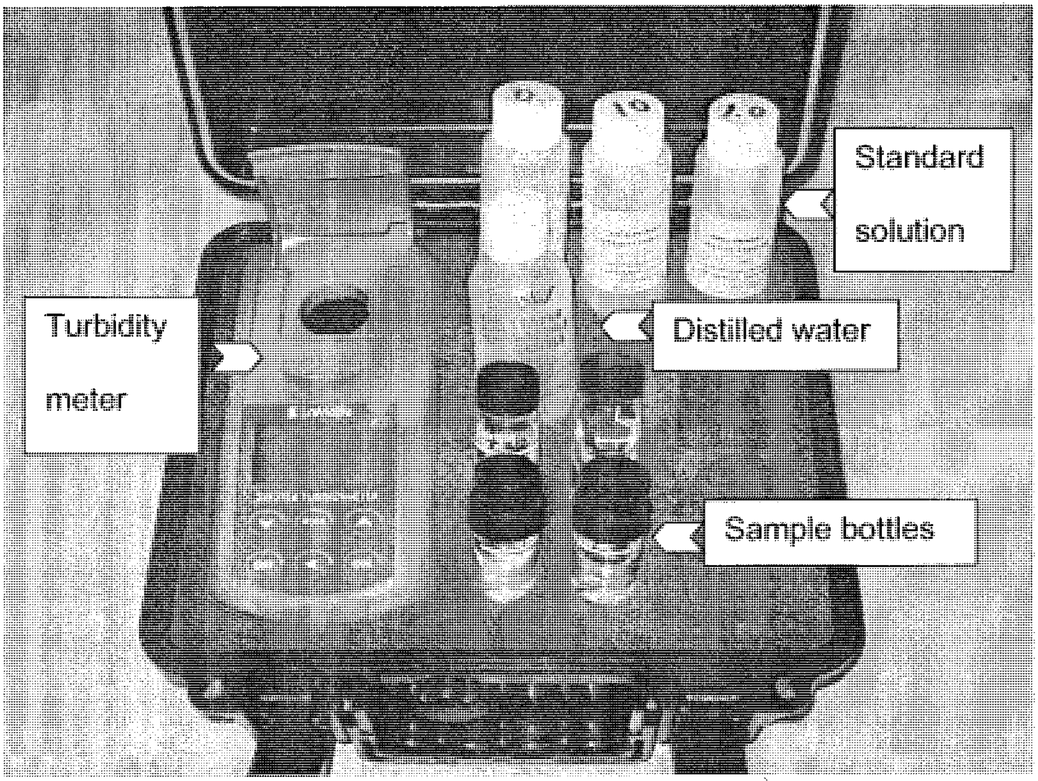


Figure 3-3 LaMotte 2020 portable turbidity kit

3.2 *Analytical Measurements*

3.2.1 Suspended solids

The ASTM method number 2540-D was used to measure suspended solids (SS) in the solution. A 100 mL sample was taken by a cylinder from a well-mixed raw sample container. A pre-weighed filter was then used for filtering SS. By means of a vacuum pump (Figure 3-4), the water was filtered through a 0.45 μm filter.

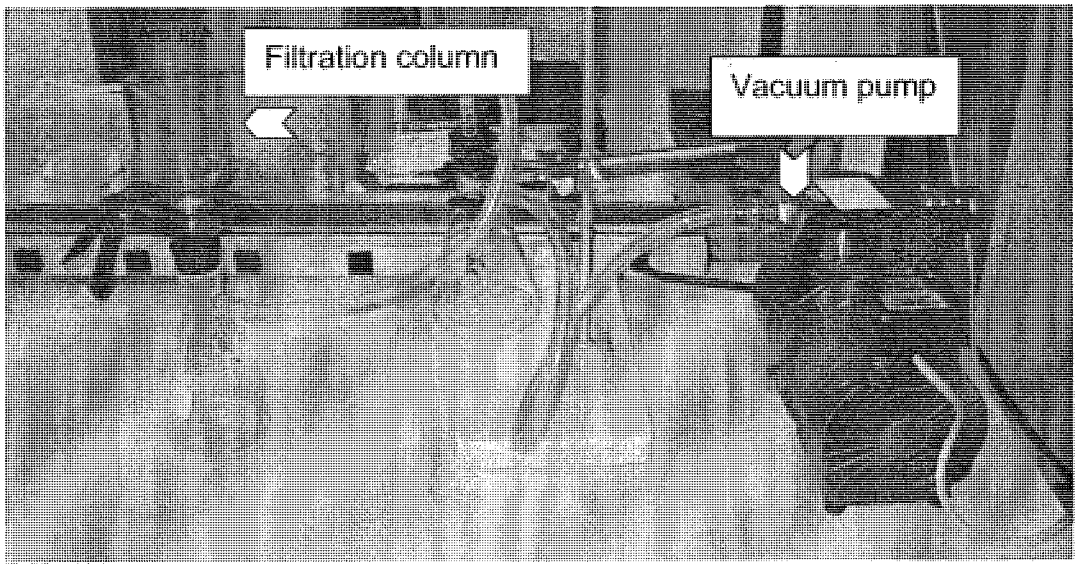


Figure 3-4 Vacuum filtration system used for separating dissolved material

The materials remaining in the water are the dissolved materials. The remaining substances on the filter are the amount of particulate solids in the water. Filters were then dried in an oven at 105°C for about one hour and thirty minutes. The filters then were transferred to a desiccator to cool to room temperature. This procedure took fifteen to twenty minutes. After that they were weighed.

The calculation for SS is shown in equation (3-1):

$$\text{Suspended Solids (mg/L)} = \frac{W_f - W_i}{V}\left(\frac{mg}{mL}\right) \times \left(\frac{1\,mg}{\frac{1}{1000}mL}\right)/L \tag{3-1}$$

in which W_f is the final weight of filter after making the solids separation, W_i is the initial weight of the filter which has been prepared before, and V is the volume of water which has been filtered. The balance detection limit was 0.0001 gram.

3.2.2 Filter media

Filters were obtained from Layfield Ltd. Table 3-2 describe its characteristics. The model was LP12 and the type was a non-woven geotextile. The opening size of the non-woven filter was 150 µm. They were cut in a circular shape with the diameter of 8.9 centimeters. The thickness of the filter was about 0.2 centimeters. A plastic square shape base, with a circular shape hole at the center of it with the exact size of the filter was used for the filter holder. It was pierced with several small holes with diameter of 1 mm to allow water to pass through. A plastic cylinder with the height of 10 cm was used at the top of the base to hold water and support the hydraulic head above the filter. There was a hole placed at the height of 7.8 cm of the cylinder which acts like an emergency spillway. It will over flow when the head above the filter exceeds 7.8 cm.

Table 3-2 Layfield's LP12 characteristics – Courtesy of Layfield ®

Property	Value
Grab Tensile (N)	1330
Elongation (%)	50
Tear (N)	511
Puncture (N)	800
AOS (microns - µm)	150
Permittivity (sec $^{-1}$)	1.0
Water flow (l/min/m^2)	3055
Weight (g/m^2)	407
Thickness (mm) nominal	3.0
UV (500 hrs)	70%
Roll size (m)	4.57 x 91.4
Roll weight (kg)	181

3.2.3 Filter coefficient of permeability

Measuring the coefficient of permeability was done in order to study the filter's ability for removing suspended solids and subsequently the contamination. This parameter is highly related to the distribution of particle size presented in the solution and the pore size of the filter (Shepherd 1989). This parameter is very well known for sand filters and anything which is related to water percolation in soil and geotechnical subjects. Studying this characteristic for the filter is mostly based on the concept of permeability. The coefficient of permeability (k) is the rate in which flow passes through a unit cross sectional area of porous media under the unit hydraulic head and unit thickness of the media layer. In this case instead of soil there is non-woven geotextile material. As described by Koerner (2005), discussion of geotextile permeability applies when liquid flow is perpendicular to filter surface. Since most of the geotextiles are thick and compressible, thickness is included in the permeability coefficient and is called permittivity. The related calculations regarding to the named reference are as follows:

$$\psi = \frac{k}{t} \tag{3-2}$$

Where

ψ = permittivity

k = coefficient of permeability

t = thickness at the normalized pressure.

Darcy (Lambe 1969) has found that there is an empirical correlation of water flow rate and porous media. He generated a formula to calculate this parameter and classify the soil types. Permeability coefficient can be calculated by knowing the hydraulic head above the column (h), the surface area of the soil (A) and the thickness of the soil layer. In this project, a geotextile membrane was used as the filter. All the parameters were measured and permeability was calculated according to Darcy's law as follows:

$$Q = k \times i \times A \tag{3-3}$$

The parameters in the equation are defined as follows:

- Q: flow rate and the dimensions are in $[L^3/T]$

- i: Hydraulic gradient and is defined as the proportional relationship between the hydraulic head and the thickness of the layer which is $\frac{dh}{dl}$. Hydraulic gradient is dimensionless.
- A: cross sectional area in which the flow passes through $[L^2]$
- k: the coefficient of permeability [L/T]
- h: the hydraulic head which is the amount of water above the filter [L]

Measurement of each state was done according to the ASTM D 2434 method which is a Constant Head Permeability Test.

3.2.4 Chemical oxygen demand (COD)

The COD test has been designed to measure the oxygen required for the equivalent amount of organic matter to become oxidized. Potassium dichromate presents in the vials is the oxidizing agent. Silver compounds present in the vial act as catalyst to promote the oxidation action. There has been also some consideration made to prevent the reaction of chloride ions by dichromate products by adding mercuric compounds. This makes the COD test more sensitive. When all the elements react in the vials the products are mainly carbon dioxide, water, and chromium ions. After oxidation the amount of dichromate which has been reacted was measured. This is the amount of reduced chromium or not reacted dichromate which can be measured. In the process of oxidizing organic materials by dichromate and sulfuric acid, most of the carbon in the sample, will be converted to carbon dioxide. In this experiment COD measurement was done with method number 10211 published by HACH™.

(Smith et al. 1999). This method generally applies for water and surface water quality studies. The general concept of dichromate chemical oxygen demand test is to measure the amount of oxygen, which is equivalent to the amount of organic matter that is oxidizable. The ultra low range digestion method consists of vials (TNTplus ™ 820) with the ability to measure COD in the range of 1-60 mg/L. Special considerations for this method were mainly for sample containers and immediate measurements. It was recommended by HACH™ that samples be kept in glass flasks to prevent the effect of alien organic material. Four 120 mL flasks were used for each sampling; two for before filtration, and two for after filtration. "Before filtration" samples were taken directly from the tank, to index the current quality of water in the tank on the time of sampling. "After filtration" samples are those taken directly drained from the filter which represents the contamination removal of filter. The other two flasks were reserved for dissolved samples which were prepared separately with passing the samples through the 0.45 µm glass fiber filters by the help of vacuum pump. In the above-named order the four flasks had been labeled respectively as follows:

- Before Filtration – Total
- Before Filtration – Dissolved
- After filtration – Total
- After Filtration – Dissolved

For each COD measurement, 2 mL of those samples were pipetted, and were transferred to separate vials. Shaking the vials for about 3 seconds makes the water samples and reagents inside the vial to start the reaction. Each vial contains sulfuric acid (H_2SO_4), potassium dichromate ($K_2Cr_2O_7$), sulfamic acid (NH_2SO_3H), and silver sulfate (Ag_2SO_4) as the catalyst. Vials with the diameter of average 16 mm fit exactly the wells of HACH™ DRB 200 reactor (Figure 3-5). In the reactor samples were kept in the temperature of 150°C for 120 minutes.

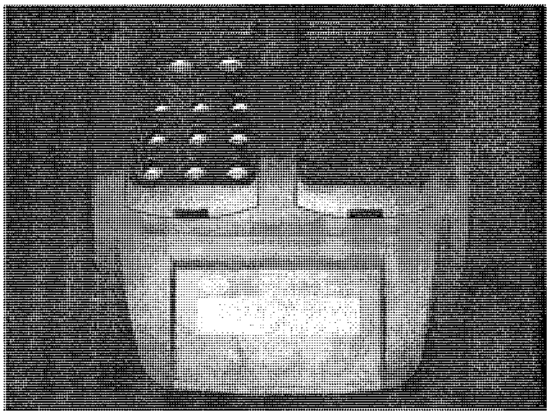


Figure 3-5 HACH™ DRB 200 reactor

According to HACH™'s manual number 1093, vials should stay in the reactor to cool down to the temperature of 120°C and then again be shaken and put in to racks to reach room vials spend approximately 15-20 minutes in the reactor to reach the temperature 120°C and afterwards another 20-30 minutes on the racks to cool down to room temperature when they are ready for measurement.

Although that it was declared by the vendor that due to the high sensitivity of the pre-programmed spectrophotometer and the use of TNTplus™ calibration is not required, standard solutions of 10 mg/L and 20 mg/L were made and the calibration curve was drawn. A 500 mg/L standard solution and organic-free water (products of HACH™) were used to make other standards. The DR 2800 spectrophotometer (Figure 3-6) was used for reading sample parameters. The COD detection limit for this method was from 1 to 60 mg/L.

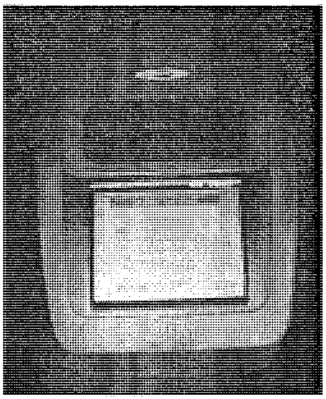


Figure 3-6 HACH™ DR 2800 spectrophotometer

Dilution was made according to the $C_1V_1 = C_2V_2$ equation. For preparing a 10 mg/L standard, 1 mL of 500 mg/L standard with 49 mL of organic-free water were mixed inside a sterilized tube. For 20 mg/L, 2 mL of 500 mg/L standard were mixed with 48 mL of organic-free water obtained from HACH™ (product number 2641549). The COD measurements were made based on the absorbance observations from the spectrophotometer. In this method wavelength was fixed to 430 µm and all the measurements were made by this wavelength. In order to have the best comparison, the conditions were not changed.

3.2.5 Heavy metals

To measure heavy metals in suspended solids, samples were centrifuged and digested using nitric acid according to the USEPA method number 3050b (USEPA 1986). The concentration of heavy metals was measured by Perkin Elmer AAnalyst 100® Atomic Absorption Spectrometer with detection limit of 0.05 ppb. (Figure 3-7).

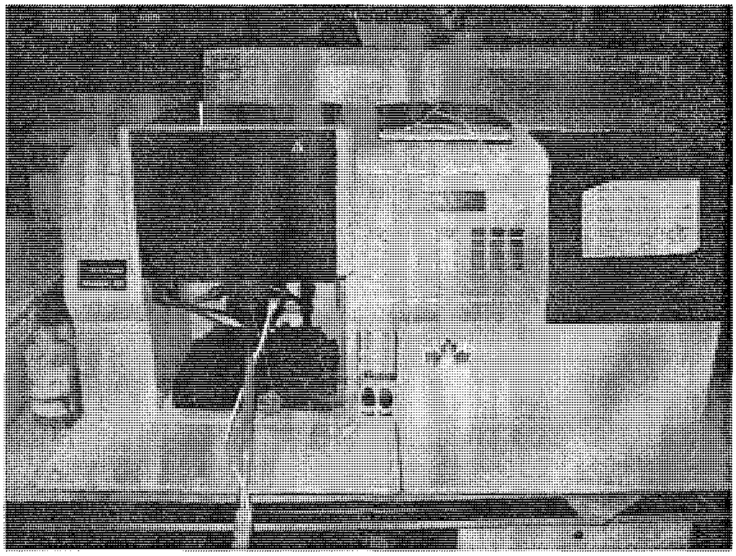


Figure 3-7 Perkin Elmer AAnalyst 100

Table 3-3 shows the allowable concentration of some heavy metals according to the Canadian environment quality guidance (2003).

Table 3-3 Allowable heavy metal concentration in fresh water

Parameter	Allowed concentration *(mg/kg)*
Chromium	37.3
Copper	35.7
Lead	35
Zinc	123

3.2.6 Total organic carbon

TOC is an important test for drinking water treatment. It is used as an indicator of organic matter. In wastewater management, TOC tests are used as a substitute for COD. Colorimetric TOC measures the total amount of non-volatile organic carbon. Common methods of measuring TOC in the lab are combustion and the UV-persulfate method. For this experiment HACH™'s method was used. The manual related to this method has been published by the provider under the general name of "method 10129". Comparative tests presented in the manual shows that HACH™'s method has very little error compared to the other two methods; UV-persulfate and TOC combustion. Comparisons have been made with both high and low concentrations. Result comparisons have been presented in separate graphs.

For both comparatives the R^2 was reported near 0.95 which shows a good relation between those methods and the new proposed method. Moreover the typical precision reported for the low range method is ±0.7 mg/L at 10 mg/L. Being quick, accessible, and inexpensive plus the acceptable precision made it the selected method for measuring TOC in this experiment. The total organic carbon direct method low range test 'N Tube™ reagent set" package contains 50 acid digestion solution reagents, 50 indicator ampoules, persulfate powder pillows, and 29 mL buffer solution (pH 2). This method, US patent number 6368870, is based on digestion in a sealed environment. Carbon compounds present in the water sample will react with persulfate oxidation and will produce carbon dioxide. The produced CO_2 then reacts with a colored pH indicator solution in the ampule which changes color. In this reaction carbon dioxide will be converted to carbonic acid and hence results in changing the indicator's color in the ampoules. The intensity of color change is proportional to the amount of carbon presents in sample. By adding the pH buffer solution to the sample, inorganic carbon will be removed. In other words, total organic carbon is equal to the amount of total carbon.

Total organic carbon = total carbon – inorganic carbon

Sample preparation was based on the published HACH's manual included in the package. Standard solutions were prepared with two main concentrations of 10mg/L and 20mg/L with dilution 50 mg/L by organic free-water, both provided from HACH™. The calibration curve is shown in Figure 3-8.

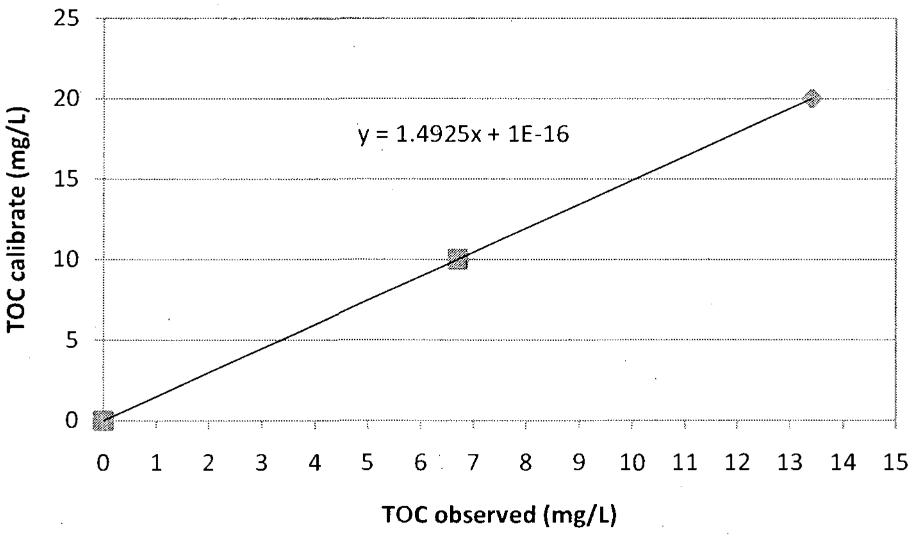
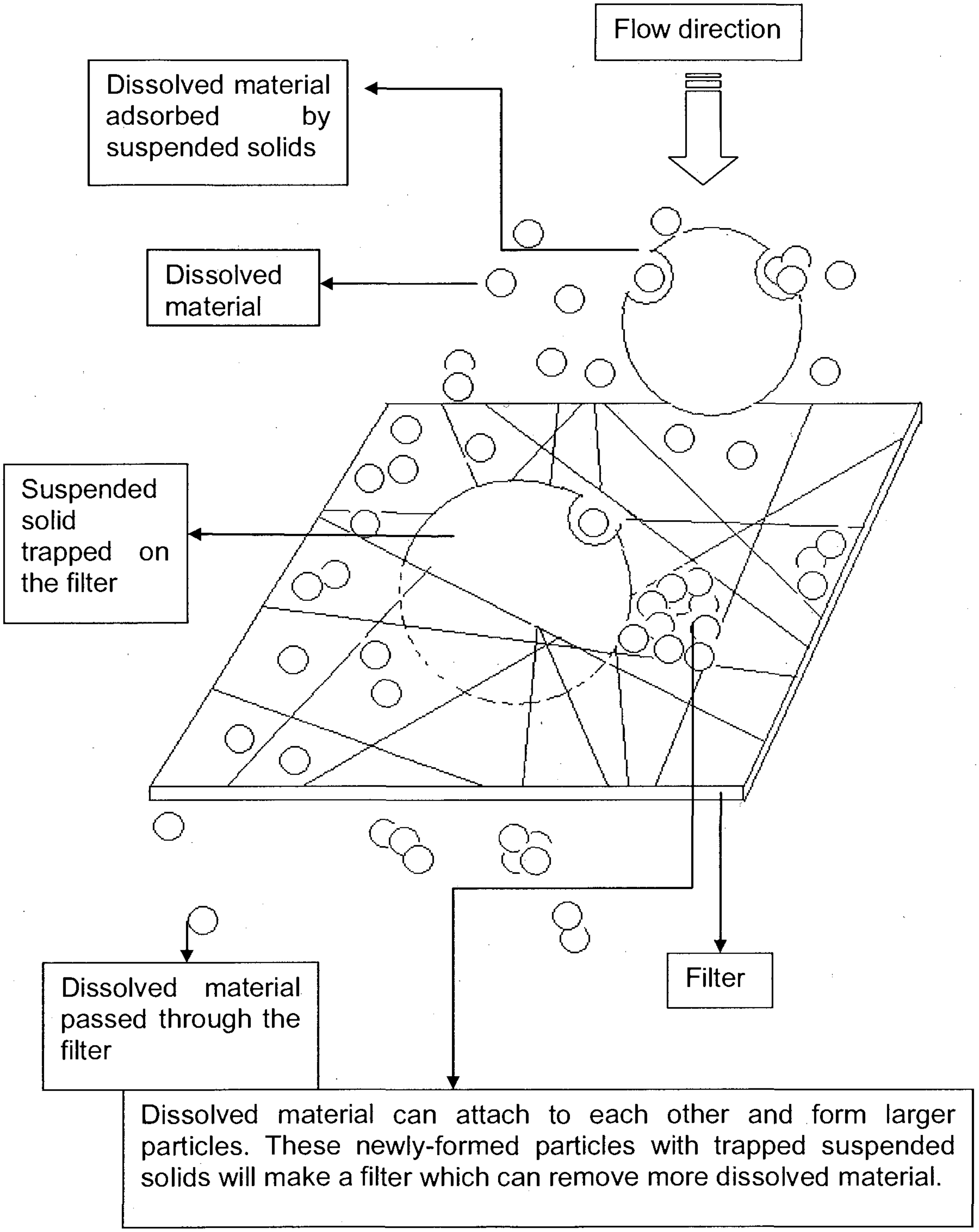


Figure 3-8 TOC calibration curve with 10 and 20 mg/L standard solutions

Samples were first mixed with buffer solution for about 10 minutes. 0.2 mL of buffer and 5 mL of sample were used. 3mL of the prepared solution are to be transferred to the 16 mm vial. Potassium persulfate was added to the vial with the small funnel provided in the package. A separate vial was labeled "Blank" and was used for zeroing the spectrophotometer. For this blank vial, organic-free-water was used as the sample water. Indicator ampoules have the diameter of 9 mm and they were easily fit in the vials. To prevent contamination, after rinsing them with distilled water and breaking the cap, they were inserted in the vials and caped securely. Vials were then transferred to the HACH™ DRB 200 reactor where they remained forspent 2 hours at 105°C. At high pressure and temperature, the sample's organic carbon was converted to carbon dioxide. This released gas will then be absorbed by the indicator and forms carbonic acid. This causes the indicator to change color. Since the carbon concentration in our samples was too low, changes were not recognizable with naked eye. Samples after passing the digestion period rested 45-60 minutes in the room temperature to cool down and then transferred to the DR 2800 spectrophotometer for measurement. Two wavelengths were used in reading the TOC concentration; one at 598 nm and the next at 430 nm.

3.2.7 Filtration process

The LP12 filters were installed in acylindrical plexiglass tube with the external and internal diameters of 10.32 cm and 8.51 cm respectively. Measurement of each state was done according to ASTM D 2434 method which is the Constant Head Permeability Test. The concept of particle trapping and removing them with filter has been shown schematically in Figure 3-9.



Dissolved material can attach to each other and form larger particles. These newly-formed particles with trapped suspended solids will make a filter which can remove more dissolved material.

Figure 3-9 Schematic view of filter's mechanisms

It is known that by the time the filter is clogged its filtration capacity would decrease. This is to be defined by permeability. The initial coefficient of permeability was measured prior to starting the experiment and it was performed by distilled water. Two 30-50 ml samples were taken each trial; one for the after and one for the before filtration sample. Comparison between these two samples will help in finding the removal efficiency. If the difference between after and before filtration is not tangible, it can be concluded that the removal capacity of the filter is full in the clogging condition and system has reached to its maximum efficiency. Hence no more dissolved residues can be adsorbed by the remaining SS above the filter, but also there is the release possibility of some solids which have been collected by the filter.

In order to start the experiment, samples were divided into three individual cases. Samples taken in June 2007 were labeled as Case I, while a portion of samples from November 2007 is Case II and the rest which has been kept in the fridge for two more months has been labeled as Case III. The characteristics and concentrations of all these cases are different. A plastic tank with a capacity of 50 liters was used as the main container. 40 liter water samples were transferred to this tank. Filtration, consisting of a pump and piping tubes which transports water to the filter medium. Cole Parmer™ is the producer of Masterflex™ pump, tubes, and rheostats. The pump model number used in this project was 7553-70 which can tolerate non-stop pumping with constant discharge over time. Water then passes through the filter and returns to the tank. Experiment set up is shown in Figure 3-10.

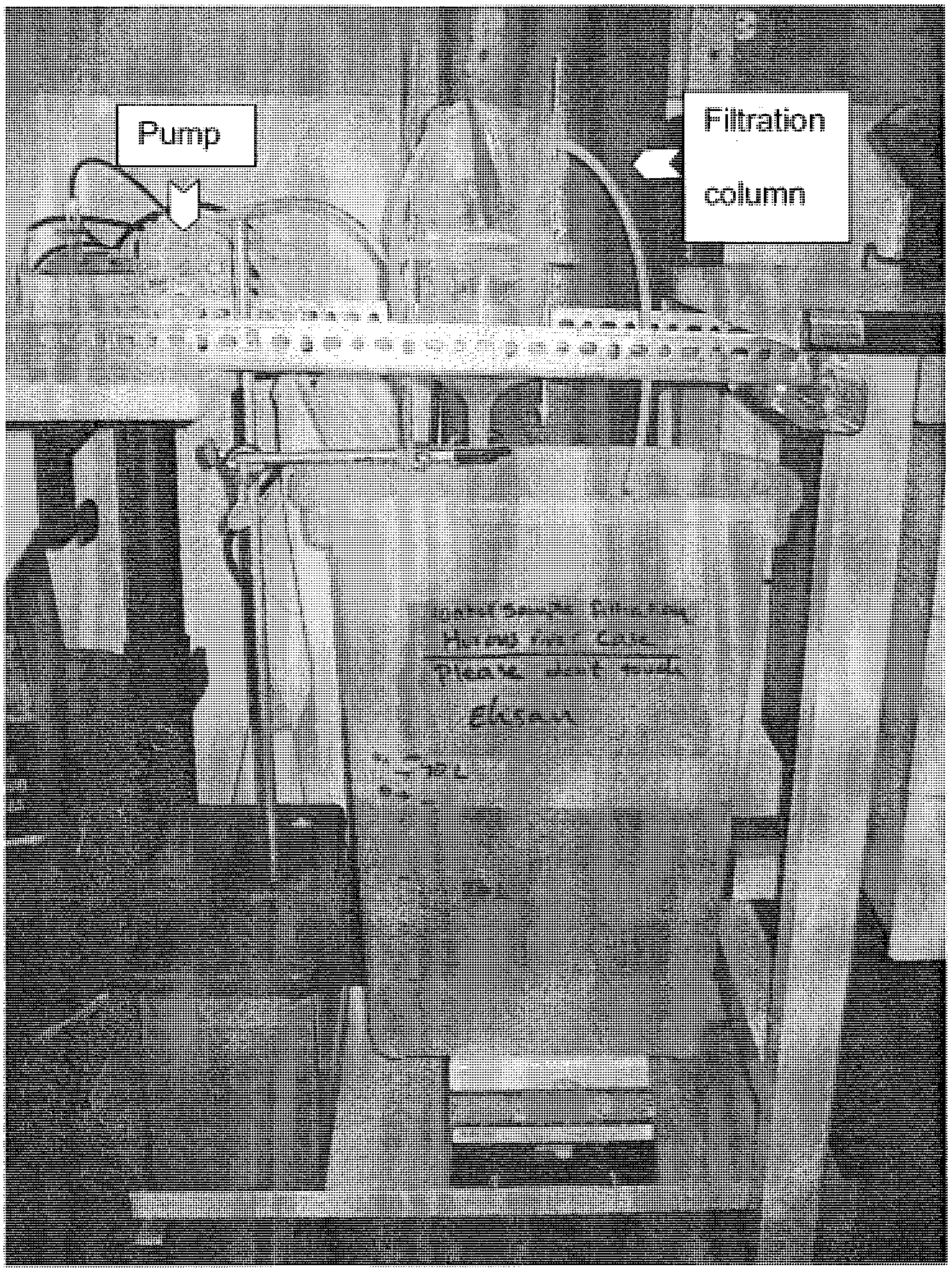


Figure 3-10 Filtration setup

The discharge capacity of the pump depends on the permeability of the filter. During the first days, the pump ran to its maximum capacity which was 10 L/min. By reaching the clogging condition the discharge reduced; after 7 days for case one and after sixty hours for case two. Therefore, the water remains above the filter until it passes through the filter. A Fisher Scientific stirrer with a hot plate was used as the main stirrer for the tank to simulate the situation of the river. Labeled as Allied™ Thermix®, its model number was 210T, the stirrer was installed at the bottom of the tank and mixes the water continuously in the order to maintain the suspension of SS in the solution. According to the results of several tests before running the actual experiment, sampling was made two times during one day of running the test (each 12 hours), until the clogging reaches its maximum capacity. In this clogging condition, the pump's discharge was decreased to 1 L/min to prevent overflow, and sampling was made once a day (each 24 hours). Depending on the results, if the changes were not remarkable, sampling was done over longer periods such as two or three days, depending on the case conditions and experimental results.

4 Results and Discussion

4.1 Introduction

The results of the experiment are discussed in this chapter. As mentioned earlier in this thesis, experiments were done with the samples from the des Hurons River. These samples were taken twice, once in July and another time in November. These samples represent a contaminated river where a filtration system could be installed for remediation. The samples were transferred to a 50 litre capacity tank and the filtration apparatus was installed above the tank. Samples were tested based on their SS and COD concentrations. These tests were made to evaluate the filtration ability in removing those substances. Moreover an additional TOC test was done on Case III to evaluate the filter ability for removing organic carbon. This is discussed in the related section. Discussion has been made independently for each contaminant (SS, COD, and TOC) present for the different cases. Samples were divided into three main cases:

- Case I, was taken from the river in the month of June.
- Case II, are the samples from November.
- Case III is the same sample water as Case II, but with a delay on experiment date. Case III samples were kept in the fridge till January.

Table 4-1 shows the properties of each case with respect to COD and SS concentrations. For all the cases, the same type of filter was used.

Table 4-1 Description of cases and their properties

	Month		initial values			
	sampling	experiment	T- COD (mg/l)	D-COD (mg/l)	SS (mg/l)	K (cm/s)
Case I	*June*	June	33.96	24.86	32	4.3×10^{-2}
Case II	*November*	November	46.00	19.10	86	4.3×10^{-2}
Case III		January	16.47	11.20	86	4.3×10^{-2}

For the reproducibility of the data, each measurement was done in triplicate and the average was reported. The error was measured based on the difference between the average and the maximum and minimum values. This error was calculated for all measured data and average error was reported in the graphs. The error margin was between 3.3% and 6.5%.

4.2 Choosing the sampling point

Based on the turbidity data during this period and the initial COD measurements, which have been done for all stations with the HACH™ method, described in the "Materials and methods", station E was selected to obtain samples for filtration tests. This station had the turbidity values of 91.7 NTU taken June 15, 2007, and subsequently 119 NTU on October 26th, 2007 and 115 NTU on November 23rd. These values were the highest among other stations tested the same day. The reason for choosing turbidity as the key test is because of its portability and the ability for in-situ measurements. The nature of its test which gives the answer in less than 5 minutes was the most important factor since we were at the first stage of studying the site. The turbidity meter was used at each sampling and results were compared. For a total of 2 out of 4 times it was found that station E has the highest turbidity, however in just one case it had the second highest turbidity among 6 other stations (Figure 4-1). This could be the result of precipitation.

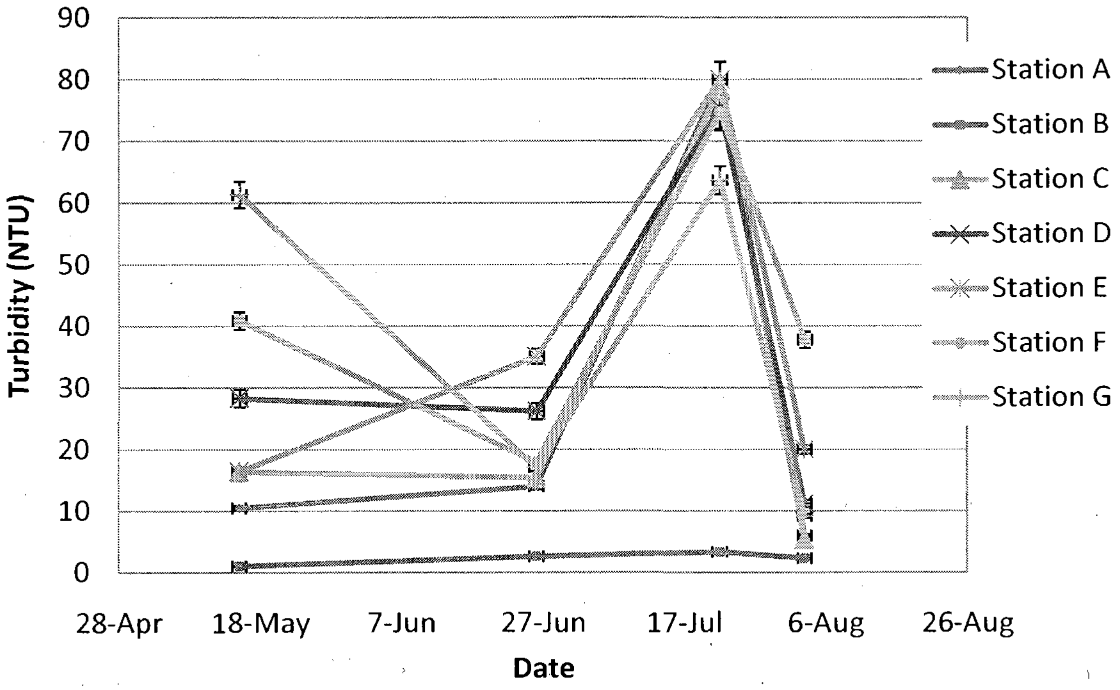


Figure 4-1 - Change of turbidity over time

4.3 Suspended solids

The suspended solids content was the first parameter to investigate. Removal of SS from the solution will reduce the possibility of contaminant release. The LP12 of Layfield™ was used as the non-woven geotextile membrane. For all three cases removal of close to 100% of solids has been obtained. The LP12 showed good performance in removing suspended solids.

Samples from November's sampling (Case II and Case III) were sent to Bodycote™ (Pointe Claire, Quebec) for particulate size distribution analysis. Figure 4-2 represents the analysis made by Bodycote on the samples taken from November. A polydisperse method was used for this analysis. According to these results (Figure 4-2), the suspended solids from the des Hurons River consist of 50% clay, 48% silt, and 2% sand of its total volume.

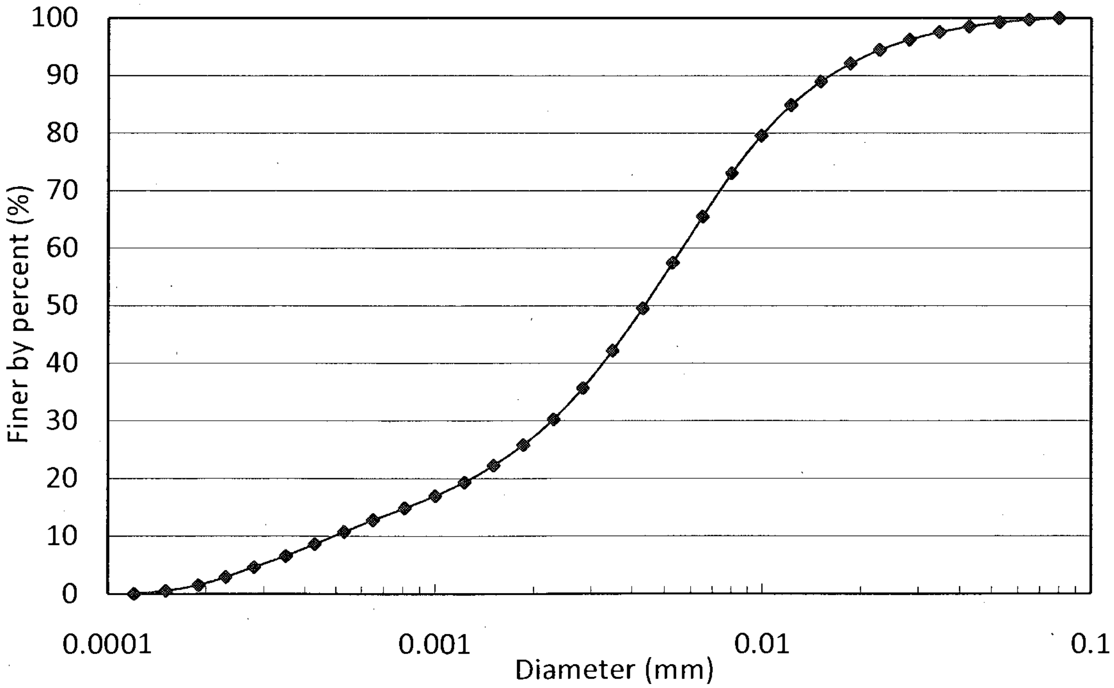


Figure 4-2 Particle size distribution for the des Huron's River SS analysis, reported by Bodycote LTD

Table 4-2 shows that the majority of the particles had a diameter of 16 µm or less. However the filter apparent opening size reported by the producer is 150 µm. At first impression, it seems impossible to remove this material.

Table 4-2 - Station E, summary of the particle size analysis by Bodycote

Station	Particle size distribution
station E	10% < 0.49 µm
	50% < 4.35 µm
	90% < 16.00 µm

According to some preliminary experiments prior to the actual experiment with the same samples, the filtration efficiency was acceptable due to the rate of clogging and the results of SS removal. For higher concentrations of suspended solids higher rates of clogging were observed. This will be more explained based on the results of the permittivity test in the following sections.

4.3.1 Case I

The pumping rate was fixed at 10 L/min at the beginning of the experiment. A thin grey layer of solids was formed on the filter medium within 3 days. The flow rate was further adjusted based on the visual condition of the filter, the particles above the filter, and the effluent flow. In order not to disturb the particles and therefore to keep the clogging as uniform as possible, the flow rate was reduced to 6 L/min. It was noticed that for the flow rates above 6 L/min, the flow above the filter medium was disturbed so that it caused the resuspension of the settled particles in this area and the formation of a ditch causing channelling which could let the unfiltered water return to the tank. On the other hand, the discharge less than the adjusted value would have caused the hydraulic head to decrease. It was observable that within the very first moments of the procedure the above parameters have a remarkable difference until day 5. This difference was again augmented within 2 days after that, but not as much as it was before. This is illustrated in Figure 4-3.

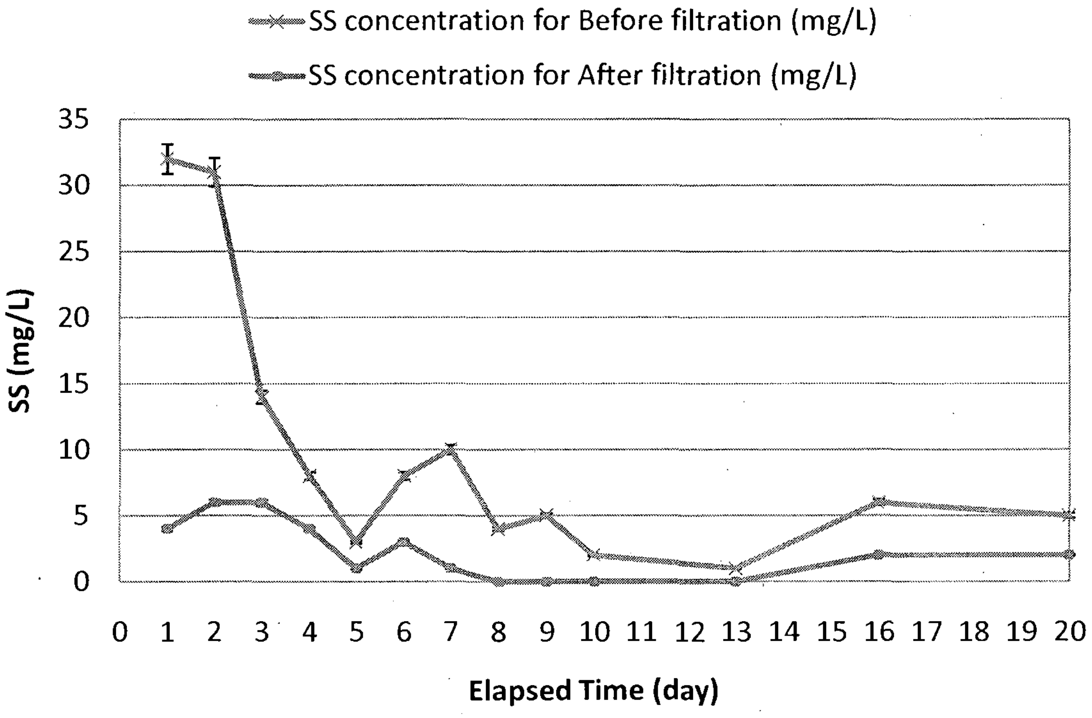


Figure 4-3 SS concentration reduction trend for Case I

The fluctuation in the concentrations could be because of the biodegradation of the late-formed particles on the filter. This filter consists of particulate and dissolved material. As it was shown schematically in Chapter 3, "Materials and methods", the formation of the filter, which itself is the result of clogging, makes it possible for the filter with an AOS value larger than the average particle size of the solids, to adsorb them. The concentration of solids in the tank changes slightly with continuous filtration. However the concentration of samples taken directly after filtration was in the range of 0 to 5 mg/L during the whole period of the filtration. The decrease in the concentration of SS started from day 2, which could be the result of passing some particles from the filter pores due to the low concentration of solids. The highest rate was from day 2 to 5, which led to the concentration below 5 mg/L. Fluctuations, which occur as the cause of low concentration, are also the result of biodegradation and re-formation of bigger solid particles on the filter. There is also the possibility of breaking the particles. It can also be due to the experimental variations. Another possibility is the breakage of the particles into smaller parts as the upshot of continuous flow through the filter.

The removal rate of SS for this case was 100%.

4.3.2 Case II

Samples for Case II and Case III had the same concentration of SS and since they were taken at the same time, most of the characteristics of the solids were the same in both cases. However due to the change in the properties (the level of initial SS is higher) and the type of the solids at that time of the year (November) which could be mainly because of extensive runoff from the farms. These effluents mostly contain soil particles and they join the stream from the banks. It seems justifiable that the results of the experiment look different from Case I (Figure 4-4).

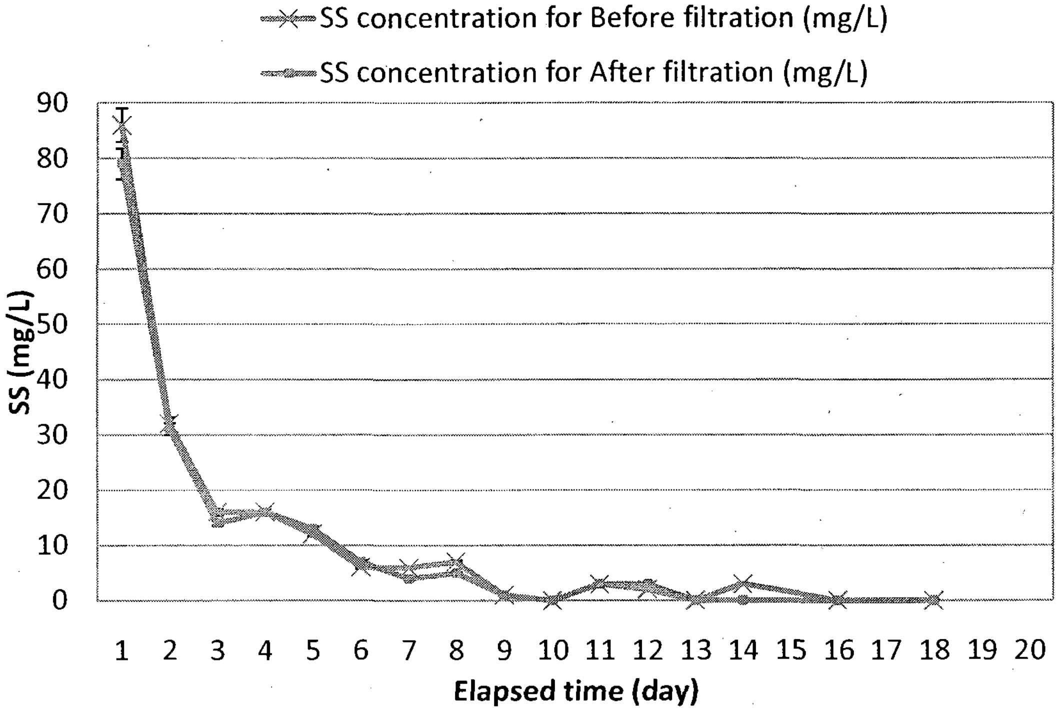


Figure 4-4 SS concentration reduction trend for Case II

The difference is discernible in representing the SS and COD. The decreasing trend and the removal rate for both values were better for Case II. The downward trends in the "After" and "Before" filtration curves overlap each other for Cases II and III. This is the sign of higher efficiency for this filter which performs better at higher concentrations of suspended solids. The trend is completely different for Case I. The removal rate for case II was almost 90% for the first 3 days of running the experiments. After that the changes were slight for 10 days. It is understood from Figure 4-4 that the best day to stop the experiment is day 16, as the changes in the concentrations after this day, were not significant. The removal rate of suspended solids for case II was 100%.

4.3.3 Case III

Case III represents the samples taken in November, which has been introduced as Case II. The main difference between the two cases (II and III) was the initial amount of COD which is due to the effect of keeping the samples in the fridge. Having the same concentration of suspended solids, this case also shows the same trends as Case II (Figure 4-5).

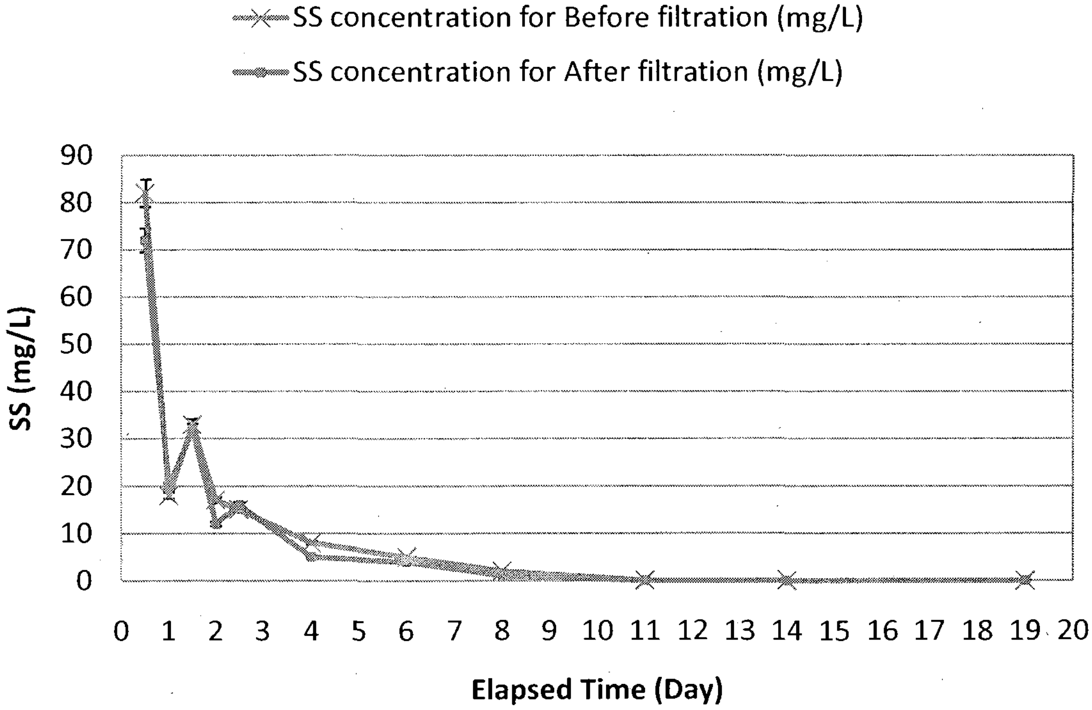


Figure 4-5 SS concentration reduction trend for Case III

There is a spike in the data for day 1.5 (36 hours after starting the pump) but this is probably because of the error in measurement. The error for the measurement of suspended solids in all three cases was 0.6% as a minimum and 2% as a maximum. For case III, removal rate of suspended solids was 100%.

4.4 Chemical Oxygen Demand

4.4.1 Case I

Evaluation of this parameter was made possible with HACH TNT™ 820 and 2 mL of the samples which were pipetted to the vials. For studying the COD removal in this project, measurements were done on four different samples each time. Two samples were taken to represent total and dissolved concentrations in the tank, named as "Before filtration", and two for the filter effluent. Based on the analysis and clogging condition of the filter, sampling intervals were determined Figure 4-6).

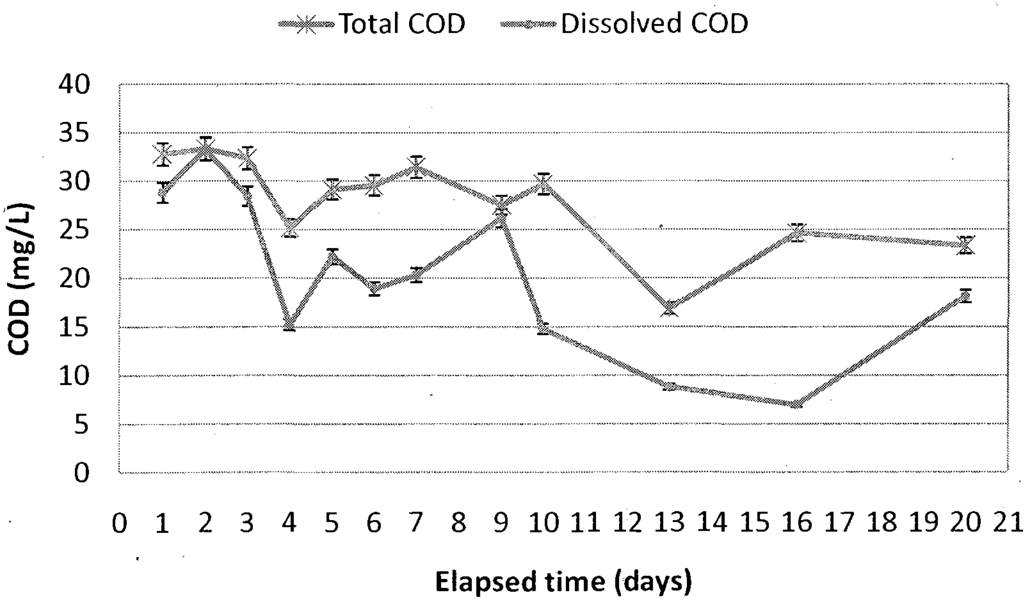


Figure 4-6 Total and dissolved COD measured for Case I

It is clear that 10 days of running the pump, which was proposed and discussed later for suspended solid removal, is the optimum time for stopping according to the COD results. Due to the special kind and characteristic of the suspended solid and its low concentration compared to the cases II and III, removal of COD for case I, was not as high as expected. A low concentration of solids also can be easily disturbed by the continuous flow. A light clogging condition occurred on the filter after finishing the process, would also explain this. Further comparison between the three cases will make it clearer.

A decreasing trend was notable in all three cases. As the concentration of suspended solids increases the removal efficiency will increase. This is also justifiable by the concept of clogging and adsorbing capacity of solids on the filter. As the COD started at 35 mg/L and declined to 20 mg/L, this shows that total COD removal is occurring. By day 16, the dissolved COD was less than 10 mg/L which is more than 15 mg/L less than the total.

There were still particulate materials that were not removed. This could probably be due to the large portion of smaller solids which could have passed through the filter pores. The test was left running for a couple more days. The result didn't improve but became worse. Comparison of the results for "Before" and "After" filtration was made in Figure 4-7.

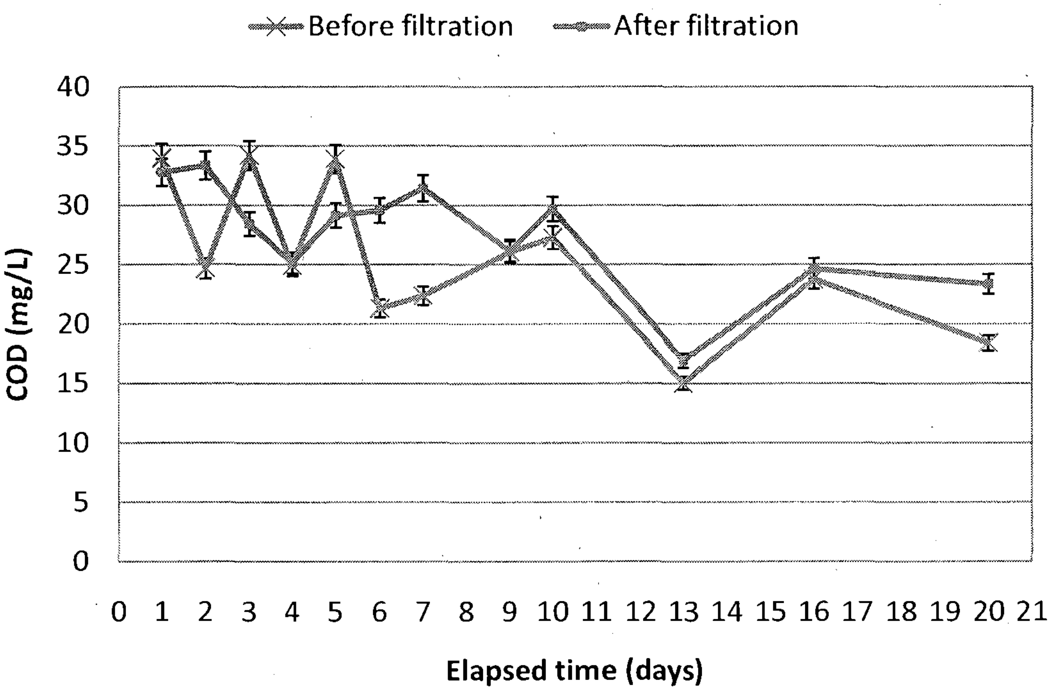


Figure 4-7 Comparison of the "Before" and "After" COD (Case I)

However with the results of Figure 4-6, it was shown that after 16 days the filter would have the “after” is larger than the “before”. It is also shown that whenever the difference between the COD concentration in the tank and the concentration of the effluent is near zero, this means that the filter has reached its removal capacity. For this case, 47% removal of total COD and 30% of dissolved COD were obtained.

4.4.2 Case II

Samples from November have their both SS and COD concentrations higher than Case I. So it was expected for this case to show heavier clogging and better removal of the materials (Figure 4-8).

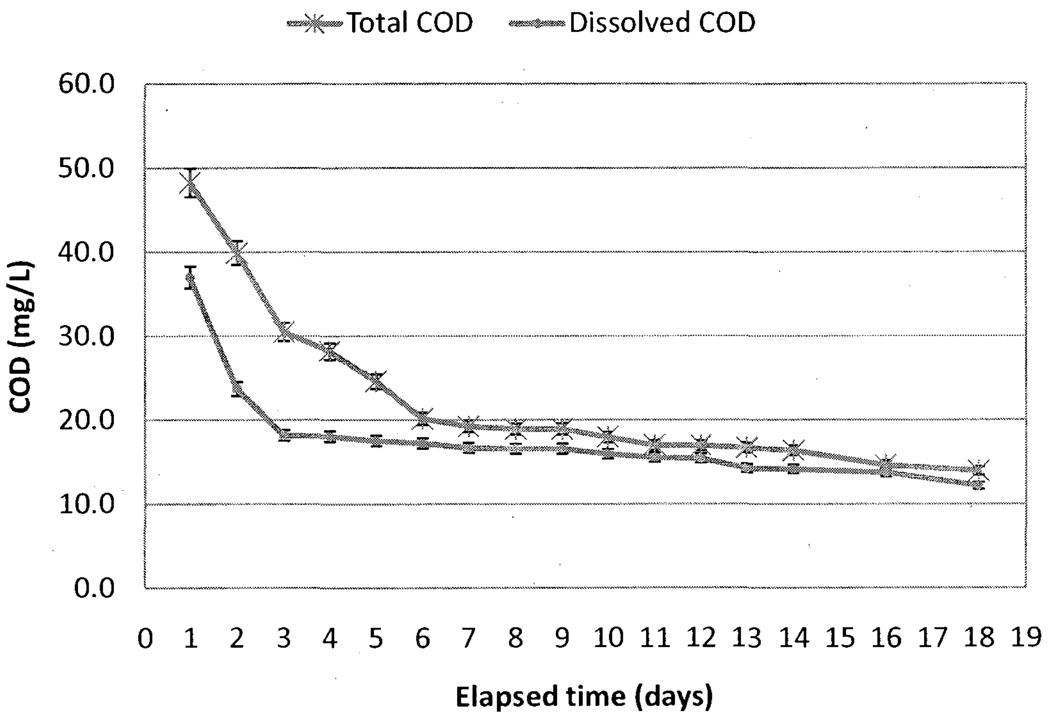


Figure 4-8 Total and Dissolved COD measured for Case II

Filter clogging occurred after almost 60 hours (2.5 days) and since the flow rate above the filter was reduced to 1 L/min after this stage (3 days), changes were made slightly. Having a closer look at Figure 4-8, it can be seen that since the concentrations of particulate and dissolved material are almost the same after day 6, it shows that suspended solids in the water could adsorb COD and particularly dissolved COD, and their capacity is reached at this time The amount of total COD for day 6 (19.1 mg/L) to day 12 (17.2 mg/L) can be considered as unchanged. However, the result changed moderately to 16 mg/L on day 16 and afterwards to 14.2 mg/L for day 18. Therefore, the filter capacity for removal of dissolved COD is related to the concentration of suspended solids present in the water, but higher concentrations need more time in order to obtain a better COD removal. Furthermore the changes that should be expected are not as much as at the start of the experiment. Studying the trend of “Before” and “After” filtration concentration in Figure 4-9 leads to understanding several differences from the last case (case I).

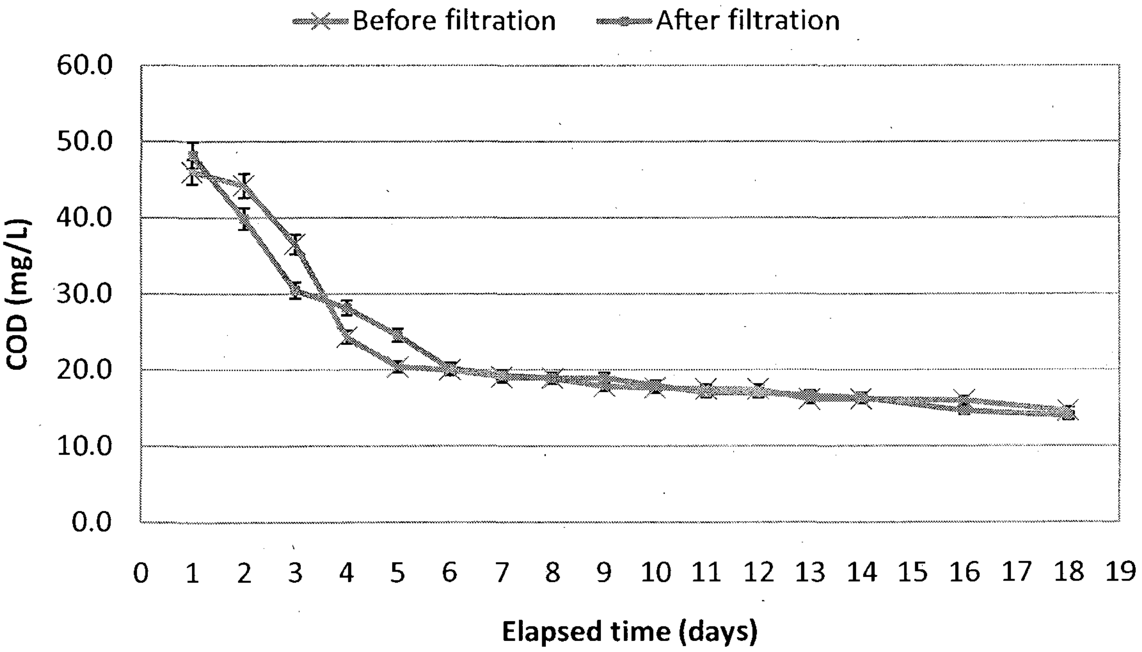


Figure 4-9 Comparison of "Before" and "After" COD (Case II)

Altering the difference between those two values, “Before” and “After”, are not as much as the case I. This is a good point which shows that the system functionality is better for higher concentrations and that is visible by the changes of concentration in the tank. As illustrated in Figure 4-9, since the amount of “Total” and “Dissolved” COD are the same from day 6, all the COD in the tank is dissolved, thus all the particulate matter was removed.

Removal of excessive dissolved material depends on the kind of suspended solid and how much capacity is available for material to be adsorbed. This is related to the physico-chemical properties of the suspended solid and their geological characteristics. Some kinds of clay material can adsorb more material than other kinds of minerals such as kaolinite, smectite, illite, and montmorillonite. For Case II a removal rate of 68% for total COD and 70.1% for dissolved COD were obtained.

4.4.3 Case III

This case is similar to Case II in the amount of SS, but not COD. The initial total COD markedly decreased from 46 mg/L in Case II to 15 mg/L but in this case from 16.5 mg/L to 6.25 mg/L (Figure 4-10).

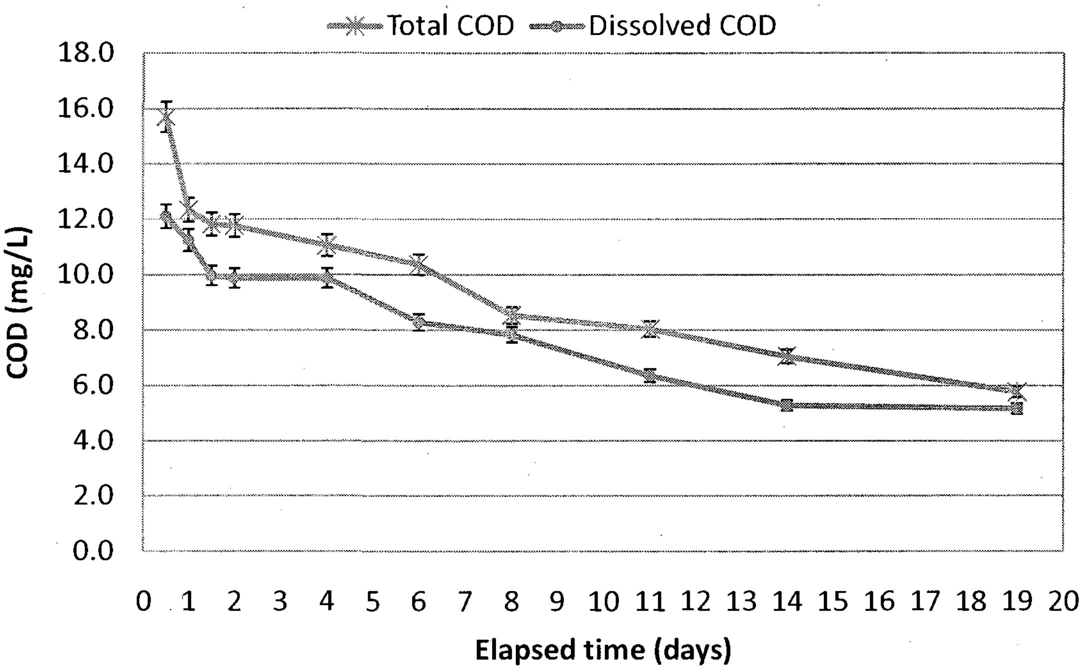


Figure 4-10 Total and Dissolved COD measured for Case III

Also the values for dissolved COD for Case II are 38.8 mg/L for the initial and 11.6 mg/L for the final concentration which for the Case III is 11.2 and 6.1 mg/L respectively for initial and final dissolved COD. Keeping the samples in the fridge caused the COD concentration to decline by 76% of its initial level. It is perceivable from Figure 4-10 that by some unknown reactions the composition of suspended solids also has changed. The trend shows that particulate and dissolved COD was present in all measurements. In Case II the difference was minimal after 6 days of running the test (Figure 4-8). This case also shows that higher amounts of the suspended solids in the water are effective with high (case II) and low (case III) concentrations of COD. It is also observable that 16 days was efficient for this kind of filter with the assigned area and water height, regardless of the amount of solids.

Figure 4-11 shows the similarity of quality changes between Cases II and III. It shows that from the beginning of filtration process, the two values, before and after COD, had the same decreasing trend and changed in a similar fashion. In these situations (as for cases II and III) the behavior of the filter, removal efficiency, and capacity plus determination of the stopping time for the process were studied. These cases were stopped based on the clogging condition of the filter and also the concentration of the solids in the tank. It is also shown in Figures 4-8 and 4-10, that after 8 days the system will remove COD very slowly and by the results of the last two cases, especially Case I, after 16 days the experiment should be stopped. Otherwise solids may be released from the filter. The removal rates for total COD and dissolved COD were 62.4% and 45.5% subsequently for case III.

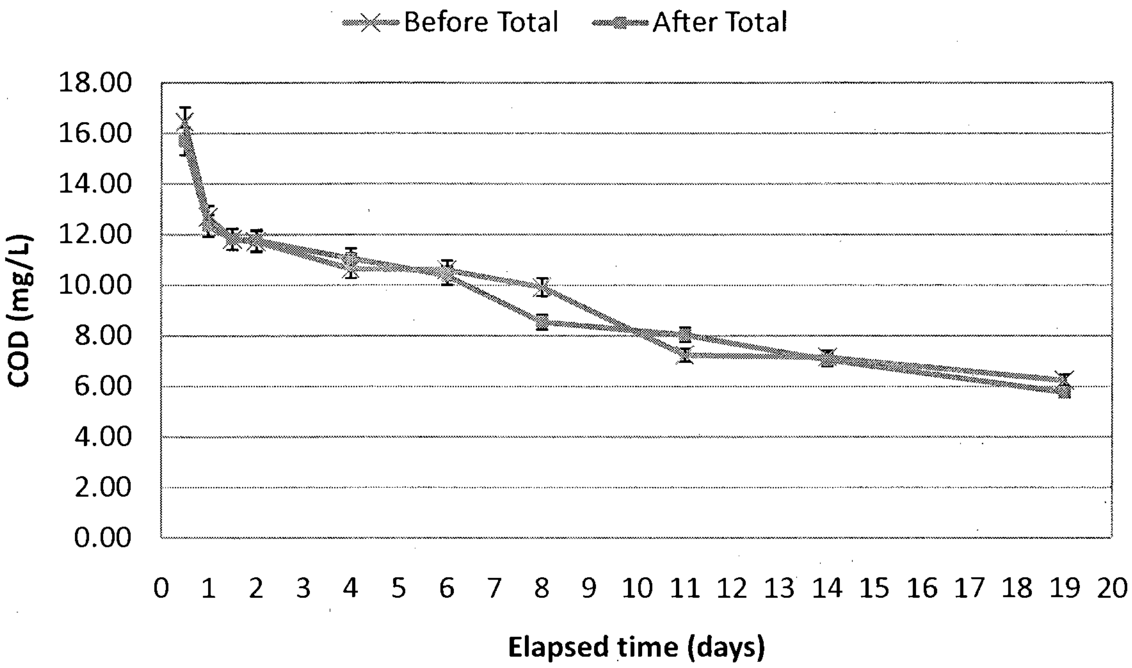


Figure 4-11 Comparison of "Before" and "After" COD (Case III)

4.5 Coefficient of permeability (permittivity)

The coefficient of permeability test was performed in order to study the flow behaviour of the filter. The graph below includes the data for the three cases. The low concentration of solids and also the difference in their characteristics for "case I" is perceptible in Figure 4-12. Not having a good clogging is the reason for not having a good efficiency in solids removal. Clogging is beneficial as it helps the formation of the filter. The results of both cases II and III show heavy clogging due to the complete removal of solids.

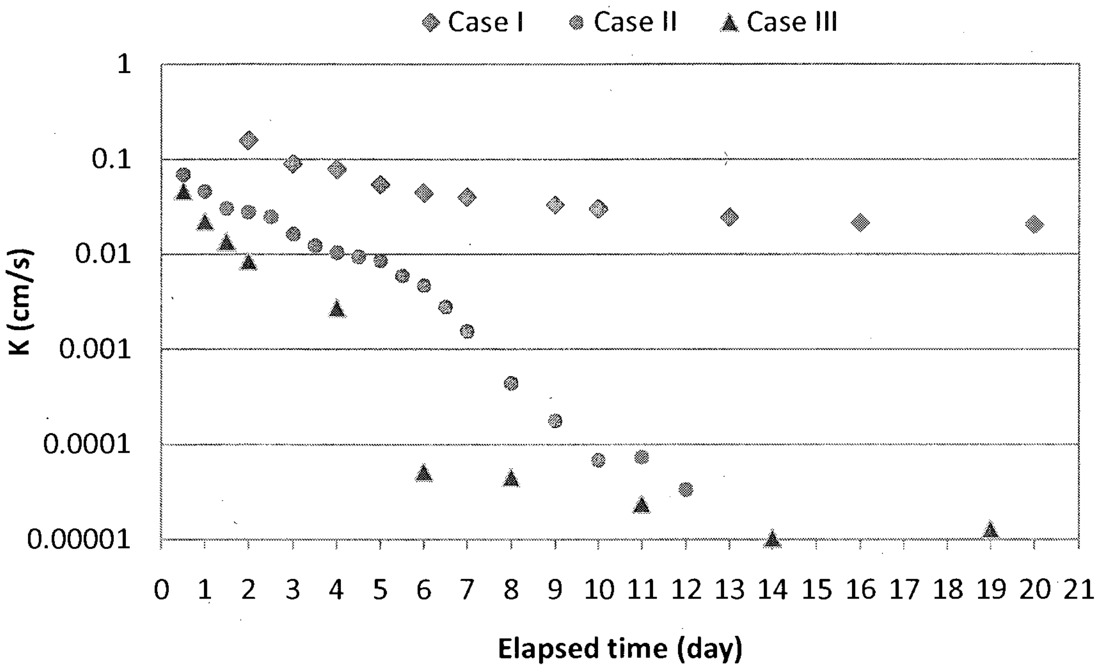


Figure 4-12 Coefficient of permeability (k) for the three cases

4.6 Correlation between SS and COD

In this project, the aim was to evaluate the removal efficiency of removing COD in the form of "Total" and "Dissolved" with removal of the solids. Removing suspended solid can lead to the removal of COD, and since the solids in this project remain above the filter they also have additional time to adsorb dissolved material. Bringing the results of SS removal with COD removal in to one graph makes it possible to compare and correlate the two parameters (Figure 4-13). It is easy to see that the concept of higher amounts of suspended solids can remove COD better. The highest correlation was for Case II where the SS and COD were the highest.

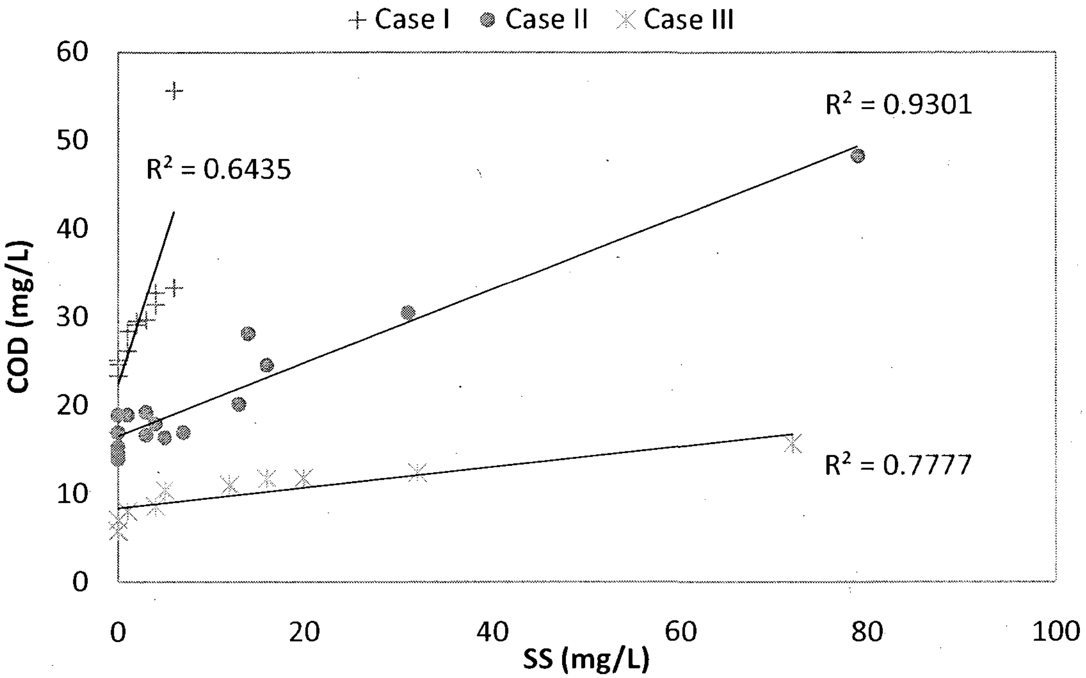


Figure 4-13 Correlation between SS removal and COD reduction

4.7 Total organic carbon

Total organic carbon (TOC) is also an alternative for measuring the organic content. The TOC test measures all organic carbon as CO_2 and is often used when the level of organic matter in the solution is low. TOC compared to COD is a more accurate indication of some of the organic pollutants that cause the most problems. However, TOC is not a replacement or an alternative method for the COD or BOD tests, as it does correlate with them on a consistent trend. TOC is important for drinking water evaluation (Faust 1999). It is used to indicate the potential formation of disinfected by-products but is usually used to determine the natural organic matter content. In this experiment TOC was measured to compare with the COD results and also to evaluate the filter ability in removing organic materials. This test was performed for Case III samples and the results show complete removal within 19 days of running the experiment (Figure 4-14).

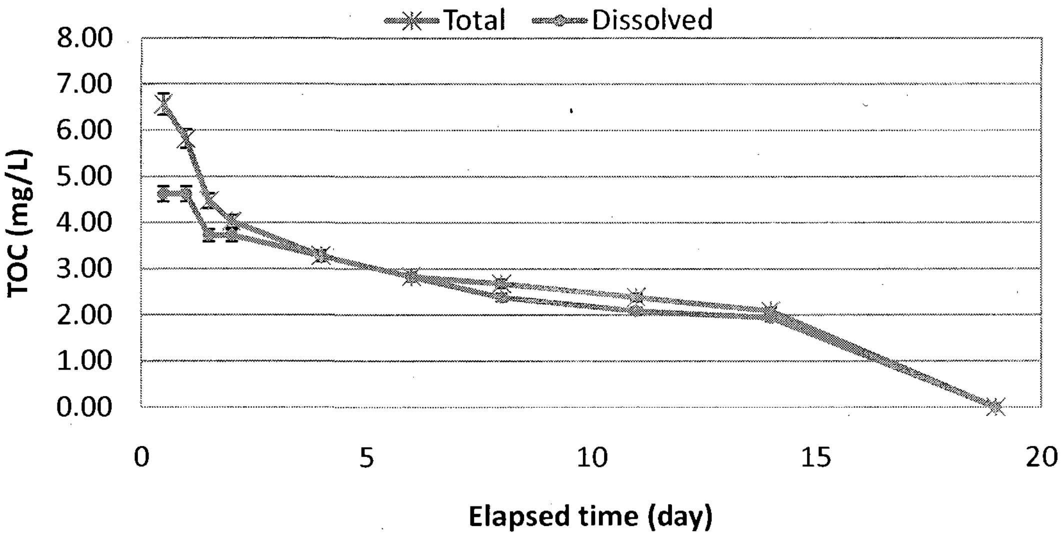


Figure 4-14 - Total organic carbon concentration for Case III

The removal of TOC is also related to the amount of COD which can be removed from the water body system. Figure 4-15 shows that removal of TOC is highly correlated with removal of COD. For higher COD removal, higher TOC removal was observed. With the calculated correlation factor of 0.82 for this water, it can be predicted that the same result would be obtained for Case II if the TOC was measured. Moreover, COD tests are more frequently done in the labs since they are faster and easier and also TOC tests are relatively more expensive than

COD. Therefore, depending on the objective of the treatment and the degree of importance of organic matter measurement, TOC and/or COD could be the desired parameter(s) to measure.

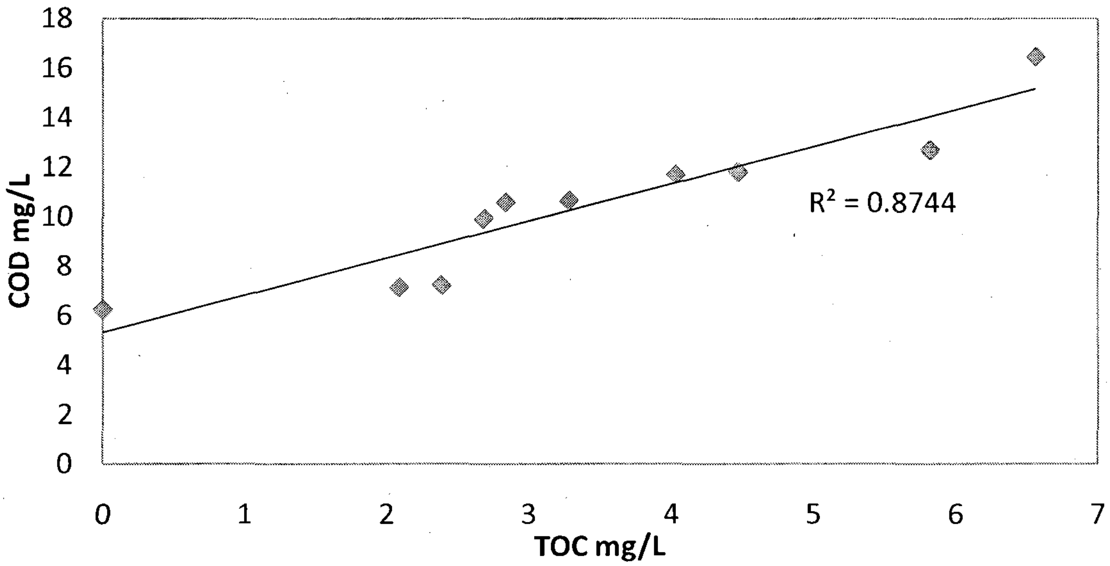


Figure 4-15 - Correlation between COD and TOC, from Case III

4.8 Heavy metals

It was observed that the removal rate of SS in all three cases was 100%, meaning that the solution obtained after filtration had no sign of SS in it. It has been reported by Fukue et. al. (2007) that removing suspended solids is related to removing heavy metals. The amount of removed heavy metals from water body systems can be calculated by equation (4-1).

$R_n = Q.a.SS.E_n$ (4-1)

Where:

R_n: removed amount of pollutant n (mg);

Q: Volume of filtered water (m^3);

SS: amount of suspended solid (kg/m^3);

E_n: concentration of the pollutant n in the water (mg/kg);

a: SS removal efficiency factor.

According to the USEPA standard, the initial concentration of metals was measured (Table 4-3).

Table 4-3 - Metal concentrations in suspended solids for Case III

	Cu (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
Station E	56.1	42.7	80.4	19.5

For 100% removal of suspended solid for case III, parameter "a" should be equal to one. Considering the volume of water in the tank (40 L) and using equation 4-1, the amount of removed pollutant is estimated as shown in Table 4-4.

Table 4-4 - Amount of pollutant removed by filtration system

Cu (mg)	Zn (mg)	Ni (mg)	Pb (mg)
0.18	0.14	0.26	0.06

These removals were obtained in 10 days of running the test for removal of 3.56 grams of solids. It is evident that the amount of contamination removed is extremely relevant to the amount of suspended solids. Therefore removing pollutants such as heavy metals strictly depends on suspended solids removal. Fukue (2005) also compared the results of two different concentrations of suspended solids in his research. He found removing high concentrations of suspended solids is more efficient for decontamination of heavy metals.

5 Conclusions

It is concluded that it is beneficial to have high concentrations of suspended solids to obtain higher COD removal. However having a higher SS will give a better removal result with higher initial COD as compared to the same case with a lower COD. The summary of the results of this research are shown in Table 5-1

Table 5-1 - Experimental results summary

case I		**Total COD(mg/L)**	**Dissolved COD(mg/L)**	**SS(mg/L)**	
	Initial	34	24.9	32	
	Final	18	17.4	< 0.0001	
	Removal rate	*47%*	*30%*	*100%*	
case II		**Total COD(mg/L)**	**Dissolved COD(mg/L)**	**SS(mg/L)**	
	Initial	46	38.8	86	
	Final	14.6	11.6	<0.0001	
	Removal rate	*68%*	*70.10%*	*100%*	
Case III		**Total COD(mg/L)**	**Dissolved COD(mg/L)**	**SS(mg/L)**	**TOC (mg/L)**
	Initial	16.5	11.2	82	6.5
	Final	6.2	6.1	<0.0001	<0.3
	Removal rate	62.4%	45.5%	100%	100%

Case II is the most successful among the three, showing a higher efficiency for COD removal for a relatively high concentration of suspended solids. Moreover comparing the original COD and the ratio of dissolved and particulate COD, show a relatively high amount of dissolved COD. Therefore, the initial condition may indicate that the amount and quality of the suspended solids are not enough to catch (retain) the dissolved COD in the water or on the filter. This method is also able to remove heavy metal pollutants, as they are adsorbed by suspended solids in the water body. This technique was successful in removing suspended solids and chemical oxygen demand (in the form of total and dissolved COD).

6 Future work

Several potential projects have been proposed to be considered as future work . They are namely as follows:

- Study the behavior of different filter medium such as different geotextiles (woven or non-woven)
- Changing the source of suspended solids; in this project the original solids present in the stream were used. As it was understood that the adsorbing potential of SS is related to its characteristics. Using SS obtained from less contaminated sources might give a better result,
- Utilizing adsorbent materials such as bentonite or trying some other kind of solids such as the mixture of clay and silty sands may cause an increase in the adsorbing probability of the dissolved material by these substances. Utilizing peat, which is the accumulation of partially decayed plants, may also be beneficial as it might increase the rate of biodegradation and likewise decrease the concentration of organic materials.
- Pilot tests should be performed to show the potential of the future in-situ system
- Performing several tests at different times in the year would determine the seasonal effect of suspended solids and the different influents and characterizing the flow in each season is the best way to do that.

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