INVESTIGATION OF OPTIMUM OPERATING CONDITIONS FOR RECIRCULATING SAND FILTERS

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By

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Abstract

Recirculating Sand Filters (RSFs) provide a compact method of secondary treatment to septic systems and lagoons, are relatively easy to operate and require little maintenance. Together, these characteristics render RSFs particularly appropriate for small communities and municipalities, as they offer a number of economic and operational advantages over conventional technologies. A preliminary study investigating RSF effluent quality, conducted jointly by McMaster University, the Great Lakes Sustainability Fund (GLSF) and the Ontario Ministry of the Environment (MOE) in 1999-2001, conducted pilot-scale experiments and demonstrated that municipal sewage can be successfully treated year-round by RSFs. The results of the preliminary study recommended that further work be conducted to investigate the selection of media size, dosing frequency, recycle ratio, and hydraulic loading rate.

The primary objective of this study was to develop design and operating conditions under Ontario climatic conditions with respect to media size, dosing frequency, recycle ratio and hydraulic loading rate by conducting further pilot-scale studies. Three pilot-scale RSFs, operating in parallel, were loaded intermittently with septic tank effluent to evaluate the above mentioned operating parameters on the removal of total suspended solids (TSS), 5-day carbonaceous biochemical oxygen demand ($cBOD_5$), total ammonia-nitrogen (TAN) and total nitrogen (TN). The addition of alum was also implemented to evaluate the removal of total phosphorus (TP). The effluent objectives for this study were based on the MOE general secondary treatment level requirements of monthly averages based on a minimum of four weekly samples. The

four-phase experimental program began in April, 2004 and ended in June, 2005. Three media sizes were investigated, with d_{10} of 2.6, 5 and 7.7 mm. The applied hydraulic loading rates were 0.2 and 0.4 m/day. Dosing frequencies of 24 and 48 times/day were observed. Recycle ratios of 300% and 500% were also evaluated.

It was found that the RSF operating with 2.6 mm media, 500% recycle ratio and 24 times/day dosing frequency under a hydraulic loading rate of 0.2 m/day produced the best quality effluent, and achieved the effluent objectives required by the MOE. These operating criteria, however, must still be investigated under cold weather conditions to ensure acceptable year-round performance in Ontario. With proper addition of alum, the TP effluent objective was achieved under the optimum operating conditions.

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$cBOD_5$	Carbonaceous biochemical oxygen demand, 5 day
COD	Chemical oxygen demand
DO	Dissolved oxygen
HLR	Hydraulic loading rate
RSF	Recirculating sand filter
RSFs	Recirculating sand filters
TAN	Total ammonia nitrogen
TKN	Total kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended Solids

Chapter 1
Introduction

1.1 Background

Lagoon treatment systems (conventional facultative lagoons) are employed throughout Ontario to treat sewage; these lagoons are subject to significant seasonal effects; which often result in poor effluent quality (Eastwood, 1996). Additionally, approximately 20% of Ontario's population live in small communities and use private septic tanks/tile beds for sewage disposal (Robertson, 2002). Many of these systems are aging or have not been maintained properly, resulting in system failure and contamination of both surface and groundwater. Both lagoon systems and septic tanks/tile beds require a substantial area, which increases the consumption of arable land as population and industrialization increases.

Recirculating Sand Filters (RSFs) provide an appropriate secondary treatment process that can significantly upgrade effluent quality from septic tank and lagoon systems. Additionally, these systems require little maintenance. Between 1999 and 2001, McMaster University completed a study for the Ontario Ministry of the Environment (MOE) and the Great Lakes Sustainability Fund (GLSF) to assess the application of recirculating intermittent sand filters to improve septic tank effluent quality (Robertson, 2002). The study was developed under the conditions shown in Table 1-1, and generated a good quality effluent. However, due to problems experienced with flow measurement and control devices, as well as pump over-sizing throughout the study, the hydraulic loading rates to the filters and the recycle ratios could not be controlled or measured accurately. Further work was recommended to determine the appropriate selection of media size, dosing frequency, recycle ratio and hydraulic loading rate. As well, investigation of total phosphorus (TP) removal was recommended.

Table 1-1. Experimental design (Roberston, 2002).

Parameter	Range
Media d_{10} (mm)	0.1 – 2.6
Sewage hydraulic loading rate (HLR) (m/day)	0.2 – 0.4
RSFs effluent recycle ratio	2:1 – 4:1
Total suspended solids (TSS) or carbonaceous 5-day biochemical oxygen demand ($cBOD_5$) loading ($g/m^2\cdot day$)	40 – 80
Application frequency (hours)	0.3 – 24
Operating temperature (°C)	5 – 20

1.2 Objective

In 2004 – 2005, McMaster University and the National Water Research Institute (NWRI) were commissioned to carry out the recommendations from the 1990 – 2001 study with funding from the GLSF and the MOE. The objective of the present study is to determine the optimum design and operational parameters for RSFs to meet the effluent criteria set by the MOE, and presented in Table 1-2. The experimental plan includes an investigation of filter media size, an evaluation of the impact of effluent recycle ratio and dosing frequency, a demonstration of cold weather operation, the selection of the hydraulic loading rate, and the investigation of a metallic coagulant application for phosphorus removal. The results of this study will be employed to develop the design and operational guidelines, to be published by the MOE for RSFs in Ontario.

Table 1-2. Effluent criteria.

Parameter	Objective*
Carbonaceous biological oxygen demand, 5 day ($cBOD_5$)	15 mg/L
Total suspended solids (TSS)	15 mg/L
Total phosphorus (TP)	1.0 mg P/L
Total ammonia nitrogen (TAN)	5 mg N/L
Total nitrogen+ (TN)	10 mg N/L

* Objective is stated as a monthly average based on a minimum of four weekly samples.
+ This objective is only applicable in groundwater discharge situations.

This thesis contains five additional chapters: a review of RSF history, operating parameters and treatment efficacy is given in Chapter 2; Chapter 3 describes the experimental materials, methods and design employed in this work; Chapter 4 presents the results and discusses the implications of these results; and Chapter 5 lists the conclusions and recommendations for future work.

Chapter 2
Literature Review

In this chapter, existing literature on RSFs is reviewed, including an introduction to RSFs and their history, their advantages and disadvantages, several typical designs that have been for RSFs, the effect of various operating parameters (i.e., media size, hydraulic loading rate, recycle ratio and dosing frequency) on treatment efficacy, the effect of temperature on effluent quality, nitrogen and phosphorus removal.

2.1 Introduction

RSFs were developed in the late 1960s and early 1970s in Illinois (Hines and Favreau, 1974) as a method of providing secondary treatment, beyond septic tanks and prior to surface water discharge. RSFs provide a simple, compact method of delivering improved treatment with relatively little maintenance; these qualities are particularly important and appropriate for small communities and municipalities. Complex biochemical and physical mechanisms function as the sewage filters through the media in RSFs providing secondary treatment by straining, adsorption and biochemical oxidation (Michels, 1996).

RSFs have been proven to offer several economic and operational advantages over conventional technologies as follows (Solomon, 1998; Owen, 1994; Robertson, 2002):

- they provide an excellent effluent quality with over 95% removal of BOD and TSS;
- they are easily monitored and require little maintenance;
- they are capable of denitrification under proper operating conditions;
- they can minimize or eliminate odors;
- they require 1/5 of the area of single-pass sand filters; and
- the cost of a septic tank/RSF combination is approximately two thirds that of a lagoon/ intermittent sand filter (ISF) combination.

In spite of these advantages, there are also some disadvantages associated with RSFs, including (Solomon, 1998):

- high costs when media is not available locally;
- some degree of maintenance is required with respect to the media, pumps and controls, and
- cold temperatures (below 0 °C) must be considered when setting the operational conditions.

2.2 Typical RSF Design

2.2.1 Conventional Recirculating Sand Filters

Conventional recirculating sand filters were originally developed to improve the quality of septic tank effluent for surface water discharge (Hines and Favreau 1974). The nitrified effluent from sand filters is recycled to the recirculating tank and mixed with the septic tank effluent. Denitrification occurs in the recirculating tank with the septic tank effluent providing the required carbon source. Several studies, such as Loudon (1984) and Piluk (2001), employing conventional RSFs have demonstrated some degree (40% to 70%) of nitrogen removal. A diagram of this type of recirculating sand filter is illustrated in Figure 2-1.

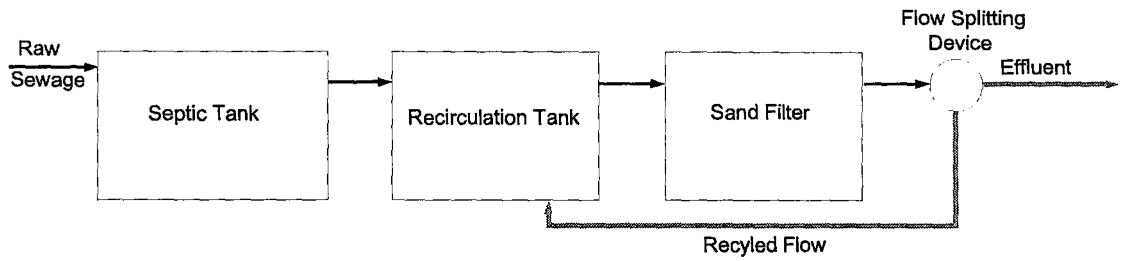


Figure 2-1. Schematic of the conventional recirculating sand filter process.

2.2.2 Sequential Upflow Filter/Sand Filter or Secondary Septic tank/Sand Filter System

Venhuizen (1996) employed a system in the Washington Island project using an anaerobic upflow filter (vertical flow rock bed anoxic reactor) in series with a sand filter aiming to provide a better anoxic environment to increase the degree of denitrification. This type of RSF demonstrated 60-90% nitrogen removal. Influent TKN ranged from 37.9 mg/L to 130 mg/L and effluent total nitrogen concentrations were generally less than 15 mg/L in all of the Washington Island systems when proper operating conditions were maintained. The process flow diagram is illustrated in Figure 2-2.

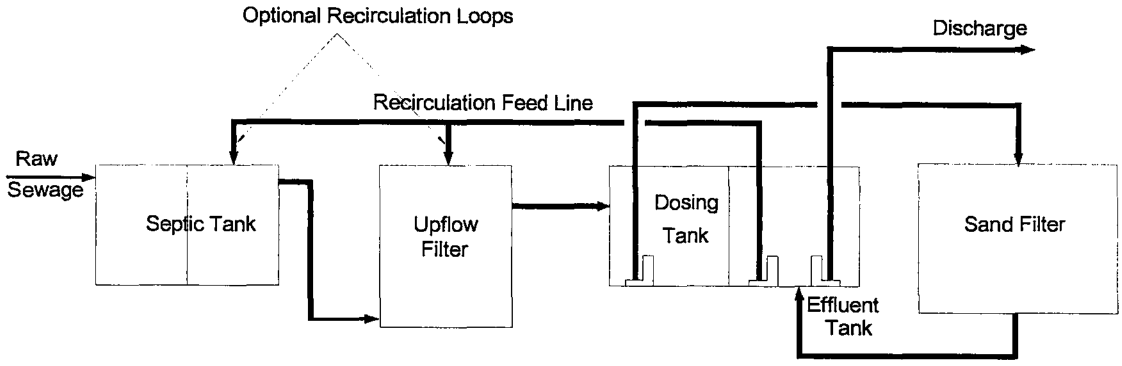


Figure 2-2. Schematic of a typical upflow filter/sand filter system.

It was found that excessive clogging of the upflow filters was a potential maintenance problem in the Washington Island systems, and the upflow filter did not reduce the organic as expected. These results urged the abandonment of the upflow filter, leading to the modified conventional recirculaing sand filter concept with a secondary septic tank, which is illustrated in Figure 2-3.

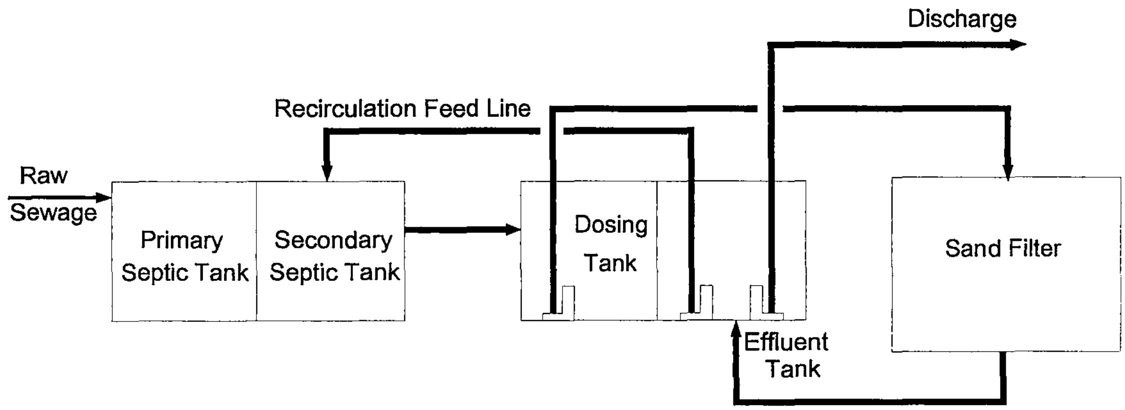


Figure 2-3. Schematic of secondary septic/sand filter System.

The Anne Arundel County project reported by Piluk and Peters (1994) employed the secondary septic tank/sand filter concept and demonstrated that with proper system design, little nitrogen removal efficiency is lost with the elimination of the upflow filter. These systems yielded an average of 64% TN removal, with effluent TN concentration averaging 20 mg/L.

2.2.3 Ruck System

Laak (1981) developed the RUCK system (Figure 2-4). The blackwater (bathroom sewage) is treated using a septic tank followed by a sand filter; while the greywater (kitchen and laundry waste water) is treated by a separate septic tank. The two treated effluents flow to a rock-filled tank where denitrification occurs. This study concluded that greywater provides effective carbon and energy sources for denitrification, and resulted in 81% nitrogen removal.

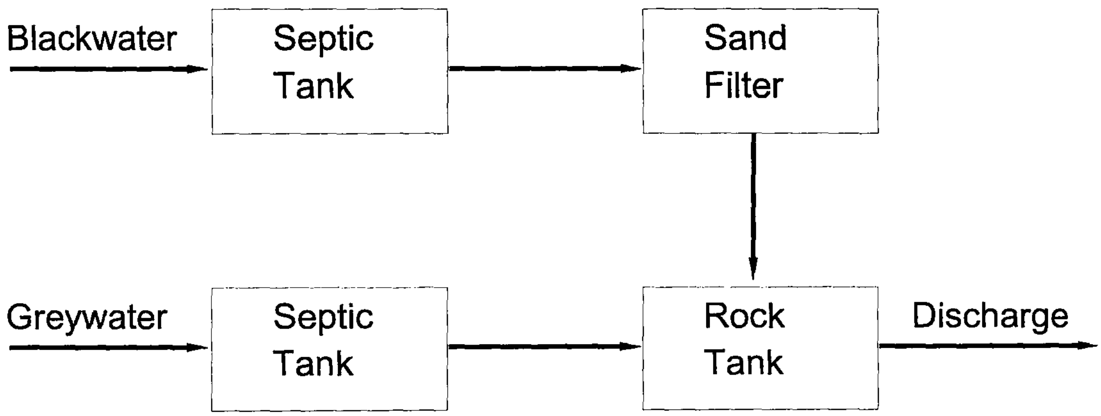


Figure 2-4. Schematic of the RUCK system.

2.3 Operating Parameters

2.3.1 Media Size

The selection of media size is an important factor in the treatment of sewage by RSFs. Pilot plant studies conducted by Bishop (1997) in northern Utah employed two different sizes of media in ISFs which were located downstream of an aerated lagoon. The first type of media had a d_{10} (grain diameter corresponding to 10% undersize product) of 0.17 mm and a uniformity coefficient (UC) of 9.73, and the second type of media had a d_{10} of 0.4 mm and UC of 4.78. The hydraulic loading ranged from 0.23 m/day to 0.94 m/day. They found that media size had a profound effect on the effluent quality, with the smaller media size providing more complete treatment with respect to BOD_5 and TSS removal. In addition, the media size was found to have an effect on the amount of time, it took for the filter to clog, with the smaller media size plugging more rapidly.

Darby (1996) also evaluated the effect of media size on ISF treatment efficiency. Her experimental parameters are presented in Table 2-1. Filters 8, 9 and 10 were used to investigate the effect of media size. The results demonstrated almost no differences in removal efficiencies for TSS, BOD_5, and COD. Slightly higher removal of turbidity by the finest media was the only statistically significant difference between the three media sizes. She believed that the similarities in removal efficiencies were due to the moderate hydraulic loading rate and the high dosing frequency. This combination resulted in a very low flowrate applied to the filter at each dosing. Loudon (1995) stated that the media chosen for stronger sewage should be coarser than that used for domestic sewage; however he does not specify any media sizes for either sewage strength.

Table 2-1. Experimental parameters for Darby (1996) ISFs investigation.

Filter Number	Effective Size, mm	Uniformity Coefficient	Hydraulic Loading Rate, m/day	Dosing Frequency, Times/day
1	0.29	4.52	0.041	4
2	0.29	4.52	0.081	24
3	0.29	4.52	0.326	24
4	0.29	4.52	0.652	24
5	0.29	4.52	0.163	24
6	0.29	4.52	0.163	4
7	0.29	4.52	0.163	12
8	0.33	1.42	0.163	24
9	0.54	1.32	0.163	24
10	0.93	1.29	0.163	24
11	0.93	1.29	0.163	4
12	0.93	1.29	0.163	12

Venhuizen (1994) employed coarse gravel media with d_{10}'s ranging from 6 to 9.5 mm in the Washington Island project, which provided good performance. However, slightly lower effluent BOD_5 and TSS levels are generally obtained with smaller media (Venhuizen, 1996). The operating conditions and experimental results for the Washington Island project are presented in Table 2-2.

Table 2-2. Venhuizen (1994) Washington Island Project operating conditions and results.

System	Media Size, d_{10} (mm)	Hydraulic Loading Rate (m/day)	Recycle ratio (%)	Filter Effluent BOD BOD (mg/L)	BOD Removal (%)	TSS (mg/L)	TSS Removal (%)	Filter Effluent TN TN (N mg/L)	TN Removal (%)
Johnson	6	0.19	773	14.4	95.6	7.4	93.7	39.8	4.9
Briesemeister	1.5	N/A	N/A	12.4	94.0	12.6	89.3	15.7	59.0
Boniface	6-9.5	0.14	780	3.8	98.8	4.7	97.1	16.8	80.3
Mann Store	Top 6-9.5 Bottom 1.5	0.10	910	10.3	98.6	5.9	96.2	13.7	89.3
Richter	1.5 mm	0.15	480	8.6	95.7	5.8	99.0	17.4	59.1

In summary, smaller media provide a higher degree of treatment efficiency, however plugging does occur more quickly. Although coarser media do not typically provide the same degree of treatment as finer media, it typically allows for a higher hydraulic loading rate. The major advantage of coarse media is that it requires less maintenance than fine media (Venhuizen, 1997). The United States Environmental Protection Agency (US EPA) (2002) recommends media with a d_{10} ranging from 1 – 5 mm for sand and 3.0 – 20.0 mm for gravel. The SBD (Safety and Buildings of Department of Commerce of State of Wisconsin, 1999) suggests that the most effective grain size has a d_{10} between 1 and 2.5 mm.

2.3.2 Hydraulic loading rate

The recommended hydraulic loading rate given by the US EPA (2002) ranges from 0.1m/day ~ 0.2m/day for sand and 0.4 ~ 0.6 m/day for gravel based on forward flow for RSFs located downstream of a septic tank. Loudon (1995) also recommended loading rates in the range of 0.1m/day~0.2m/day for domestic strength influents. Ball (1991) recommended loading rates as high as 0.4m/day for media with d_{10} of 2.5 – 4.0 mm (UC = 2 – 2.5) and recycle ratio of 500%. However, he did not give an effective dosing frequency. Venhuizen (1996) suggest a hydraulic loading rate of 0.2 ~ 0.4 m/day for RSFs with larger media (i.e. gravel), frequent dosing and high recycle ratio, as a result of the Washington Island Project (Table 2-2).

Darby (1996) evaluated the effect of the hydraulic loading rate on the performance of ISFs at dosing frequencies of four and twenty four times/day. The details of the experiment conditions are presented in Table 2-1. It was found that increasing the hydraulic loading rate from 0.081 to 0.163 m/day had little effect on COD removal at a dosing frequency of 24 times/day; however, the removal rates of COD, BOD_5, TSS, NH_3-N and Organic-N were significantly lower at a hydraulic loading rate of 0.326 m/day than 0.163 m/day. At a dosing frequency of 4 times/day, the COD removal in the filter dosed at 0.163 m/day was slightly, but consistently, less than the filter dosed at 0.041 m/day. A hydraulic loading rate between 0.163 m/day and 0.326 m/day was the maximum sustainable loading for this study; beyond this, clogging occurred in less than three months of operation.

2.3.3 Recycle Ratio

It has been stated that the treatment obtained by both ISFs and RSFs is independent of hydraulic loading rate, but is correlated to the filter influent TSS or BOD_5 concentration (Robertson, 2002). Some references state that, in order to preclude premature clogging, it is expected that the organic loading rate should be limited to less than 260 g $BOD_5/m^2/day$ (Anderson, 1985). The purpose of recirculating the treated effluent is to dilute the influent sewage, thereby reducing the concentration of the influent sewage. With a fixed influent, plus the recycled effluent from the filter, recirculation will increase contact time between the microorganisms providing the treatment and the organic matter within the sewage (Risgaard, 1996). Moreover, the noxious odors can be eliminated through recirculation, which increases the oxygen content in the effluent that is distributed on the filter bed (Solomon, 1998). Together, these qualities result in superior treatment through recirculation.

The recycle ratio is defined as the ratio of the total flow onto the filter bed to the forward flow rate [(recirculation flow + forward flow)/forward flow]. The US EPA (2002) recommends a recycle ratio from 300% to 500%; although no studies have actually been conducted examining the relationship between treatment efficacy and recycle ratio. Risgaard (1996) suggests that during start-up the recycle ratio should be 500%. As the treatment efficiency increases and the operator gains experience the recycle ratio can be decreased to 400%, 300%, or 200% to save energy costs on pumping. As a result of the Washington Island project, Venhuizen (1997) concluded that a recycle ratio of 300% is a good compromise when treating domestic sewage.

Increasing the recycle ratio results in a lower C to N ratio in the recirculation tank, which may result in insufficient carbon thereby limiting denitrification. Gold (1992) encountered poor denitrification in a sand filter when the nitrified effluent was recirculated through a septic tank with a recycle ratio of 400% to 500%. Lower recycle ratios, however, decreases the effluent quality due to the higher organic loading on the sand filter surface. In the actual operation of RSFs, the corresponding recycle ratio is a parameter highly related to the concentration of the influent sewage.

2.3.4 Dosing Frequency

Darby (1996) examined the effect of dosing frequency on the performance of ISFs. The detailed experimental parameters are presented in Table 2-1. It was found that increasing the dosing frequency from 4 to 24 times/day generally improved the performance of the filters. However, the improvements were more dramatic for the coarse sand filters than for the finer sand filters. For both fine and coarse sand, increasing the dosing frequency from 4 to 12 times/day resulted in a statistically significant increase in removal of turbidity, COD, and organic-N. For both media types, increasing the dosing frequency from 4 to 12 times/day had a greater effect than increasing it from 12 to 24 times/day.

Darby (1996) explained the excellent performance at high dosing frequencies by discussing the manner of sewage flow through the media. At higher dosing frequencies a smaller volume of sewage is directed to the filter. If the application rate does not exceed the water holding capacity of the media, the applied sewage flows over the media grains in a thin film allowing maximum oxygen diffusion and maximum contact between organic matter in the water and the microbial growth attached to the media. The thin film allows longer contact time between a given portion of the sewage and attached microbes than would occur under higher flows due to lower dosing frequencies.

The US EPA (2002) recommends 48 times/day or higher for the dosing frequency. Loudon (1995) concluded that the best treatment is obtained when the dosing frequency results in correspondingly low flow from each orifice in the dosing pipe with each dose. Dosing 24 – 48 times/day has worked well in his experiments. Using this cycle length results in a dose of less than 0.011 m^3 per orifice and a minimum of 24 minutes between cycles for the sewage to move though the media. With these loading rates, experience has shown that the solids are biologically decomposed as fast as they are filtered out with no appreciable build-up of organic material within the media. To the knowledge of this author, no studies have been conducted to examine the effect of dosing frequency on larger media (i.e., gravel) or dosing frequencies higher than 48 times/day.

2.4 Temperature Effect

The temperature of sewage is a very important parameter because of its effect on chemical reactions and reaction rates, aquatic life, and bacterial activity (Metcalf and Eddy, 2003). These mechanisms will all be hindered by cold temperatures. On the other hand, biochemical reactions are also hindered when the oxygen concentration decreases, and oxygen is less soluble in warm water than in cold water. Therefore, in North America, the summer months are associated with an increase in the rate of biochemical reactions, combined with a decrease in oxygen concentrations. Optimum temperatures for bacterial activity are in the range of 25 to 35 °C. Aerobic digestion and nitrification cease when the temperature rises above 50 °C. When the temperature drops to about 15 °C, methane-producing bacteria become relatively inactive, and the autotrophic nitrifying bacteria practically cease functioning at about 5 °C (Metcalf and Eddy, 2003). Harris

(1977) found that the rate of nitrification decreased at temperatures less than 5 °C and did not recover until temperatures increased to 10 °C. At 2°C, even the chemoheterotrophic bacteria acting on carbonaceous material become essentially dormant (Metcalf and Eddy, 2003).

Past operating experiences indicate that RSFs operate very well under cold weather conditions (Loudon, 1984; Owen, 1994; Michels, 1996). Owen (1994) studied winter operation and performance of RSFs and found that nitrification can be consistently achieved during winter months with sewage temperatures as low as 2 to 3 °C. Their observations suggest that the denitrification rate increased with both time and temperature.

Loudon (1984) experienced extremely cold weather in Michigan in January, 1984, when the average air temperature was -10.9 °C and the average filter temperature was 2 °C. Even in these cold temperatures, the filter continued to produce a high-quality effluent. BOD_5 and TSS concentrations in the final effluent were generally below 10 mg/L, and fecal coliform levels were generally less than 200 per 100 mL. Nitrogen removal through two parallel RSFs averaged between 40 to 60%. The operating conditions are presented in Table 2-3.

Table 2-3. Operating conditions in Loudon (1984) RSFs study.

Media Size (mm)	Hydraulic Loading (m/day)	Dosing Frequency (times/day)	Recycle ratio (%)
0.3 (UC = 4.0)	0.11	Dosing once each hour at daytime, and dosing twice at night	500

Loudon (1984) measured air temperature, media temperatures at varying depths, and water temperature in the septic tank, the dosing tank, and the filter drain. He found that although the cold weather lowered the soil temperatures to below freezing at a depth of 18 inches, the water was able to pass through the media without freezing and be treated. He concluded that RSFs should be able to function well throughout any winter, likely to occur in mid-Michigan.

Michels (1996) reported that removal efficiency in terms of BOD and TSS was apparently not affected by the harsh winter weather of south central Wisconsin where the air temperature drops below -10 °C. Although ice forms regularly on the surface of the filter, the sewage flows over and under the ice and is apparently distributed adequately throughout the filter to produce effluent with consistent BOD_5 and TSS levels.

2.5 Eutrophication, Nitrogen and Phosphorus Removal

2.5.1 Eutrophicaton

Eutrophicaton in the aquatic system is a natural evolutionary process. However, human activities, including agriculture, domestic use of fertilizers and the modification of buffer zones near surface water increase the amount of nutrients reaching the water. Elemental nitrogen and phosphorus, essential to the growth of microorganisms, plants and animals are known are known as nutrients (Metcalf and Eddy, 2003). The increased load of nutrients stimulates algae growth, decreasing the clarity of the water. As the algae decompose they take up oxygen, which affects the supply for fish and other aquatic life.

2.5.2 Nitrogen

The control of nitrogen in the aquatic environment may be required for several reasons in addition to its role as an algal nutrient (Chowdhry, 1979). The discharge of effluents containing TAN exerts environmental stress in receiving waters (Jenkins, 1969). It has been demonstrated that the oxygen demand exerted during the oxidation of NH_4^+ is at least as large as that of carbon (Jenkins, 1969). By decreasing the dissolved oxygen concentration, nitrification process inhibits aquatic metabolisms (Jones, 1964). In fact, ammonia has been found to be toxic to trout fry and rainbow trout at concentrations as low as 0.3 mg N/L, therefore, some types of fish may be adversely affected by the presence of 0.5 mg/L of ammonia due to the nitrification process (McKee, 1963).

When the effluent from septic tanks or ISFs is discharged into the ground, the converted nitrogen from ammonia to nitrate will move readily through soils and may reach ground water. Nitrate contamination in groundwater is exemplified in Maryland, where nitrates above the background levels appear to be more widespread than any other known contaminants (Maryland, 1986). Water with high levels of nitrates when consumed by infants or pregnant women may affect the hemoglobin in the blood, preventing it from carrying oxygen creating a condition known as methmoglobinaemia or "blue baby" syndrome (Bosch, 1950). Consequently, both the U.S. Environmental Protection Agency and the World Health Organization specify the maximum nitrate concentration in drinking water to be 10 mg/L as nitrate-N (Sayre, 1988). Additionally, nitrates in groundwater may contribute to the eutrophication of surface water (Walker, 1973)

2.5.3 Phosphorus

The presence of phosphorus in lakes has been stated to be a limiting factor for aquatic growth (Metcalf and Eddy, 2003). Because of noxious algal blooms that occur in surface waters, there is presently much interest in controlling phosphorus compounds that enter surface waters through domestic and industrial waste discharges and natural runoff. Municipal sewage, for example, may contain from 4 to 15 mg/L of phosphorus as P. The effluent design objective given by MOE is 1.0 mg/L TP (OWRA, 1990).

2.5.4 Nitrogen Removal

One of the main advantages of RSFs employed in series with septic tank is their ability to remove nitrogen. When the recirculated nitrified sand filter effluents mix with septic tank effluent in the recirculating tank, denitrification occurs; with the septic tank effluent providing the required carbon source.

There are two mechanisms for nitrogen removal via biological process. First, a small amount of nitrogen is removed due to the new biomass growth. Second, nitrogen is removed through nitrification and denitrification.

The nitrification/denitrification process is a two step process that requires an aerobic environment followed by an anoxic environment (Metcalf and Eddy, 2003). The first step of nitrification/denitrification is the biological process where ammonia is oxidized to nitrite and then nitrate through nitrifying bacteria in the presence of oxygen. Nitrifying bacteria, however, are very sensitive organisms. Ammonia concentrations, temperature, pH, alkalinity, and dissolved oxygen concentration all affect the rate of growth and nitrification. An optimal pH range for nitrifying bacteria is between 6.5 and 8.0 (Endter, 1996). Nitrification is reported to occur at temperatures ranging from approximately 4 to 45 ^{o}C (Endter, 1996). It is must be maintained at DO levels above 2 mg/L and alkalinity above 40 mg/L (Sandy, 1987). For nitrification, a 7:1 alkalinity/ TKN (total kjeldahl nitrogen) ratio is recommended (Laal, 1981). Nitrification in sand filter generally improves at lower ratios of BOD_5 to TKN, which produce higher populations of nitrifiers resulting in higher nitrification rates (Piluk, 2001).

The second step is denitrification, in which facultative heterotrophic bacteria use nitrite and nitrate as a substitute for oxygen in their respiratory processes in anoxic environments. The denitrifiers convert the nitrate to nitrogen oxides (N_2O) and nitrogen gas (N_2) which are released into the atmosphere. For denitrification to occur, an electron donor or carbon source is required as an energy source. Unlike nitrification, denitrification produces alkalinity. In this step, about half of the alkalinity used up in the nitrification process is recovered (Metcalf and Eddy, 2003).

Loudon (1984) found a 40% - 60% reduction of nitrogen in his experiments conducted with RSFs. Lamb (1990) found that denitrification was achieved when the sand filter effluent was mixed with three different carbon sources (methanol, ethanol, and septic tank effluent) prior to entering a buried rock tank. With septic tank effluent providing the only carbon source, only 25% denitrification occurred, whereas the addition of methanol and ethanol produced a mean denitrification of 99%. Silora (1977) investigated the denitrification of nitrified septic tank effluent containing 40 to 50 mg/L NO_3-N in RSFs under both laboratory and field conditions with methanol addition. They concluded that the system worked well, but that the use of an external carbon source can be too complicated and costly. Laak (1981) developed the RUCK system, a modification of a conventional septic system that employs the organic matter in greywater (kitchen and laundry waste) septic tank effluent as the carbon source for the denitrification of nitrified blackwater (bathroom sewage). He and subsequent investigators (Lamb, 1987) found that greywater is an effective carbon and energy source for denitrification. Healy and Rodgers (2004) studied RSFs for the treatment of synthetic dairy parlor washings without an external carbon source, and found that RSFs reduced total nitrogen (TN) in the sewage by 83.2% over the 170 day study duration.

2.5.5 Phosphorus Removal

Phosphorus can be removed through a biomass synthesizing process, physical/chemical processes, or biological process (Metcalf and Eddy, 2003). Some phosphorus is required to produce new heterotrophic biomass; the amount of phosphorus taken up for this purpose is typically about 1/5 of the nitrogen required for new biomass synthesis. The following paragraphs will describe the mechanisms of phosphorus removal, and present the results of various studies examining phosphorus removal by RSFs.

For physical/chemical processes, the addition of certain chemicals (e.g. alum, sodium aluminate, ferric chloride or sulfate and lime) to wastewater produces insoluble or low-solubility salts when combined with phosphate. These low-solubility salts precipitate, thereby removing the phosphorus. The advantages of chemical/physical processes are that they are stable and easy to implement. The disadvantages include the sludge produced by the precipitate and costs associated with the purchase of chemicals.

Chemicals can be added at several points in the treatment process including: (1) raw sewage; (2) the effluent from the primary sedimentation facilities, the mixed liquor (in the activated-sludge process), or biological treatment process prior to secondary sedimentation; or (3) the effluent from secondary sedimentation facilities. For RSFs, the chemical is typically added to the raw sewage or the sand filter effluent. The advantages and disadvantages of the removal of phosphorus by the addition of chemicals at various points in a treatment process are summarized in Table 2-4.

Table 2-4. Advantages and disadvantages of chemical addition for phosphorus removal at various points in the treatment process.

Level of treatment	Advantages	Disadvantages
Primary	Applicable to most plants; increased BOD and suspended solids removal; lime recovery demonstrated	Least efficient use of metal; polymer may be required for flocculation; sludge more difficult to dewater than primary sludge
Secondary	Lowest cost; lower chemical dosage than primary; improved stability of activated sludge; polymer not required	Overdose of metal may cause low pH toxicity; with low-alkalinity sewage, a pH control system may be necessary; cannot use lime because of excessive pH; inert solids added to activated-sludge mixed liquor, reducing the percentage of volatile solids
Advanced-precipitation	Most effective for phosphorus removal; most efficient metal use; lime recovery demonstrated	Highest capital cost; highest metal leakage in discharge
Advanced-single and two-stage filtration	Low cost can be combined with the removal of residual suspended solids	Length of filter run may be reduced with single-stage filtration. Additional expense with two-stage filtration process

Adapted from Metcalf and Eddy (2003).

Biological phosphorus removal is a complicated process requiring both aerobic and anaerobic environments (Metcalf and Eddy, 2003). The process is dependent on the presence of facultative bacteria referred as phosphorus accumulating organisms (PAOs) which are cycled between anaerobic (no oxygen or nitrate present) and aerobic conditions. In the anaerobic zone, PAOs take up the volatile fatty acids (VFAs), releasing of phosphorus to the liquid phase via polyphosphate cleavage, which provides energy for

VFA transport. Glycogen is utilized to provide enough reducing power to drive the transformation of VFAs into polyhydroxybutyrate (PHB). At the end of the anaerobic period, no VFAs remain, and there is high phosphorus concentration in the liquid phase. In the aerobic zone, PAOs use stored PHB to generate new PAO biomass, to replenish the glycogen and polyphosphate pools and to aid in the uptake of phosphorus. The amount of phosphorus taken up in the aerobic phase is larger than amount of phosphorus released in the anaerobic phase, and therefore there is a net phosphorus removal from the liquid phase. At the end of aerobic period, the PHB content is low, the PAO population is large, the glycogen and polyphosphate contents are relatively high, and the soluble phosphorus concentration is very low (even zero). As a portion of the biomass is wasted, stored phosphorus is removed from the biotreatment reactor for ultimate disposal with the waste sludge. Biological phosphorus removal can only be accomplished successfully when the proper environment is maintained for phosphorus uptake.

For on-site sewage treatment, the physical/chemical method of phosphorus removal is preferable due the process' reliability and ease of implementation. The extra treatment units are required for biological phosphorus removal, and the operation of this process, is much more complicated.

In the RSF process, phosphorous removal can be accomplished through microbial uptake, chemical reactions and adsorption to the media (Risgaard, 1996). Sauer and Boyle (1978) reported that substantial phosphorus attenuation can occur in sand filters during the initial start up period (6 months to 2 years) due to adsorption or precipitation on media surfaces. The cold climate study performed by Loudon (1984) found some phosphorus removal initially, but removal rates dropped to zero after 1.5 years. Gold (1992) reported that the phosphorus removal rate during his first year of RSF operation was 75%, and annual phosphorus removal was 31.9% for the next two years of the three-year study periods with no significant seasonal trends.

Pell and Nyberg (1989) examined the ability of a pilot-scale sand filter system to reduce both organic matter and phosphorus. Early in the experiment, phosphorus rapidly adsorbed to the sand particles, however adsorption became less effective over the course of the study. The efficiency with which the newly started, conventionally constructed sand-filter system removed phosphorus was 91%. By the end of the 78 day experiment, the removal efficiency reduced to 70%. Pell and Nyberg (1989) also found that the adsorption rate of PO_4^{3}-P under partially anaerobic conditions in a column was higher than under the aerobic conditions in the pilot-scale sand filter. They also found that it was more difficult to control phosphorus levels than to control COD in their sand-filter system.

Overall, from the existing literature, RSFs have been demonstrated be an appropriate technology for the small communities and municipalities, providing the secondary wastewater treatment. The optimization of RSF's operating conditions under Ontario climatic conditions is a necessary step to implement this methodology in Ontario, which has never been conducted in previous research. Further work is required to investigate the optimum operating conditions for RSFs under Ontario climatic conditions to develop the design and operating guidelines of RSFs in Ontario.

Chapter 3
Materials and Methods

3.1 Pilot Plant Description

The pilot plant is located in Clifford, Ontario. The map showing the location of Clifford is presented in Figure 3-1. A plan view of the pilot plant schematic diagram is presented in Figure 3-2, and the process flow diagram is illustrated in Figure 3-3. There are four sand filters operating in parallel in the pilot plant, three of which were employed in these experiments. The fourth sand filter is a commercial Orenco unit, and was not included in the experimental plan, as it is configured quite differently and would therefore present difficulties in comparing results.

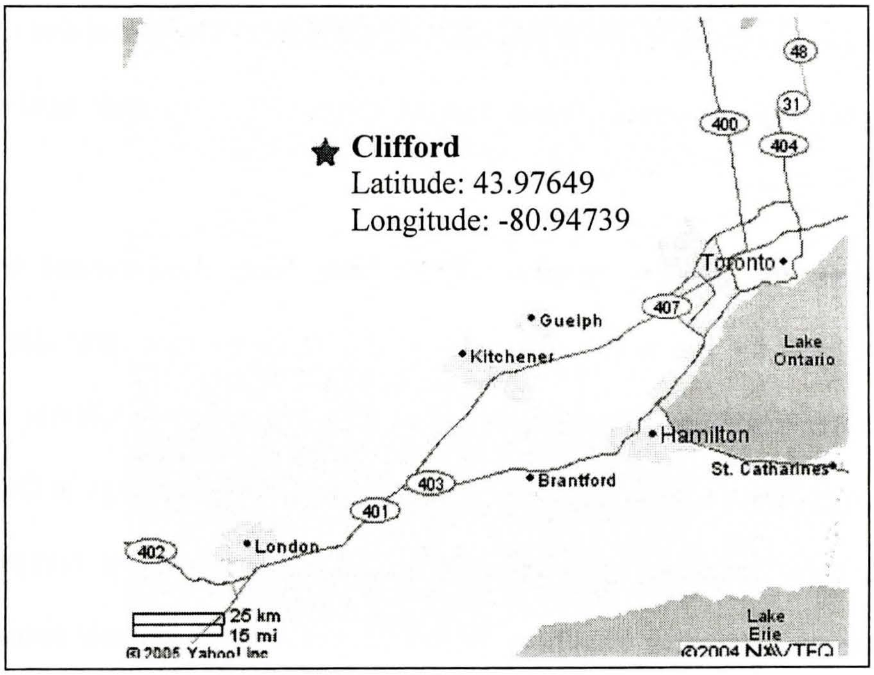


Figure 3-1. Map of Clifford location.

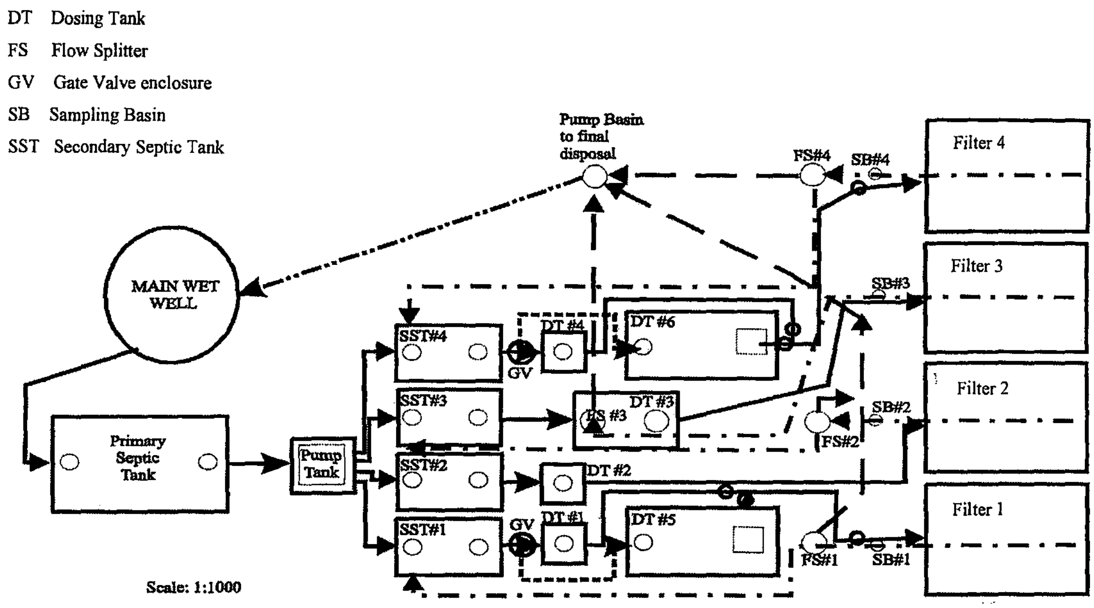


Figure 3-2. Schematic diagram of the Clifford Pilot Plant layout.

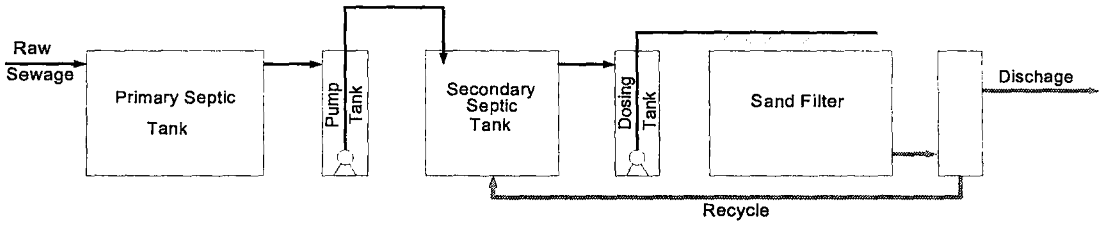


Figure 3-3. Clifford recirculating sand filters process.

Raw sewage is pumped from the main wet well to a primary septic tank, and from there into a secondary septic tank. The treated effluent from the primary septic tank (PST) is mixed with the recycled effluent from the sand filter in the secondary septic tank (SST). Denitrification occurrs in the secondary septic tank under anoxic conditions, with the primary effluent providing the required carbon and energy sources and the previously nitrified recirculated sand filter effluent acting as the electron acceptor. The recycle also serves to dilute the primary effluent organic load on the sand filters, resulting in denitrified and diluted primary effluent flowing by gravity from the secondary tank to the dosing tank, at which point it is dosed onto the surface of the sand filters intermittently. Complex biochemical and physical mechanisms function within the sand filters, where the majority of the organics and solids are removed, and nitrification occurs to some degree. The sand filter effluent is collected in a network of underdrains, and flows to a splitter at which point a predetermined fraction is recycled to the secondary septic tank and the rest flows to a wet well and from there returned to the main wet well. The raw sewage at the Clifford wastewater treatment plant is not significantly diluted by the recycle process due the forward flow through the pilot plant represents less than 5% of the total flow from the Clifford village.

3.2 Pilot Plant Facilities

The pilot facilities were constructed at Clifford in 1999. Figure 3-4 shows a photograph of the site. The primary septic tank, pump tank, secondary septic tanks and dosing tanks are fabricated from precast concrete. The sand filter units are constructed with plywood walls and covered with vinyl rubber liner.

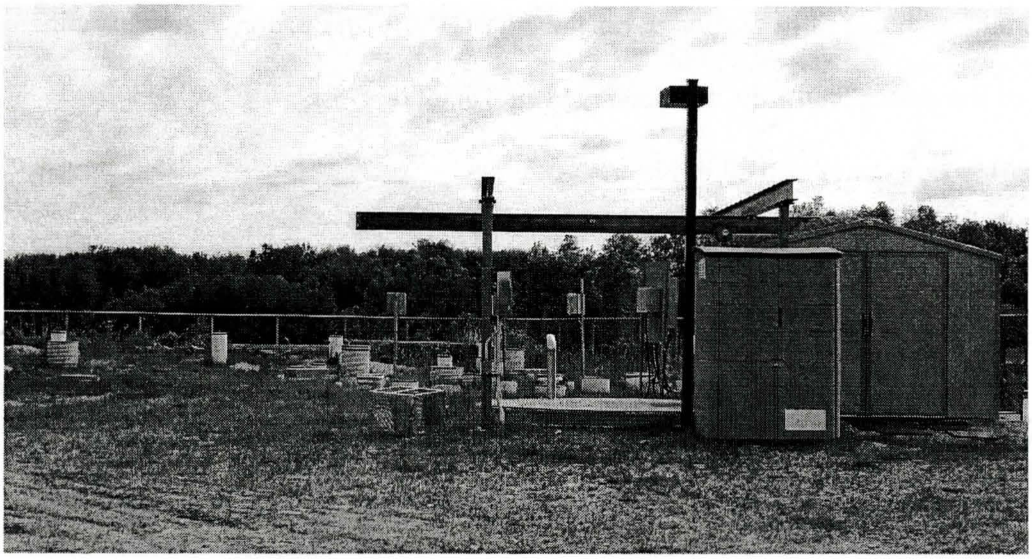
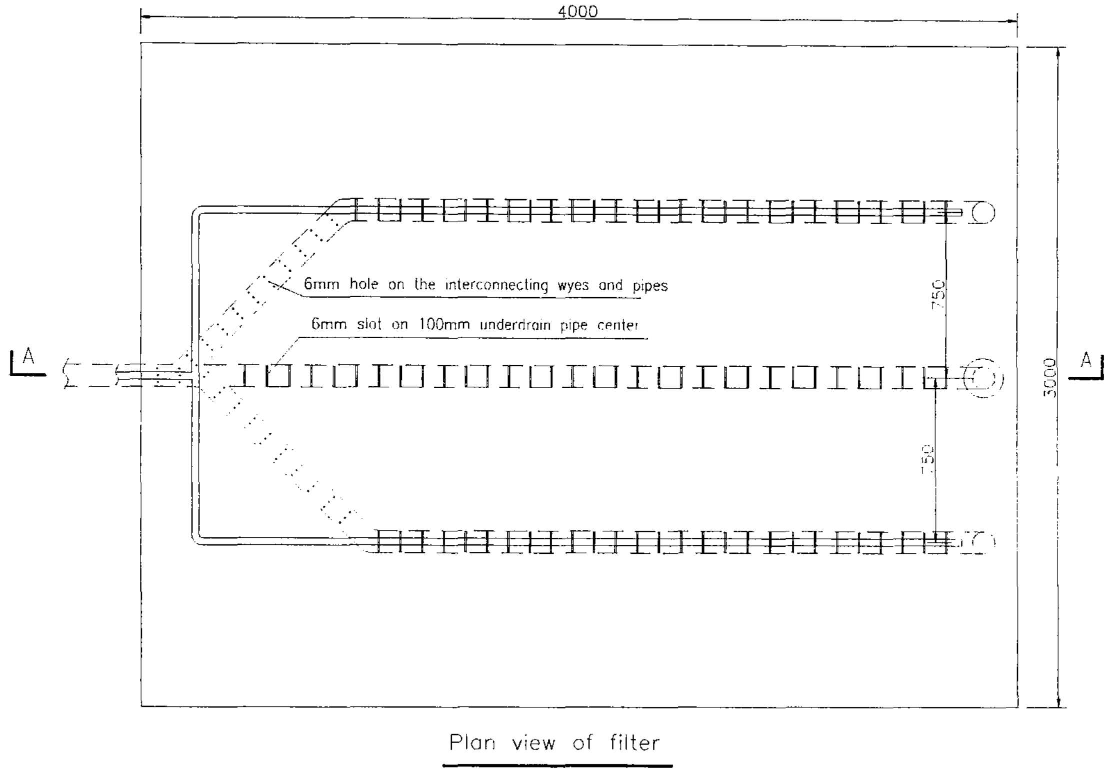


Figure 3-4. Clifford pilot plant site.

In 2003 and 2004, new instrumentation was installed and adjustments were implemented by NWRI to adapt the pilot plant to fill the requirements of the current study. Genericlot RTD temperature transmitters were installed in every filter in 2003. The 24 v DC temperature transmitters ranged from -40 to +40 °C. Magnetic flow meters were installed in the late summer of 2003 in the individual secondary septic tank influent and sand filter dosing pipelines. Analog outputs from the temperature transmitters and the flowmeters are transmitted to the SCADAPack™ programmable logic controller (PLC). An on-site computer was used to store and retrieve online data and facilitate remote access to either the SCADAPack™ or the Orenco PLC to modify operating conditions. A 25 mm diaphragm valve was installed to throttle the filter dose flow to a value less than 60 L/minute in every dosing tank. In August 2004, an autosampler was installed for 24 hour composite sampling in the main wet well. In November 2004, the underdrains servicing filters 2 and 4 were modified from a single pipe to three pipes. A pump was installed for alum addition to raw sewage on the line prior to the primary septic tank. Scale details of the pilot plant units are presented in Table 3-1. A plan view and cross-section of the filter unit are presented in Figure 3-5.

Table 3-1. Clifford pilot plant process units scale.

Component	Detail	Experimental Stream		
		1	2	4
Main pump well	Pump	Grundfos EF150	After Mar 20, 05	ABS S182W
Primary Septic Tank	Operating Volume, L	11300		
Pump Tank	Operating Volume, L	1800		
	Pump	Grundfos EF33E		
Secondary Septic Tank	Operating Volume, L	3900	3900	3900
Dosing Tanks	Operating Volume, L	1100	1100	1100
	Pump	Grundfos EF33E	Grundfos EF33E	Grundfos EF33E
Sand Filters	Surface Area, m^2	3x4	3x4	3x4
	Depth, mm	510	510	510
	No. of Laterals per Cell	2	2	2
	Diameter of Laterals, mm	32	32	32
	Distance between laterals, mm	1500	1500	1500
	No. of orifices	16	16	16
	Orifice location	side	side	Side
	Orifice diameter, mm	6	6	6
	Orifice spacing, mm	1000	1000	1000
Underdrains	Number	1	1 (3 in Phase 3 and 4)	1 (3 in Phase 3 and 4)
	Depth of 5.05 mm gravel over underdrain pipe,mm	150	150	150
	Diameter of underdrains, mm	100	100	100
	Vents per filter	1	1	1
Recirculation device	Type	Splitter basin	Splitter basin	Splitter basin



Note: In Phase 1 and 2, each filter was installed only one underdrain pipe,
In Phase 3 and 4, Filter 2 and 4 underdrain was modified by including two additional laterals of the same 1/2 slotted pipe.

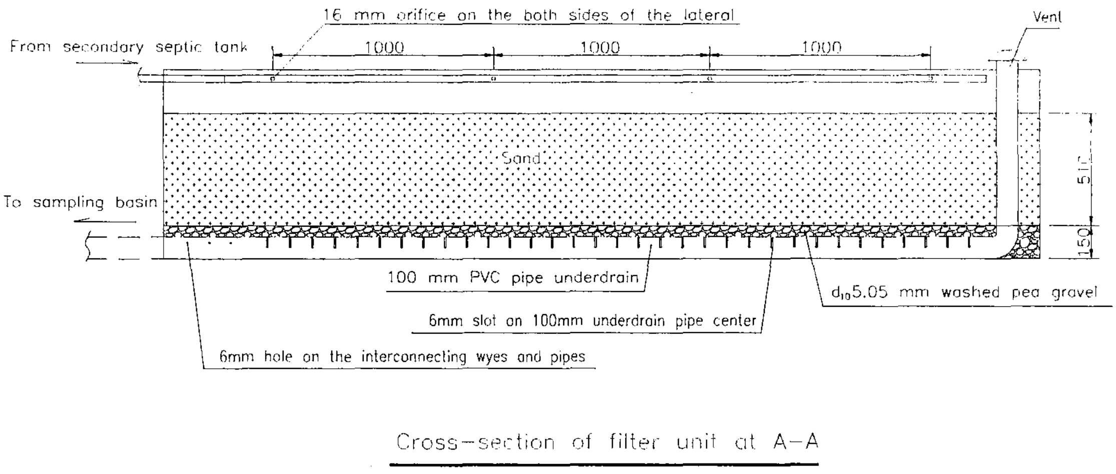


Figure 3-5. Plan view and cross-section of the filter unit.

3.3 Experimental Design

3.3.1 Operating Conditions

The technical steering committee for this investigation, with members from Environment Canada, the MOE, the NWRI and McMaster University, set the initial experimental plan and made periodic adjustments according to the progress of the study. The detailed plan is presented in Table 3-2. Each phase lasted approximately thirteen weeks, including three weeks for acclimation and ten weeks for monitoring. Different operating conditions were applied in each RSF in each phase of the study. Since the three RSFs have the same hydraulic design and equipment specifications, performance variation can be ascribed to the different operating conditions such as media size, hydraulic loading rate, recycle ratio and dosing frequency. Figure 3-6, 3-7 and 3-8 show photographs of sand filters with 2.6, 5, 7.7 mm (d_{10}) diameter media respectively.

Table 3-2. Experimental plan.

Phase	RSF	Media Size d_{10} (mm)	Influent Loading (m/day)	Recle Ratio	Dosing frequency (times/day)
1 (April 2004 to July 2004)	1	2.6	0.2	300%	48
	2	2.6	0.2	500%	48
	4	7.7	0.2	500%	48
2 (August 2004 to November 2004)	1	2.6	0.4	500%	24
	2	2.6	0.4	500%	48
	4	7.7	0.4	500%	48
3 (December 2004 to March 2005)	1	2.6	0.4	500%	24
	2	5	0.4	500%	24
	4	7.7	0.4	500%	24
4 (April 2004 to June 2004)	1	2.6	0.4	500%	24
	2	5	0.4	500%	24
	4	7.7	0.4	500%	24

Comparisons

RSF 1 and RSF 2 (April 2004 – July 2004) – Effect of recycle ratio

RSF 2 and RSF 4 (April 2004 – July 2004) – Effect of media size

RSF 1 and RSF 2 (August 2004 – November 2004) – Effect of dosing frequency

RSF 2 (April 2004 – July 2004) and RSF 2 (August 2004 – November 2004) – Effect of forward loading rate

RSF 4 (April 2004 – July 2004) and RSF 4 (August 2004 – November 2004) – Effect of forward loading rate

RSF 1 (August 2004 – November 2004) and RSF 1 (December 2004 – March 2005) – Effect of temperature

RSF 1 (December 2004 – March 2005) and RSF 1 (April 2004 – June 2005) – Effect of temperature

RSF 1 (August 2004 – November 2004) and RSF 1 (April 2004 – June 2005) – Replication of temperature results

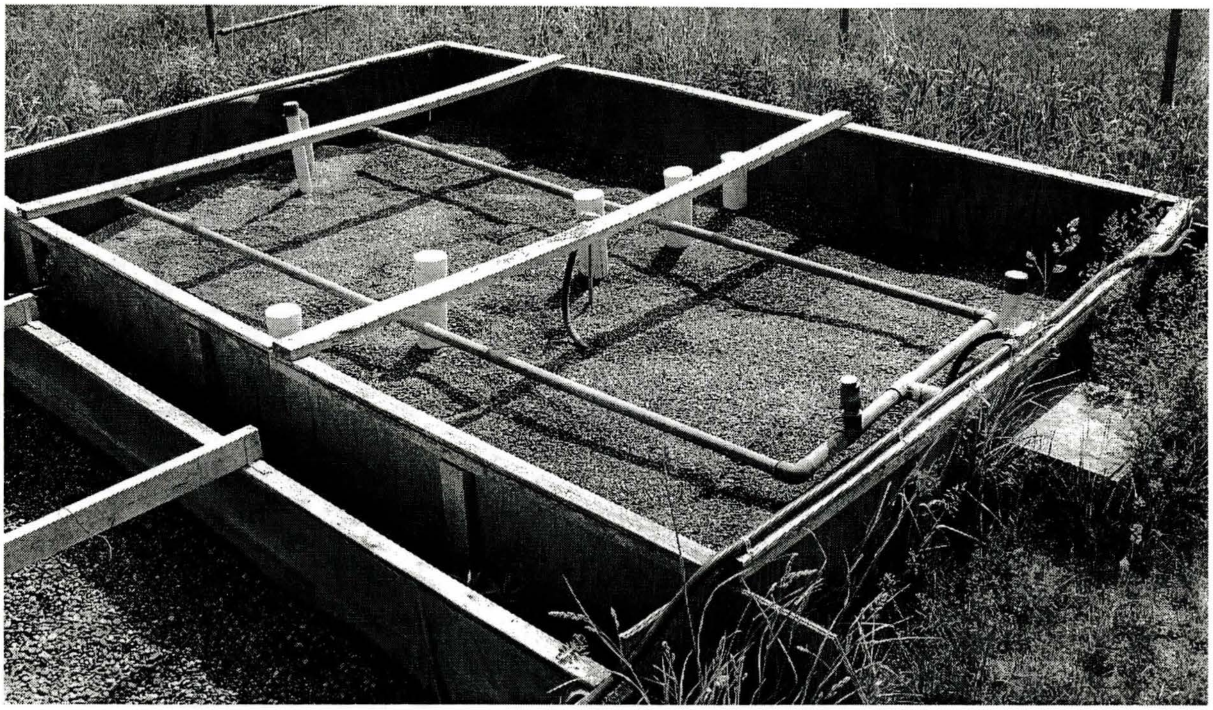


Figure 3-6. Filter 1 with a 2.6 mm d_{10} media.

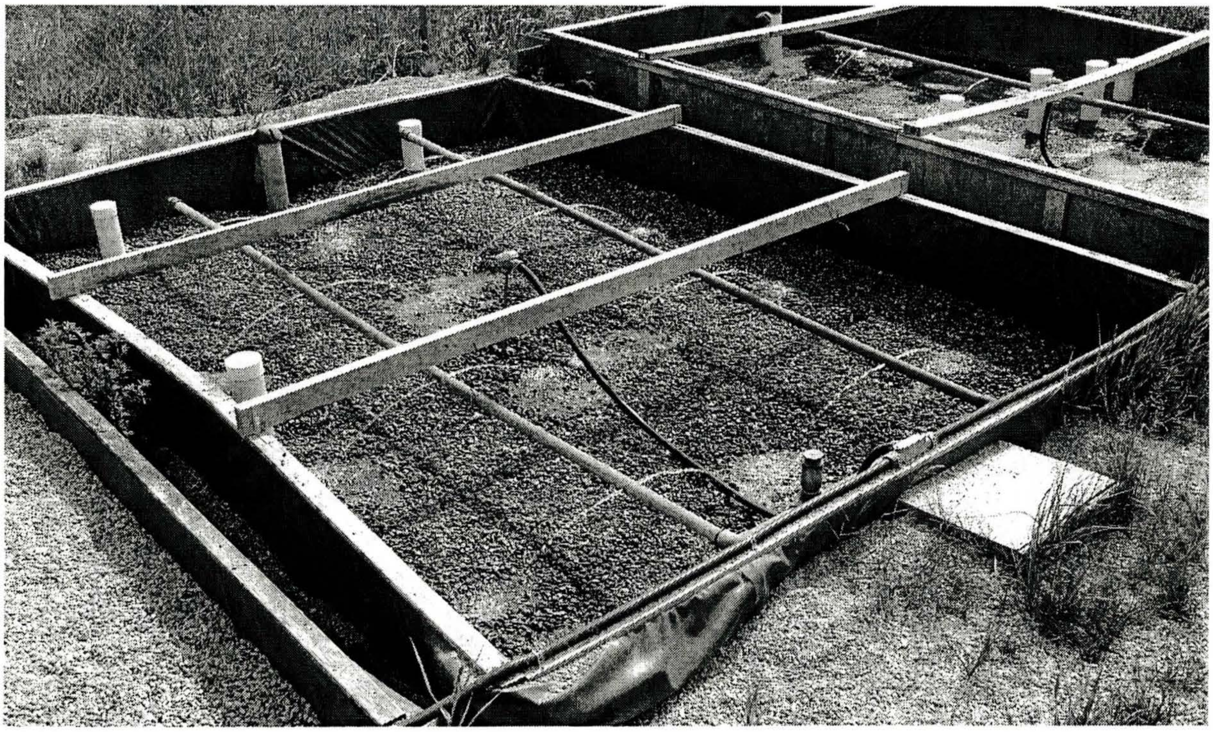


Figure 3-7. Filter 2 with 5 mm d_{10} media.

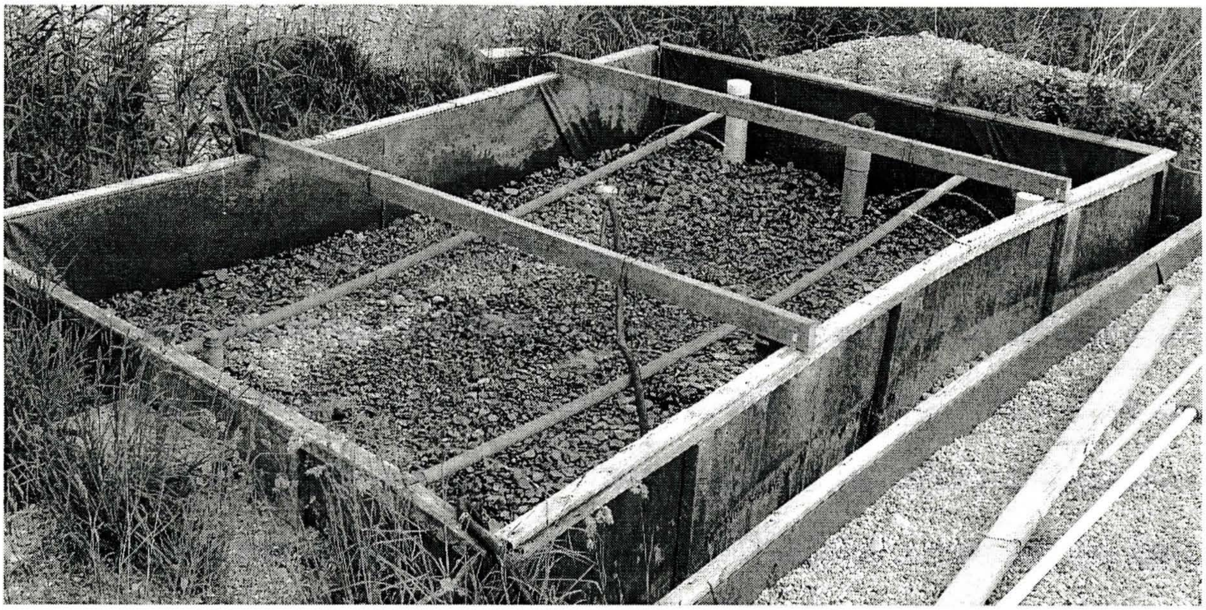


Figure 3-8. Filter 4 with 7.7 mm d_{10} media.

3.3.2 Coagulation Study

Previous research (Eastwood and Murphy 1991; Narasiah, 1994) has found that the removal of filterable phosphorus from sewage is not stoichiometric. Eastwood and Murphy (1996) performed jar tests to study the effect of alum on phosphorus removal, and fit a non-linear regression using an exponential decay function as follows:

$$(P_r / P_0) = 0.92 * \exp[-1.15 * (Al / P_0)] + 0.083 \qquad (3\text{-}1)$$

where:

P_r = the residual concentration of filterable total phosphorus (TPf) (mg P/L),

P_0 = the initial concentration of TPf (mg P/L)

Al = the aluminum dosage (mg Al/L)

This function demonstrates that an alum dosage of four times the initial soluble phosphorus concentration will remove approximately 90% of the soluble phosphorus, regardless of the initial filterable phosphorus concentration.

A bench scale coagulation study was conducted to determine the optimal coagulant dose required for the filter influent to achieve the target concentration of TP less than 1 mg/L. Additionally, this study served to evaluate the validity of the function presented in (3-1). Raw sewage from Clifford pilot plant was collected on October 19, 2005 and October 26, 2005 to perform jar tests. 26 experiments were conducted to analyze the concentration of TP, TPf, and TSS in the sewage with the addition of alum.

3.4 Sampling Techniques and Analytical Techniques

3.4.1 Sampling Techniques

Sampling consisted of weekly grab samples collected from the main wet well, the septic tank outlet and the filter effluent. Composite (24 hour) sampling was applied to collect influent raw sewage from the main wet well on a weekly basis in Phases 2 and 4. Each grab sample was collected during a dosing event, which lasted from 6 to 18 minutes and occurred once or twice per hour.

Flow and filter temperature data were logged for the entire period the study. Air temperature was taken from the Mount Forest weather station which is located 20 kilometer east of Clifford. Dissolved oxygen (DO), and temperatures were measured on site as part of each weekly sample event. Samples were analyzed for COD, TP, TSS, TAN, NO_3-N, NO_2-N, SO_4^{2-}, pH, conductivity and alkalinity at the McMaster University laboratory within 24 hours of sample collection. Samples were stored at 4 °C from the time of collection to the time of analysis. Samples were analyzed for $cBOD_5$ and E.Coli by the MOE laboratory. A sampling matrix is presented in Table 3-3. Duplicate samples were collected and sent to the MOE lab for analysis of TP, TSS, NH_3-N, TKN, NO_3-N, NO_2-N, alkalinity, and conductivity as a QA/QC measure for the McMaster University Laboratory. All samples sent to the MOE laboratory were packed in a cooler before they were transported.

Table 3-3. Sampling activity and sampling location.

Activity	Sampling Point	Sampling Location	Analytes
Phase 1	1	Raw sewage: Main wet well	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N
	2	Primary effluent: Pumping tank	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N
Phase 2	3	Secondary septic tank 1 effluent: Dosing tank 1	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, conductivity, alkalinity, E.coli
	4	Secondary septic tank 2 effluent: Dosing tank 2	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, conductivity, alkalinity, E.coli
Phase 3	6	Secondary septic tank 4 effluent: Dosing tank 4	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, conductivity, alkalinity, E.coli
	7	Filter 1 effluent: Sampling basin 1	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, conductivity, alkalinity, E.coli
Phase 4	8	Filter 2 effluent: Sampling basin	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, conductivity, alkalinity, E.coli
	10	Filter 4 effluent: Sampling basin	$cBOD_5$, COD, TP, TSS, NH_3-N, TN, NO_3-N, NO_2-N, $SO4^{2-}$, pH, Conductivity, Alkalinity, E.coli
Coagulation Study	1	Raw sewage: Main wet well	TSS, TP, TPf

3.4.2 Analytical Techniques

Filter temperature and flow data were remotely transferred from the on-site computer using PC Anywhere 10.5 (Symantec). Analytical techniques for the other parameters conducted by the McMaster University Environmental Systems Laboratory and the MOE Laboratory are presented in Table 3-4 and Table 3-5 respectively.

Table 3-4. University laboratory analytical techniques.

Parameter	Method	Instrument	Filtered
DO	Onsite	YSI Model 57 oxygen meter	N/A
Temperature	Onsite	YSI Model 57 oxygen meter	N/A
COD	Standard Methods (1992), method 5220 D	Hach DL/2000 sperctrophotometer	No
TSS	Standard Methods (1998), method 2540 D	Mettler HL 52 balance	Yes
TAN	Hach Method 8038	Hach DL/2000 sperctrophotometer	Yes
Nitrate	Standard Methods (1998), method 4110 B	CD25 conductivity detector, IONPAC® AS12A analytical column, Prostar 410 autosampler, Prostar 230 solvent delivery module	Yes
Nitrite	Standard Methods (1998), method 4110 B; Hach Method 8038 (After Dec 7, 2004)	Hach DL/2000 sperctrophotometer	Yes
TN	Hach Method 10071	Hach DL/2000 sperctrophotometer	No
TP	Hach Method 8190	Hach DL/2000 sperctrophotometer	No
pH	Standard Methods (1998), method 4500-H+	Accumet Model 915 pH Meter	No
Alkalinity	Standard Methods (1998), method 2320	Accumet Model 915 pH Meter	No
Conductivity	Standard Methods (1998), method 2510	Hach Condutivity/TDS meter	No

Table 3-5. MOE laboratory analytical techniques

Parameter	Method
$cBOD_5$	BODC 3182
TSS	SIGN 3188
TAN	DISNUT 3366
Nitrate	DISNUT 3366
Nitrite	DISNUT 3366
TKN	TOTNUT 3368
TP	TOTNUT 3368
pH	PHALCO 3218
Alkalinity	PHALCO 3218

Chapter 4
Pilot Plant Performance and Discussion

4.1 Influent Sewage Characteristic

Historic Clifford wastewater treatment plant data, from 1997 to 2002, are tabulated and reported in Table 4-1. These values represent averages of twice monthly raw sewage grab samples collected by the plant operator. These values demonstrate that the influent sewage used in this study was typical municipal sewage.

Table 4-1. Analysis of influent sewage characteristic of Clifford wastewater treatment plant.

Year	Flow (m^3/d)	$cBOD_5$ (mg/L)	TSS (mg/L)	TKN (mg N/L)	TAN (mg N/L)	TP (mg P/L)
1997	136.6	142	165	32	26	4.8
1998	128.4	192	197	42	36	5.5
1999	132.4	147	175	44	37	5.6
2000	181.1	157	210	28	24	4.4
2001	222.4	161.3	233.1	24.2	22.6	4.7
2002	211.6	144.7	240.9	28.9	24.7	4.7
Minimum	109	81	107	12.5	10.5	1.69
Maximum	595.6	482	1020	58.3	52.5	8.8

4.2 Pilot Plant Performance

4.2.1 Phase 1 Performance

In phase 1, the forward flow hydraulic loading rate was 0.2 m/day and the dosing frequency was 48 times/day for all RSFs. The recycle ratio was 300% for RSF 1 and 500% for RSFs 2 and 4. The media had a d_{10} of 2.6 mm for RSFs 1 and 2 and 7.7 mm for RSF 4 (See Table 3-2). The purpose of this phase was to evaluate the effects of media size and recycle ratio on treatment efficiency. Phase 1 started on April 1, 2004 and ended on July 26, 2004. The first sampling event was on April 7, 2004 and the last sampling occasion was on July 20, 2004. Prior to April 1, 2004, RSFs 1, 2 and 4 had been operating since November, 2003, however, they experienced several days of downtime due to maintenance. Therefore, the period prior to April 1, 2004 can be considered an acclimation phase.

4.2.1.1 Phase 1 Ambient Temperature, Online Filter Temperatures and Flow

The ambient temperature and online filter temperatures are presented in Figure 4-1 and 4-2 respectively. In this phase, the minimum of ambient temperature was -8.3 ^{o}C, and the maximum of ambient temperature was 29.7 ^{o}C, with 8 days of records missing in June, 2004. The online filter bed temperature data show an average increase of 13 ^{o}C over the experimental period.

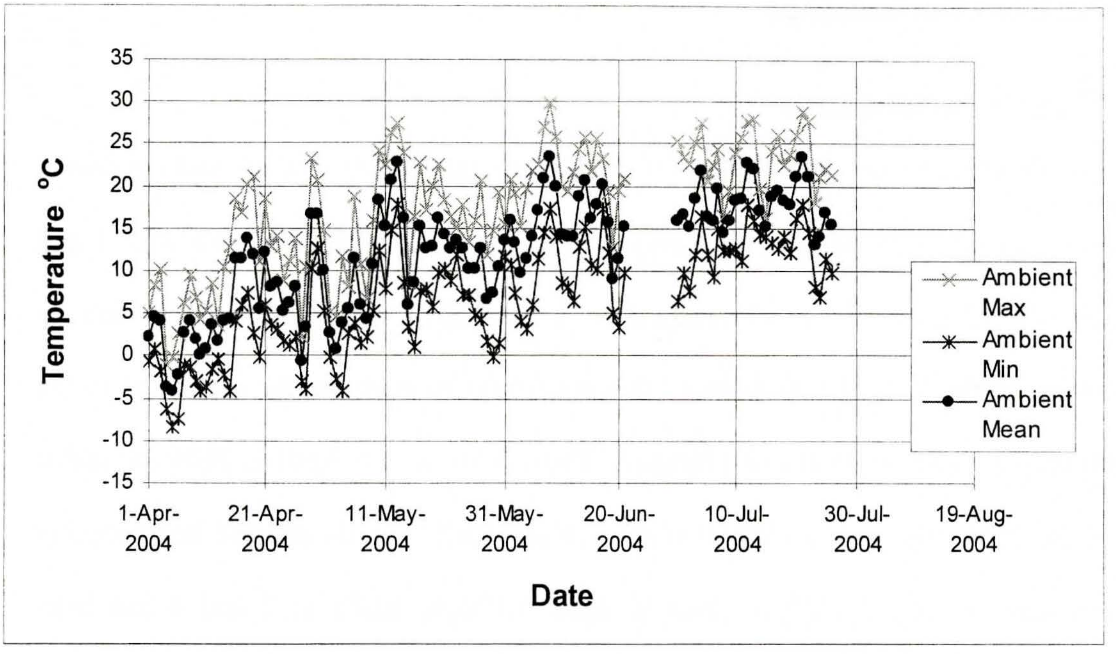


Figure 4-1. Phase 1: Ambient temperature.

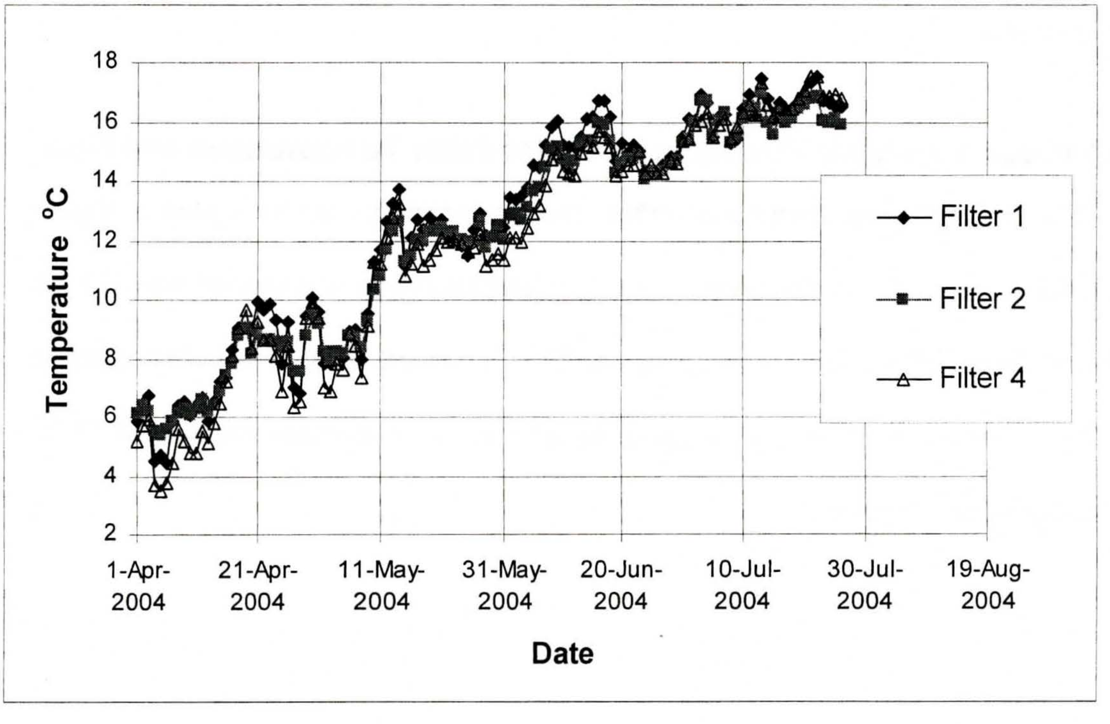


Figure 4-2. Phase 1: Online filter temperatures.

The daily RSF forward and total hydraulic loading rates are presented in Figure 4-3. The recycle ratios are presented in Figure 4-4. The total hydraulic loading is defined as the forward flow plus the recycled effluent flow from the filter. The recycle ratio is as the total flow applied to the filter expressed as a percentage of the forward flow, as defined by the US EPA. The total hydraulic loading from the dose tank was 0.6 m/day for filter 1 and 1.0 m/day for filters 2 and 4. On April 1, 2004 and April 14, 2004, all flows were interrupted due to maintenance on the raw sewage feed pump. The mean recycle ratios for RSFs 1, 2 and 4 were 284%, 550% and 502% respectively. Occasionally, those exceptionally high recycle ratios for RSFs were due to debris fouling the pumps.

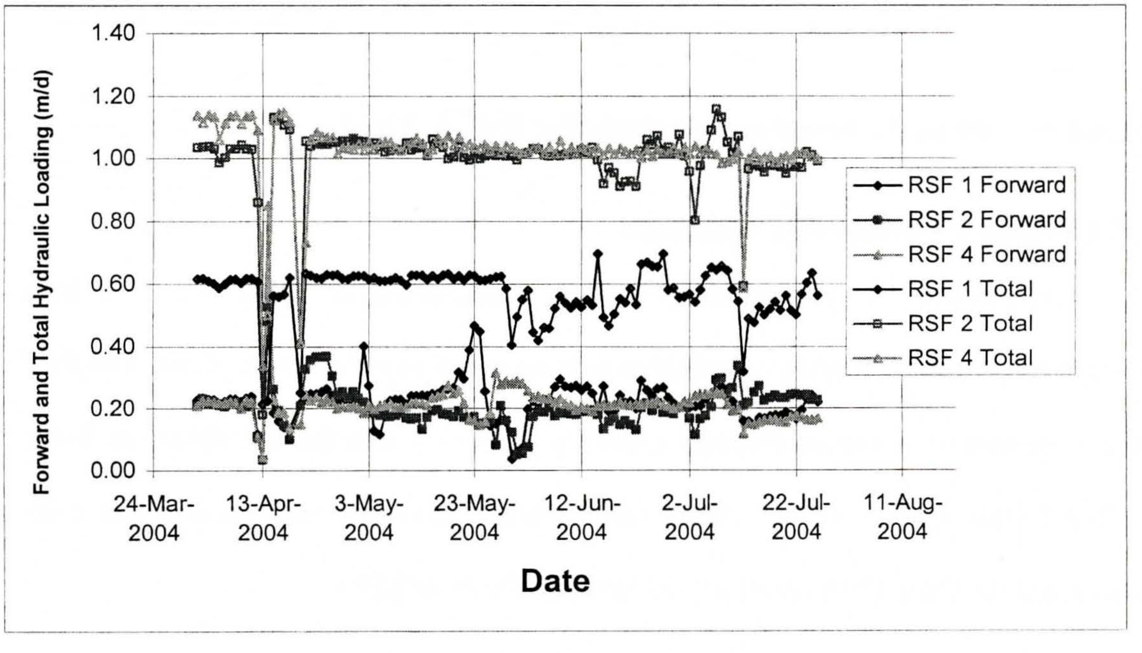


Figure 4-3. Phase 1: Summary of actual hydraulic loadings for RSFs 1, 2 and 4.

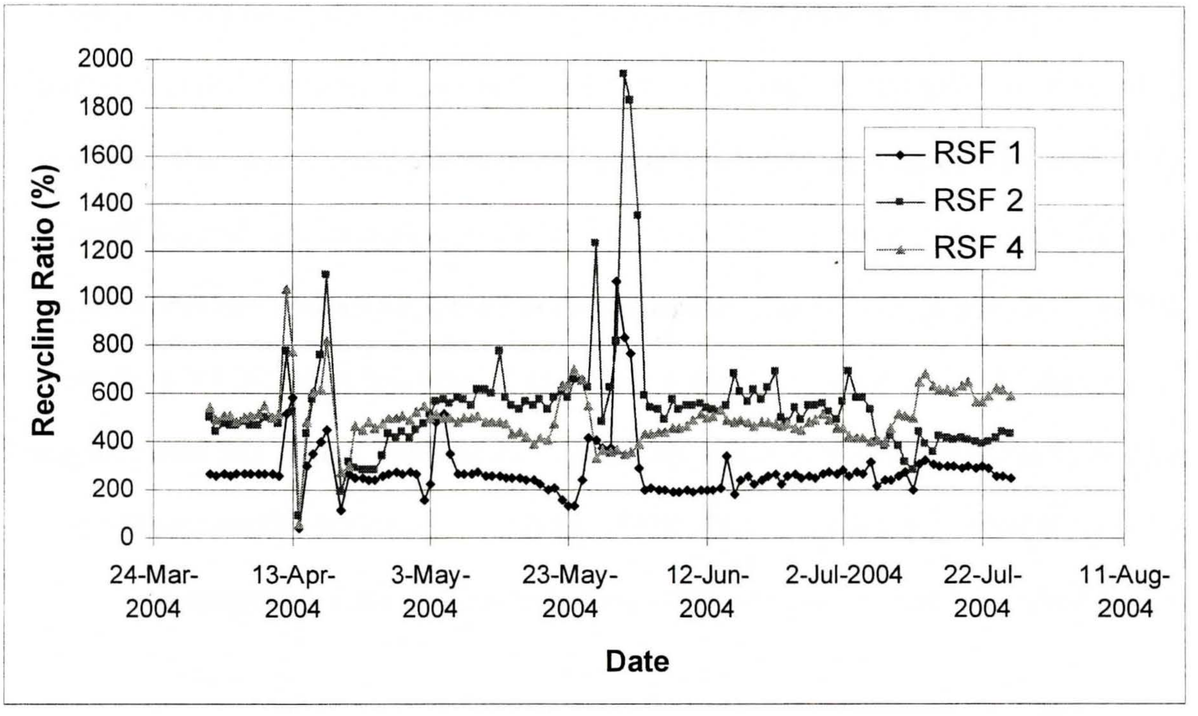


Figure 4-4. Phase 1: Actual recycle ratios for RSFs 1, 2 and 4.

4.2.1.2 Phase 1 Performance Results

Performance results for this phase are summarized in Table 4-2. The data presented represent the weekly sampling results averaged over the entire phase. The RSF effluent parameters based on monthly averages of weekly samples are shown in Table 4-3. The following paragraphs discuss each effluent parameter individually, and offer explanations for the differences observed between the three RSFs.

Table 4-2. Phase 1 RSFs performance results (April, 2004 ~ July, 2004).

ITEM		RAW SEWAGE	PST EFFLUENT	SST 1 EFFLUENT	SST 2 EFFLUENT	SST 4 EFFLUENT	RSF 1 EFFLUENT	RSF 2 EFFLUENT	RSF 4 EFFLUENT
MEDIA SIZE (mm)							2.6	2.6	7.7
SEWAGE FLOWRATE (m/day)	DESIGN	0.6	0.6	0.6	1	1	0.2	0.2	0.2
	ACTUAL	0.64	0.64	0.57	1.00	1.02	0.22	0.20	0.21
RECYCLE RATIO (%)	DESIGN						300	500	500
	ACTUAL						284	550	502
Dosing Frequency (times/day)							48	48	48
TEMP (°C)							12.42	12.11	11.87
DO (mg/L O_2)		5.3	1.0	1.3	1.6	1.1	2.3	2.4	1.4
$cBOD_5$ (mg/L)		84.4	90.4	33.6	13.9	25.3	2.1	0.7	8.7
COD (mg/L)		294.0	258.3	115.1	73.7	99.0	32.8	24.4	61.6
TSS (mg/L)		155.4	48.7	26.5	20.8	22.9	6.6	5.8	13.5
TAN (mg N/L)		13.84	13.83	8.15	4.78	10.42	1.38	0.67	9.33
NO_2^- (mg N/L)		0.005	0.001	0.076	0.123	0.032	0.041	0.070	0.027
NO_3^- (mg N/L)		0.076	0.056	0.292	0.930	0.288	7.226	6.870	0.924
TN (mg N/L)		28.7	24.0	13.3	10.1	16.9	9.5	7.9	15.0
TP (mg P/L)		5.11	4.51	4.23	3.90	4.30	3.89	3.90	4.14
SO_4^{2-} (mg/L)		142.5	81.2	83.9	91.7	67.1	95.5	93.2	57.8
pH				7.04	7.09	7.24	7.20	7.19	7.39
CONDUCTIVITY (μs/cm)				1707	1713	1720	1707	1660	1763
ALKALINITY (mg $CaCO_3$/L)				352.6	324.3	382.3	288.9	283.8	378.4
E.coli (10^3cfu/100mL)				1612.5	1270.0	1765.0	26.5	7.4	952.0

Table 4-3. Phase 1: RSF effluent parameters.

RSF	Month	$cBOD_5$ (mg/L)	TSS (mg/L)	TAN (mg N/L)	TN (mg N/L)	TP (mg P/L)
RSF 1	April, 2004 (2)*		3.9	0.93	9.5	3.13
	May, 2004 (4)*	3.6	9.5	2.64	8.9	3.94
	June, 2004 (5)*	1.5	7.4	0.34	7.3	3.94
	July, 2004 (3)*	2.8	3.4	1.09	9.0	4.25
RSF 2	April, 2004 (2)*		5.1	1.23	10.1	3.03
	May, 2004 (4)*	1.1	6.7	0.28	8.5	4.19
	June, 2004 (5)*	0.6	6.3	0.37	6.5	4.04
	July, 2004 (3)*	2.8	4.3	1.33	7.9	3.88
RSF 4	April, 2004 (2)*		12.8	3.37	10.9	3.48
	May, 2004 (4)*	8.1	13.6	6.31	10.7	4.54
	June, 2004 (5)*	8.6	14.2	12.18	18.4	4.16
	July, 2004 (3)*	9.0	12.6	12.57	17.8	4.00

Note: 1. The effluent concentrations presented represent a monthly average based on weekly samples.

2. The shaded areas indicate effluent concentrations exceeding the MOE objective.

* This number indicates the number of sampling events incorporated into the average.

In phase 1, the $cBOD_5$ was not examined until May 25, 2004 due to the fact that the MOE sampling bottles were not ready. The phase 1 effluent $cBOD_5$ and overall removals of $cBOD_5$ for all RSFs are presented in Figure 4-5. RSFs 1 and 2 demonstrated excellent removal of organic matter, with effluent concentrations consistently falling below 2 mg/L and 4 mg/L respectively. The overall average removal of $cBOD_5$, based on the raw sewage concentration, for RSFs 1 and 2 was 97.1% and 99.2% respectively. The effluent $cBOD_5$ for RSF 4 was much higher than that of RSFs 1 and 2, with the overall average removal of $cBOD_5$ being 89.4%. In spite of this, the maximum $cBOD_5$

concentration never exceeded 15 mg/L, which is the objective $cBOD_5$ effluent criterion. This experimental phase demonstrates that RSFs have excellent capability for organic removal. Even with media as coarse as 7.7 mm, the $cBOD_5$ still meets the MOE's effluent criterion. The reason that RSFs perform better with smaller media is that the smaller media provide a larger surface area which can accumulate more microbes to treat organic in the influent. Alternatively, a higher recycle ratio can dilute the organic concentration in the forward flow, and increase the total hydraulic loading thereby increasing the contact time between the microorganisms and organic matter.

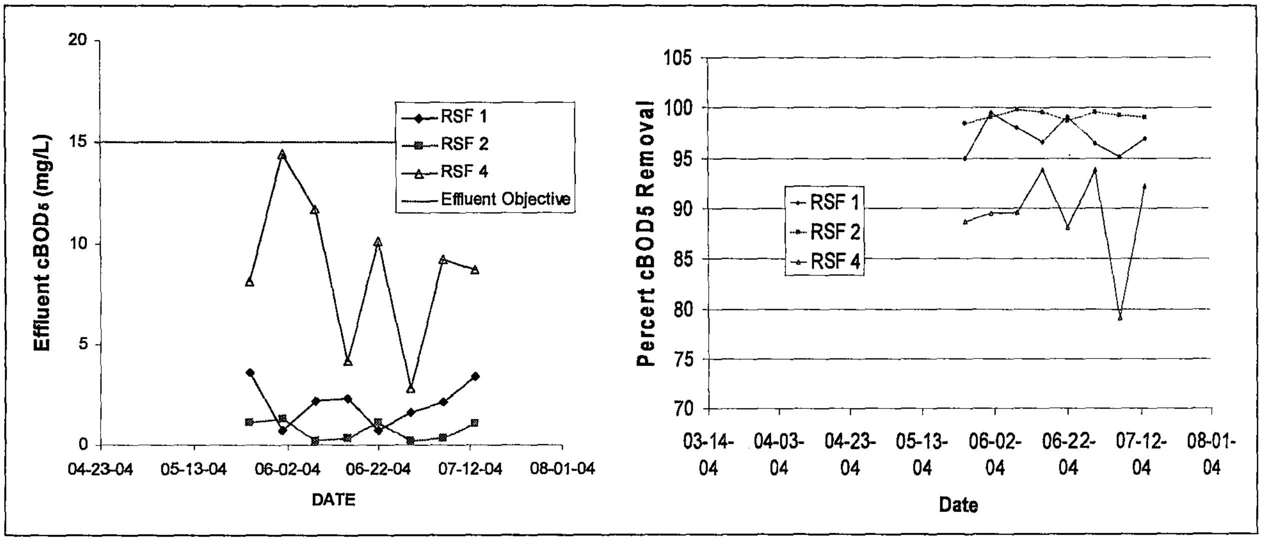


Figure 4-5. Phase 1: Effluent $cBOD_5$ concentration and overall $cBOD_5$ removal by RSFs.

Figure 4-6 shows the effluent TSS concentrations from RSFs 1, 2 and 4, as well as the overall TSS removal for each RSF in Phase 1. There was one occasion, May 11, 2004, when raw sewage was not collected due to the fact that the sampling location was locked. RSFs 1 and 2 produced similar effluent TSS concentrations and removals. RSF 2, however, performed more consistently than RSF 1, which exceeded the 15 mg/L TSS effluent criterion on one occasion. This exceedence, however, may be due to the method employed to collect the sample, as grab samples represent a single sampling event, and maybe be collected at a time when the effluent concentration is high. The effluent quality for TSS was much worse for RSF 4 than the other two RSFs, producing an effluent with more than double the TSS concentrations of RSFs 1 and 2. The overall average removals for RSFs 1, 2 and 4 were 95.4%, 95.7% and 90.0% respectively. All three RSFs did, however, achieve the effluent TSS criterion under their respective operating conditions. Higher TSS removal rates by smaller media are due to the smaller pore space between the grains which can strain more solids out. Again, the higher recycle ratio acts to reduce the TSS concentration in the filter loading leading to lower effluent TSS concentrations.

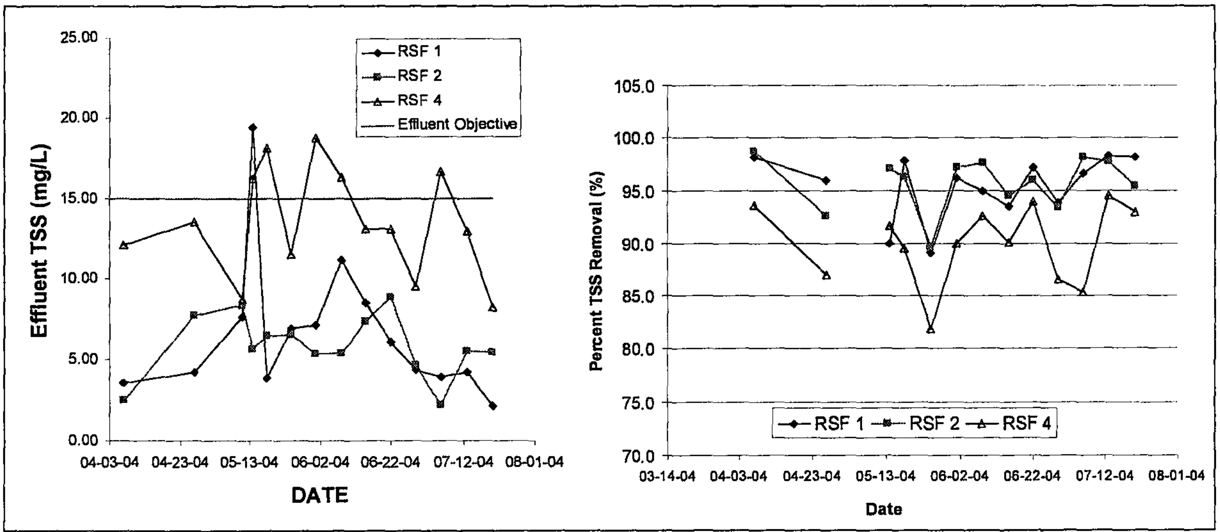


Figure 4-6. Phase 1: Effluent TSS concentration and overall TSS removal by RSFs.

The transformation of nitrogen throughout this phase is presented in Figure 4-7 . The effluent concentrations of TN and TAN are presented in Figure 4-8 and Figure 4-9 respectively. In phase 1, RSFs 1 and 2 experienced significant nitrification, whereas the degree of nitrification by RSF 4 was respectively low. This was demonstrated through alkalinity measurements in the RSF effluent. In the nitrification phase, with the TAN being oxidized to nitrate, alkalinity is consumed by the H^+ which is product of nitrification. Therefore, more alkalinity is consumed with a higher degree of nitrification. RSF 2 had the lowest alkalinity followed by RSF 1; RSF 4 had a much higher alkalinity (Table 4-2). Because the Clifford wastewater treatment plant's sewage is rich in alkalinity, nitrification was not inhibited in the RSFs. The TKN removal rates were 92.4%, 96.6% and 50.9% for RSFs 1, 2, and 4 respectively. As presented in Table 4-3, both RSFs 1 and 2 achieved the total nitrogen effluent objective of 10 mg N/L, although RSF 2 did exceed the target on one occasion and RSF 1 exceeded the target on 5 occasions. The reason for RSF 2's higher TN treatment efficiency is the higher recycle ratio diluting the forward flow concentration. The higher recycle ratio also acts to increase the total hydraulic loading, thereby increasing microbial contact time in the filter. RSF 4 effluent was, on average, 50% higher than the 10 mg N/L effluent criterion. The effluent TAN concentrations from RSFs 1 and 2 were consistently lower than the criterion of 5 mg N/L, whereas the effluent from RSF 4 exceeded the criterion. The lower TAN and TN concentrations from the RSFs with d_{10} 2.6 mm media are due to the fact that the smaller media provide a larger surface area on which to accumulate more nitrifying bacteria. Therefore, they can remove more TAN in the effluent, thereby more nitrates, which are then denitrified in the secondary septic tank leading to lower TN concentrations in the RSF effluent.

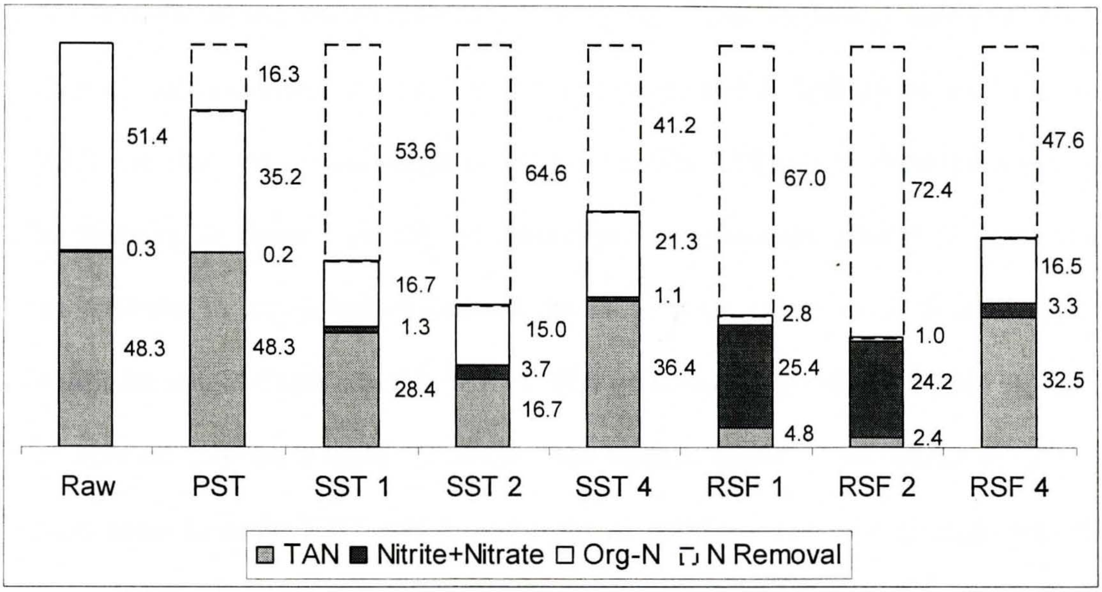


Figure 4-7. Phase 1: Form of N throughout the treatment expressed as a percentage of TN in the raw sewage.

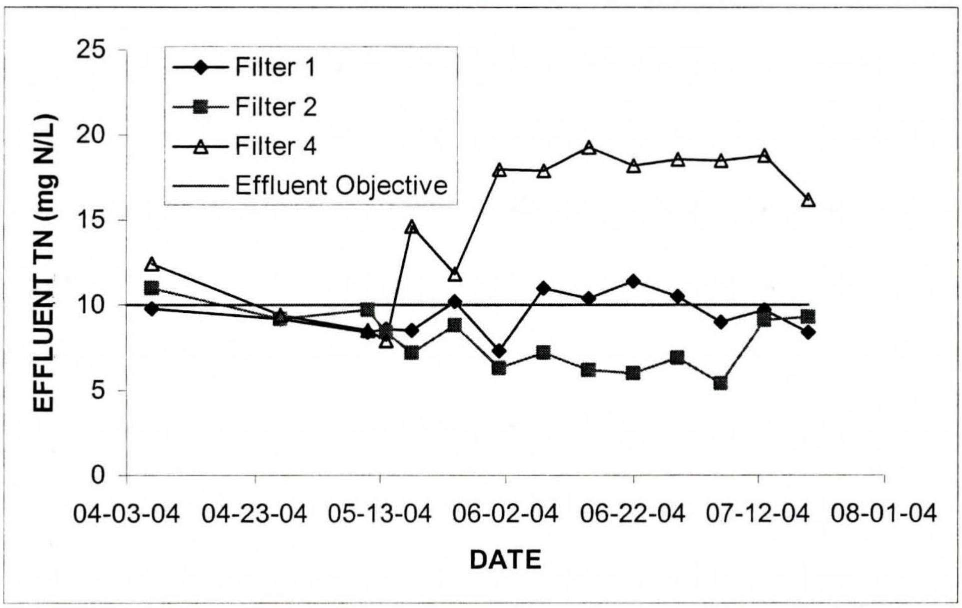


Figure 4-8. Phase 1: TN concentrations in the RSF effluent.

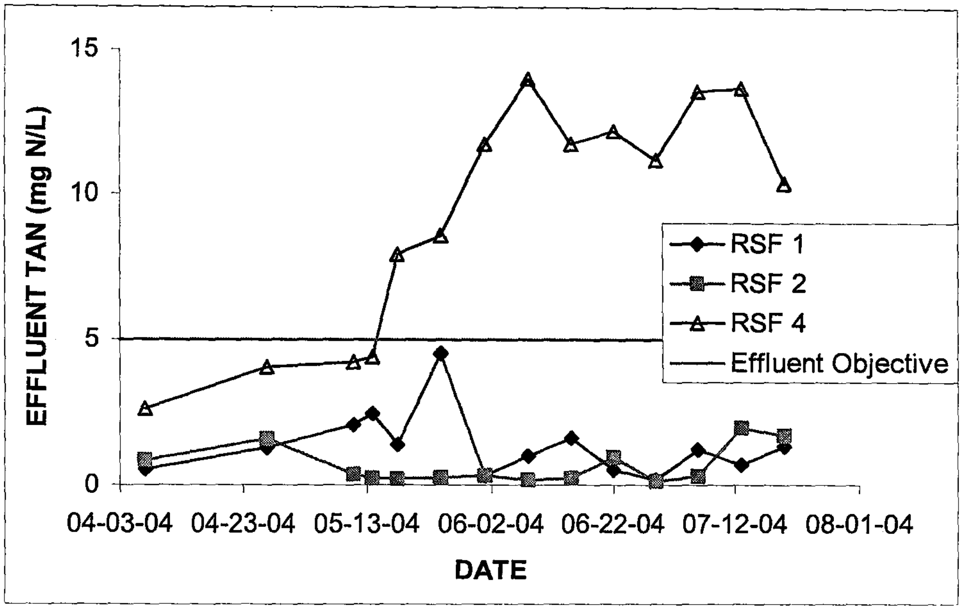


Figure 4-9. Phase 1: TAN concentrations in the RSF effluent.

All three RSFs demonstrated similar treatment results for TP in Phase 1 with approximately 20% TP removal, however, the TP concentration in the effluent from all three RSFs exceeded the effluent criterion which indicates that they cannot achieve the target without coagulant addition. Figure 4-10 shows that the effluent TP and overall TP removal of RSFs was very similar by the RSFs 1, 2 and 4, however RSFs 1 and 2 performed slightly better than RSF 4. The reason for the slightly better removals experienced by RSFs 1 and 2 is the smaller media size employed in these filters, which provides a larger surface area for adsorption. On one occasion, June 29, 2004, the overall TP removal was negative, which was, again, likely due to the grab sampling methodology.

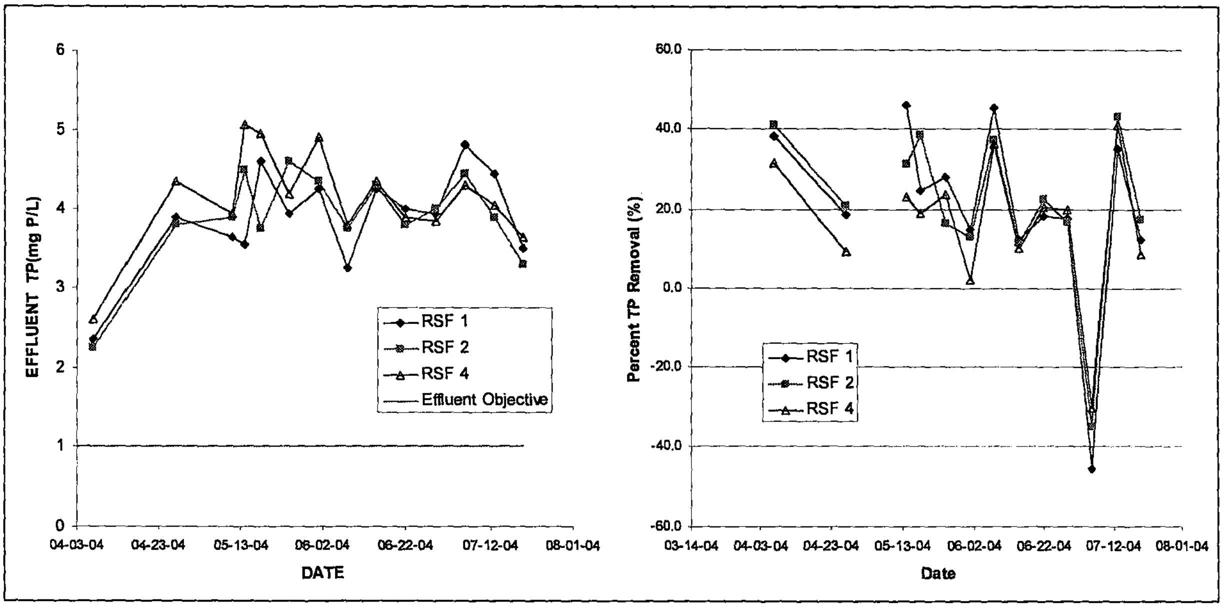


Figure 4-10. Phase 1: Effluent TP concentration and overall TP removal by RSFs.

E.coli testing commenced on May 25, 2005, however, samples were not tested on several occasions due to delays in the delivery to the MOE Lab. Generally, RSF 2 had the best E.coli removal followed by RSF 1. RSF 4 had much higher E.coli concentrations in its effluent, by nearly two orders of magnitude. The effluent E.coli concentrations from phase 1 are presented in Figure 4-11. Higher treatment efficiency for the RSFs with smaller media is once again due to the fact that the small media provide a larger surface area, which accumulates more microbes to decompose the microorganisms in the influent sewage. The higher recycle ratio diluting the E.coli concentration in the forward flow also results in lower effluent E.coli concentrations, due to the reasons discussed previously.

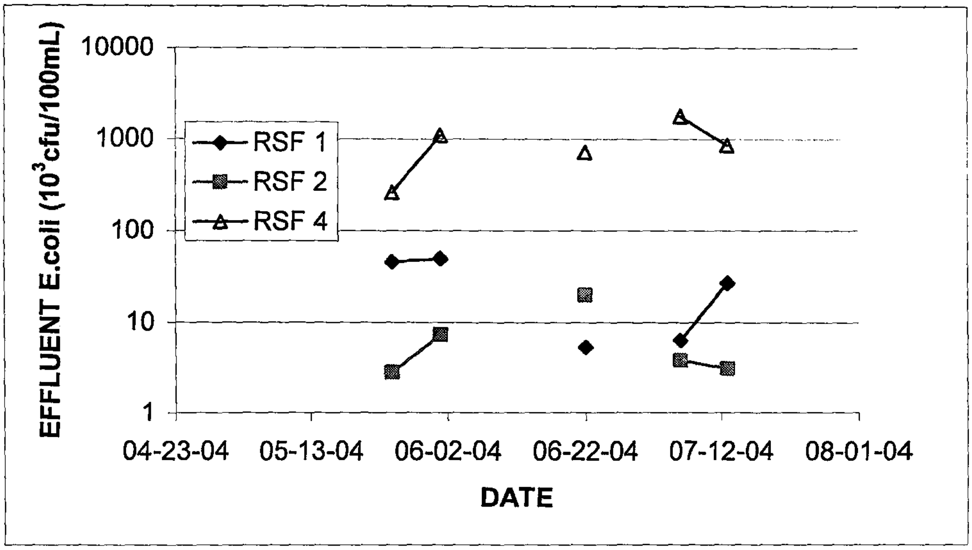


Figure 4-11. Phase 1: Effluent E.coli Concentrations from RSFs 1, 2 and 4.

In summary, the RSF with the smallest media (d_{10}= 2.6 mm), which provided a larger surface area, allowing larger contact area between the microbes and pollutants in the sewage. Additionally, the higher recycle ratio acts to dilute the primary effluent, thereby providing a longer contact time between microbes and pollutants. Therefore, RSF 2, with the 500% recycle ratio and d_{10}=2.6 mm media, produce the highest effluent quality followed by RSF 1 with a 300% recycle ratio and d_{10}=2.6 mm media. The effluent characteristics of RSF 4 were worse than those of RSFs 1 and 2, with the exception of TP, for which all RSF effluent qualities were similar.

4.2.2 Phase 2 Performance

The forward flow hydraulic loading rate was set to 0.4 m/day for all RSFs throughout this phase and the recycle ratio was set to 500%. The dosing frequency was set to 24 times/day for RSF 1, while RSFs 2 and 4 remained at a dosing frequency of 48 times/day. The media were not changed from Phase 1 (See Table 3-2). The purpose of this phase was to evaluate the effects of dosing frequency and hydraulic loading. Phase 2 started on August 16, 2004 and ended on November 8, 2004. The first sampling event was on August 17, 2004, and the last sampling event was on November 2, 2004. 24 hour composite samples of the raw sewage were collected weekly beginning on September 20, 2004.

4.2.2.1 Phase 2 Ambient Temperature, Online Filter Temperatures and Flow

The ambient temperatures and online filter temperatures measured throughout Phase 2 are presented in Figures 4-12 and 4-13 respectively. Throughout this phase, the minimum ambient temperature was -6.3 °C and the maximum ambient temperature was 27.9 °C. The online filter bed temperature data show an average decrease of approximately 8 °C, from 18 °C to 10 °C, over the course of this experimental phase.

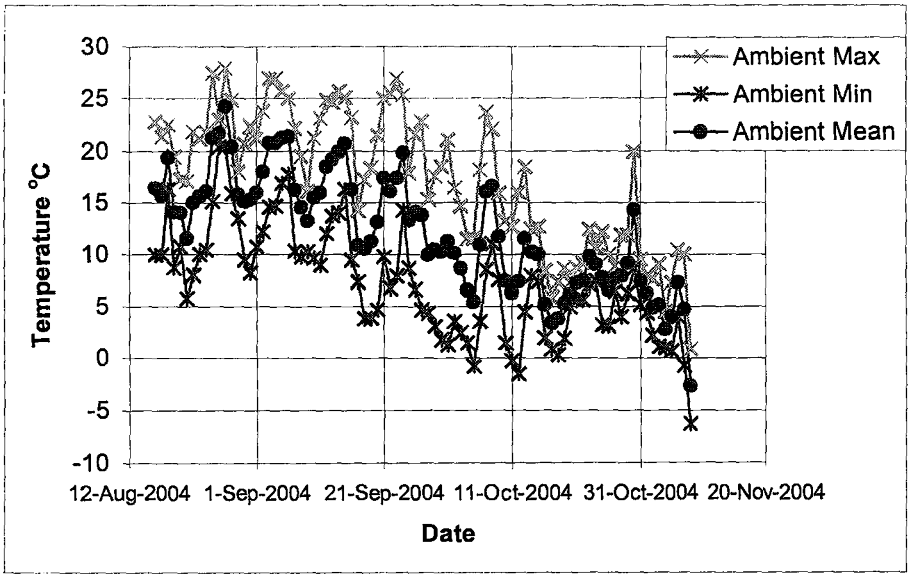


Figure 4-12. Phase 2: Ambient temperature.

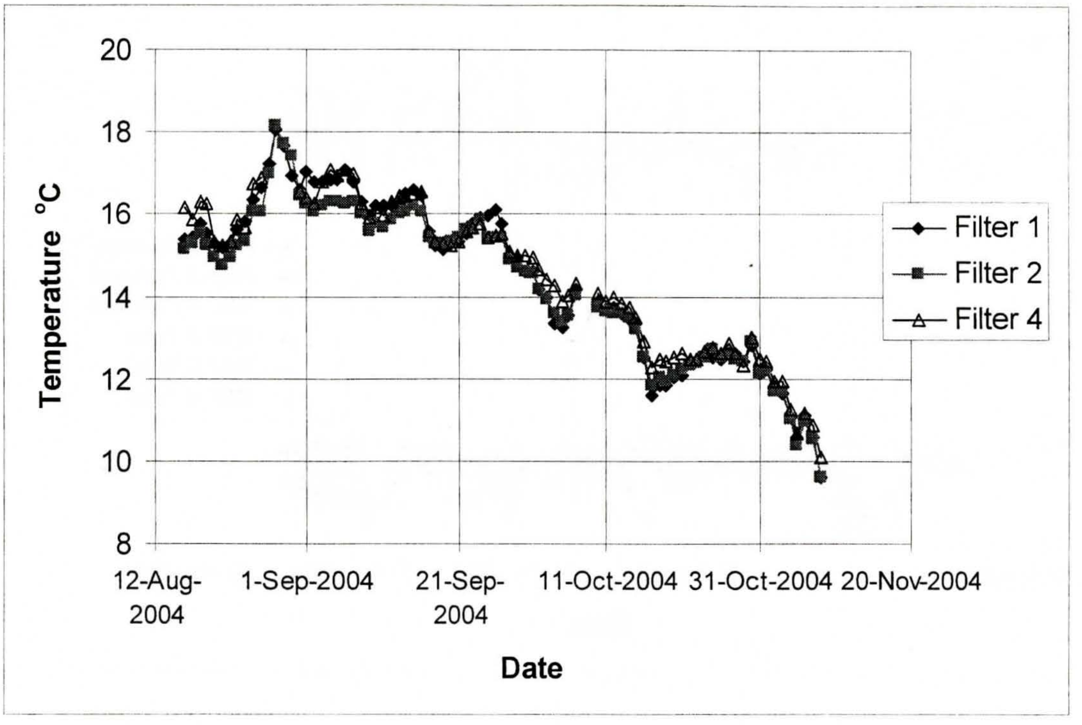


Figure 4-13. Phase 2: Online filter temperatures.

The actual daily RSF forward flow and total hydraulic loading data, as measured by the flow meters, are presented in Figure 4-14. The forward flow was shut down for maintenance on several occasions; these data were excluded. The mean recycle ratios for RSFs 1, 2 and 4 were 525%, 587% and 481% respectively. Occasionally, those exceptionally high recycle ratios were due to debris fouling the pump.

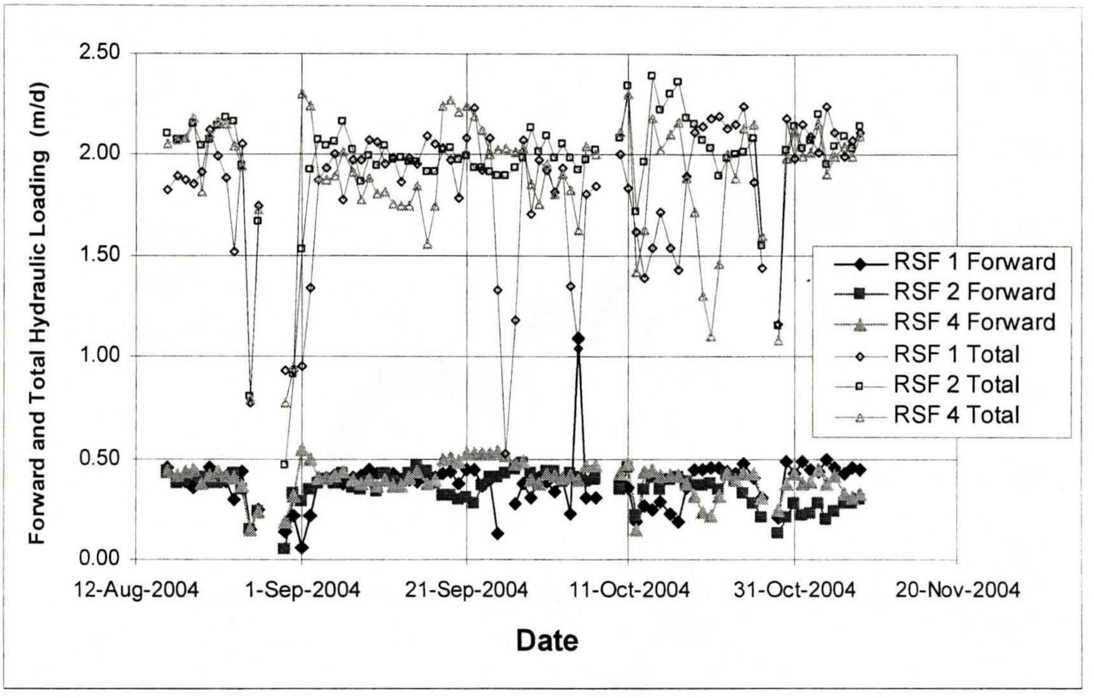


Figure 4-14. Phase 2: Summary of actual hydraulic loadings for RSFs 1,2 and 4.

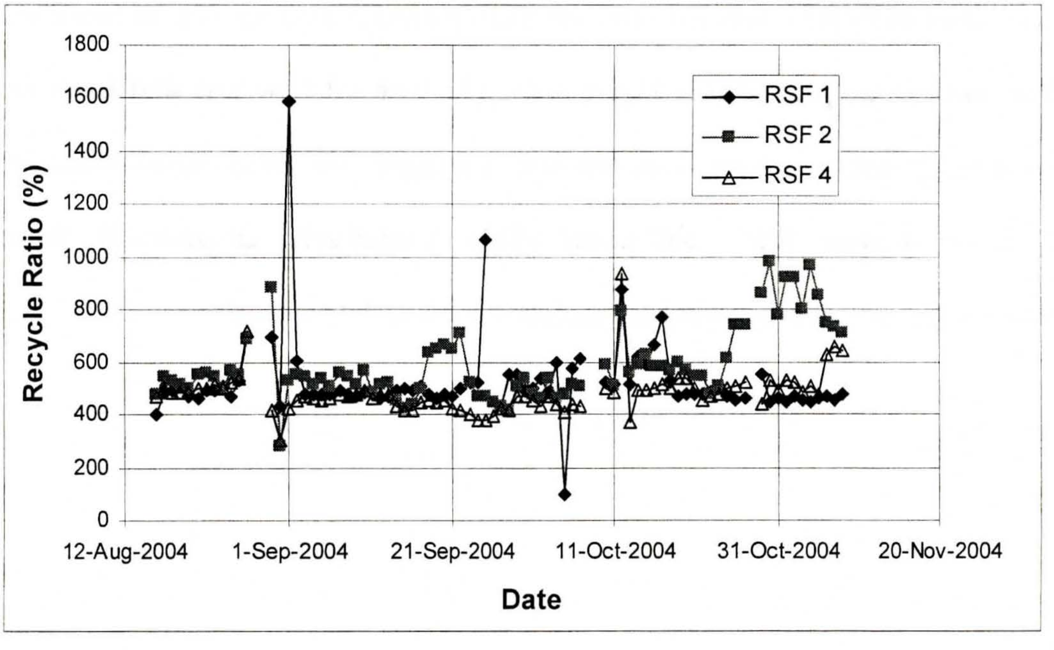


Figure 4-15. Phase 2: Actual recycle ratios for RSFs 1, 2 and 4.

4.2.2.2 Phase 2 Performance Results

Table 4-4 summarizes the performance results from Phase 2. The data presented represent the average of all samples measurements collected throughout this phase. The RSF effluent parameters are presented as monthly averages of weekly samples in Table 4-5. The following paragraphs discuss each effluent parameter individually, and offer explanations for the differences observed between the three RSFs.

Table 4-4. Phase 2 RSFs performance results (August, 2004 ~ November, 2004).

ITEM		RAW SEWAGE INFLUENT	PST EFFLUENT	SST 1 EFFLUENT	SST 2 EFFLUENT	SST 4 EFFLUENT	RSF 1 EFFLUENT	RSF 2 EFFLUENT	RSF 4 EFFLUENT
MEDIA SIZE (mm)							2.6	2.6	7.7
SEWAGE FLOWRATE (m/day)	DESIGN	1.2	1.2	2	2	2	0.4	0.4	0.4
	ACTUAL	1.13	1.13	1.82	1.96	1.89	0.38	0.35	0.40
RECYCLE RATIO (%)	DESIGN						500	500	500
	ACTUAL						525	587	481
Dosing Frequency (times/day)							24	48	48
TEMP (°C)		14.6	14.0	15.3	15.0	15.3	14.5	14.3	14.5
DO (mg/L O_2)		3.3	1.6	2.3	2.2	2.1	2.1	1.9	2.2
$cBOD_5$ (mg/L)		192.3	67.7	17.1	28.5	30.7	2.9	5.0	12.4
COD (mg/L)		604.1	207.1	85.6	109.5	109.5	30.5	46.7	85.0
TSS (mg/L)		299.7	57.0	25.8	31.0	34.6	5.2	10.3	18.9
TAN (mg N/L)		15.28	16.80	6.50	12.48	12.95	2.62	9.30	11.14
NO_2^- (mg N/L)		0.014	0.000	0.272	0.000	0.000	0.219	0.204	0.044
NO_3^- (mg N/L)		0.129	0.167	2.030	0.180	0.202	5.642	1.520	1.015
TN (mg N/L)		31.7	25.1	12.0	17.9	18.7	8.9	14.7	16.2
TP (mg P/L)		6.23	3.86	3.45	3.85	3.49	3.13	3.89	3.33
SO_4^{2-} (mg/L)		148.741	104.750	114.352	87.825	94.901	116.544	83.898	92.501
pH				7.01	7.05	7.20	7.16	7.16	7.35
CONDUCTIVITY (μs/cm)				1818	1874	1857	1779	1817	1834
ALKALINITY (mg $CaCO_3$/L)				317	362	360	287	346	348
E.coli (10^3 cfu/100mL)				947	1863	2169	11	341	1093

Table 4-5. Phase 2: RSF effluent parameters.

RSF	Month	$cBOD_5$ (mg/L)	TSS (mg/L)	TAN (mg N/L)	TN (mg N/L)	TP (mg P/L)
RSF 1	Aug, 2004 (2)*	2.55	4.9	3.41	8.3	3.60
	Sept, 2004 (4)*	3.3	5.6	2.58	8.2	3.15
	Oct, 2004 (4)*	3.0	4.9	2.43	9.5	2.96
	Nov, 2004 (1)*	2.0	4.9	1.98	11.0	2.75
RSF 2	Aug, 2004 (2)*	4.9	10.2	6.35	13.9	4.18
	Sept, 2004 (4)*	4.5	8.3	6.98	12.8	4.00
	Oct, 2004 (4)*	5.6	13.1	13.19	17.5	3.91
	Nov, 2004 (1)*	4.4	7.8	8.90	12.6	2.80
RSF 4	Aug, 2004 (2)*	13.7	21.1	9.83	14.4	3.58
	Sept, 2004 (4)*	14.4	20.9	10.49	17.6	3.33
	Oct, 2004 (4)*	11.1	17.2	13.15	16.5	3.30
	Nov, 2004 (1)*	8.8	13.6	8.30	13.1	2.95

Note: 1. The effluent concentrations presented represent a monthly average based on weekly samples.

2. The shaded areas indicate effluent concentrations exceeding the MOE objective.

* This number indicates the number of sampling events incorporated into the average.

The phase 2 effluent $cBOD_5$ concentrations and overall removals of $cBOD_5$ for all RSFs are presented in Figure 4-16. The $cBOD_5$ data from the sampling event on September 14, 2004 are missing. On all occasions, the RSF 1 and 2 effluent $cBOD_5$ were lower than 10 mg/L, which is significantly lower than the MOE objective of 15 mg/L. The average overall removals of $cBOD_5$ for RSFs 1 and 2 were 97.8% and 96.2% respectively. Although the average $cBOD_5$ concentration in the RSF 4 effluent was lower than the effluent objective, there were 3 sampling events when the $cBOD_5$ concentration exceeded the MOE effluent target of 15 mg/L. The average removal of $cBOD_5$ for RSF 4 was 90.1%. Overall, all three RSFs performed well in terms of organic removal, even at the higher hydraulic loading rate, achieving the MOE effluent criterion.

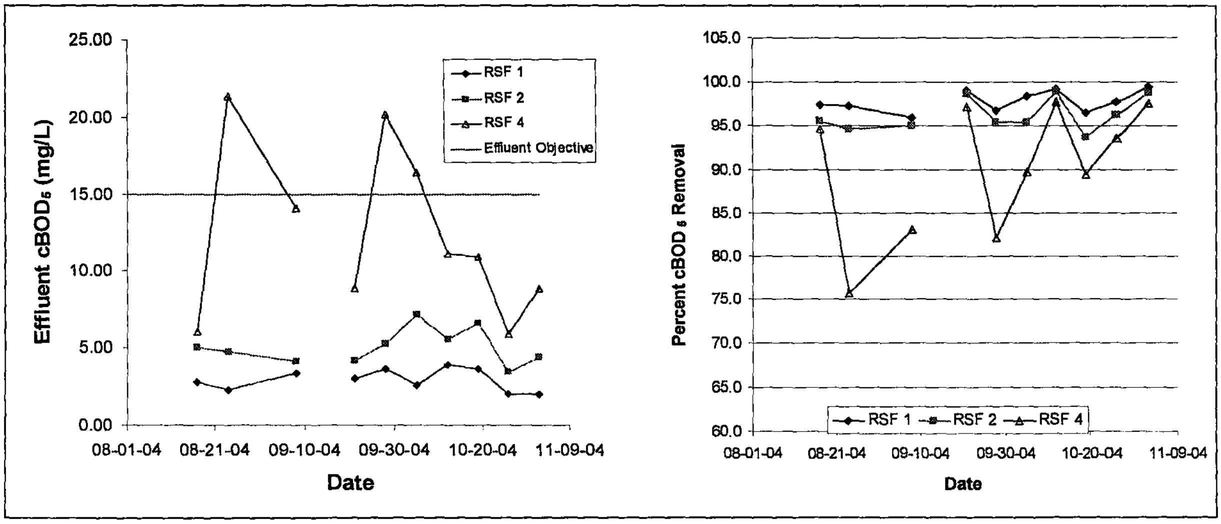


Figure 4-16. Phase 2: Effluent $cBOD_5$ concentration and overall $cBOD_5$ Removal of RSFs.

The Phase 2 effluent TSS concentrations and overall TSS removal from all three RSFs are presented in Figure 4-17. Again, RSF 1 performed best, with the effluent TSS being lower than 10 mg/L throughout the entire phase. The average TSS removal by RSF 1 was 97.1%. As presented in Table 4-5, the effluent TSS concentration from RSF 2 was less than the MOE effluent target of 15 mg/L, however, there was one occasion in which it exceeded the target. The average TSS removal by RSF 2 was 95.0%. RSF 4 had the worst performance in terms of TSS removal, only achieved the MOE effluent objective in November 2004 when there was just one sampling occasion. The average TSS removal by RSF 4 was 90.5%.

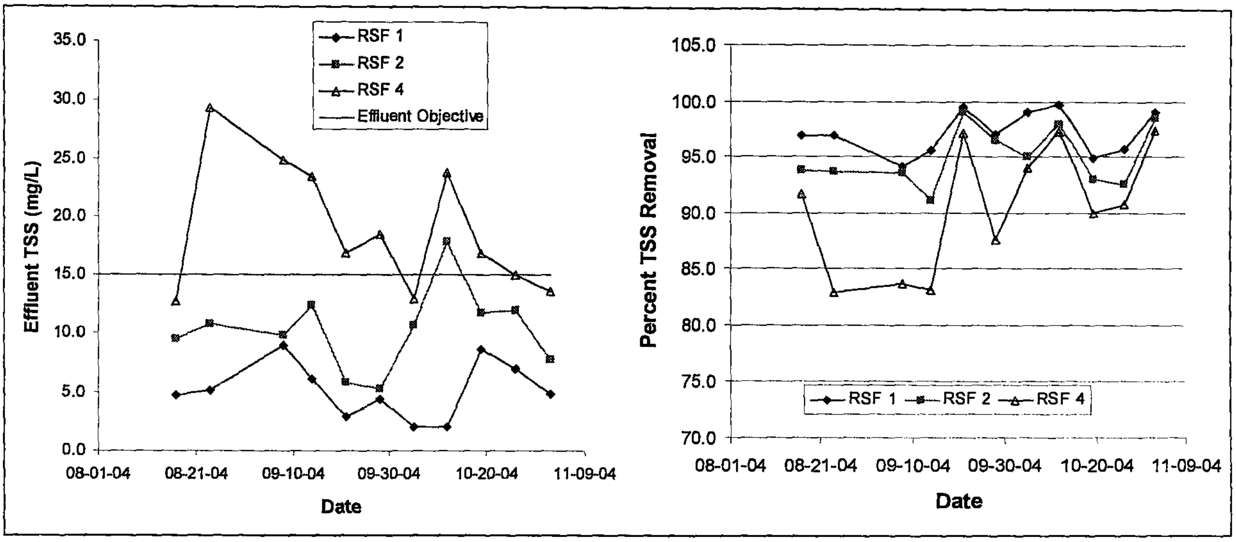


Figure 4-17. Phase 2 effluent TSS concentration and overall TSS removal by RSFs.

The effluent nitrate and TAN concentrations from Phase 2 are presented in Figure 4-18. The sewage was well nitrified by RSF 1; the effluent TAN concentration remained under the effluent objective of 5 mg N/L throughout the entire phase. RSFs 2 and 4 however, consistently exceeded the objective. The nitrification performance achieved by RSF 2 was similar to that of RSF 4 since September 21, 2004. NWRI (2005) reported that RSF 2 took 40 minutes to completely drain. Slow drainage likely minimized the amount of air percolating through the filter; which may attribute to the poor nitrification performance as nitrification requires and aerobic environment.

The Phase 2 effluent TN concentrations and overall TN removals are presented in Figure 4-19. RSF 1 performed well in terms of nitrification and denitrification. On most occasions, the effluent TN from RSF 1 was below the effluent objective of 10 mg N/L until the last month of this phase; exceedences in this last month were likely due to the decline in temperature. The average TN reduction achieved by RSF 1 was 69.8%. The effluent TN from RSFs 2 and 4, however, consistently exceeded the effluent objective. The average TN reduction achieved by RSFs 2 and 4 were 50.4% and 44.3% respectively.

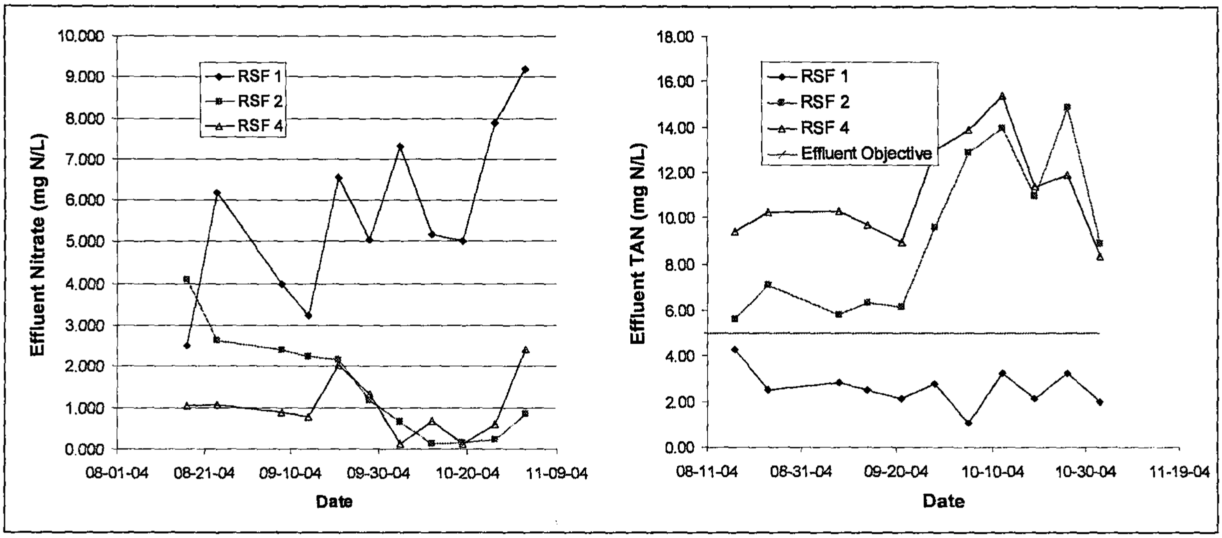


Figure 4-18. Phase 2: Nitrate and TAN concentration from RSFs 1, 2 and 4.

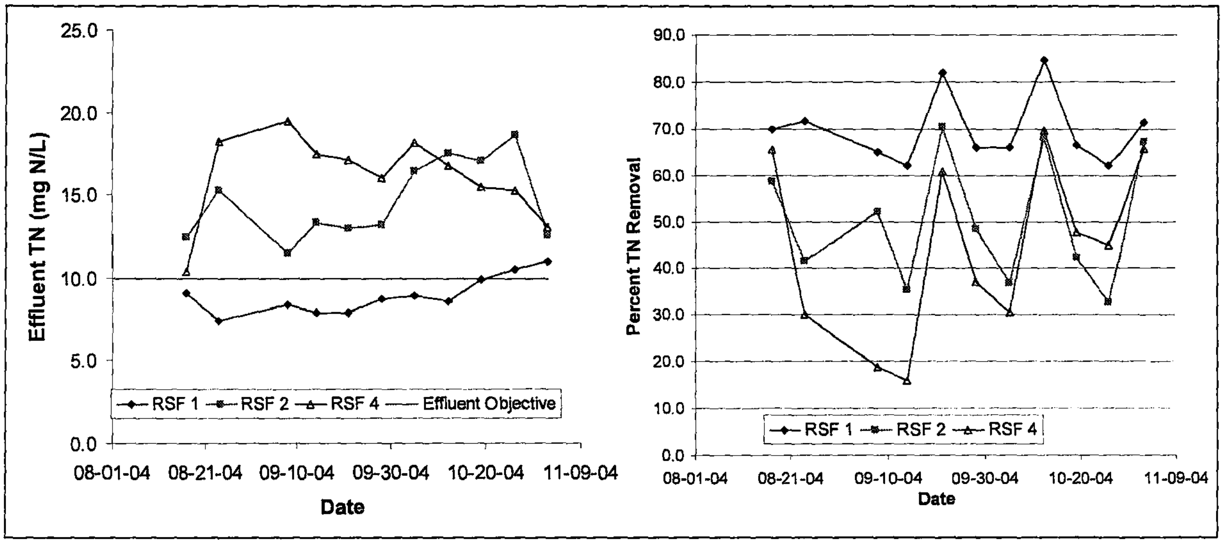


Figure 4-19. Phase 2: Effluent TN concentration and overall TN removal by RSFs

The effluent TP concentrations and overall TP removal achieved in this phase for all RSFs are shown in Figure 4-20. The TP reduction was similar to that achieved in Phase 1. The effluent TP was consistently higher than the effluent objective of 1.0 mg P/L. The average TP removal efficiency for all three RSFs was between 20% and 30%. Without coagulant addition, the RSFs do not have the ability to achieve the effluent objective. On several occasions, the TP effluent concentrations were higher than the raw sewage concentrations may be attributed to the grab sampling methodology, as it represents only a single event, and the TP concentration in the raw sewage is not consistent. On those occasions when the TP removal was high, it is more likely due to a very high TP concentration in the raw sewage.

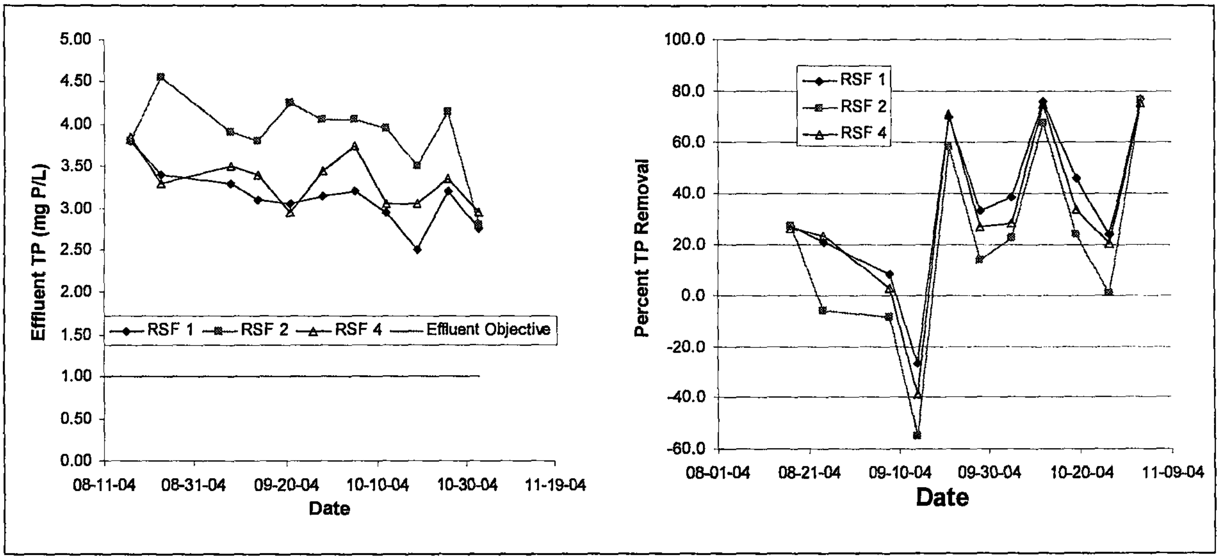


Figure 4-20. Phase 2: Effluent TP concentration and overall TP removal by RSFs.

The phase 2 effluent E.coli concentrations are presented in Figure 4-21. Data from sampling event on September 14, 2004 is missing due to the fact that E. coli tests were not conducted. RSF 1 had the best performance in terms of E. coli removal followed by

RSFs 2 and 4. The various performances of E. coli removal from each RSF can be attributed to dosing frequencies and media size. RSFs with a dosing frequency of 48 times/day require take 40 minutes to completely drain. Slow drainage likely minimizes the amount of air percolating through the filter. This may attribute to less E.coli being oxidized resulting in less E.coli removal for RSF 2 than that for RSF 1. Additionally, RSF 2 has smaller media, and therefore a larger surface area than RSF 4 with which grows more microbes, resulting superior performance.

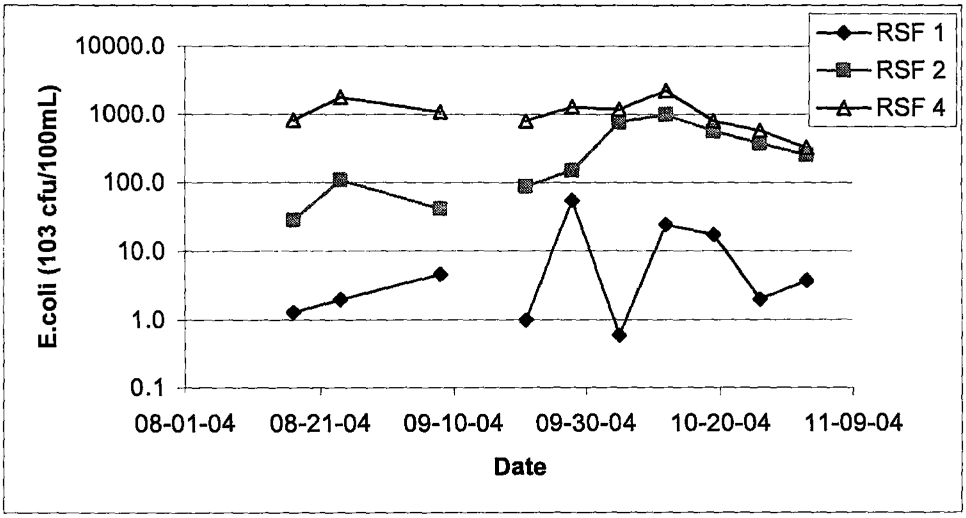


Figure 4-21. Phase 2: Effluent E.coli concentrations from RSFs 1, 2 and 4.

In summary, RSF 1 achieved the best treatment performance at all parameters followed by RSFs 2 and then 4. The results of this phase demonstrate that superior RSF performance is achieved with a dosing frequency of 24 times/day over 48 times/day. It was observed, RSF with a dosing frequency of 48 times/day required longer time to completely drain; this slow drainage likely minimized the amount of air percolating through the filter, which may attribute to the poorer performance than RSF with a dosing frequency of 24 times/day. Better performance was achieved by the RSF with smaller media under the higher hydraulic loading (0.4 m/day). Again, it is due to the fact of that the smaller media provide a larger surface that accumulates more microbes for sewage treatment.

4.2.3 Phase 3 Performance

The Phase 2 performance demonstrated that a dosing frequency of 24 times/day provided superior performance to a dosing frequency of 48 times/day. Therefore, in Phase 3, all three RSFs were operated under a dosing frequency of 24 times/day to evaluate the effect of temperature on RSF performance. The media in RSF 2 was replaced with d_{10}=5 mm gravel to evaluate the performance of this media size. The 7.7 mm (d_{10}) media in filter 4 was washed and return into the tank, and the media in filter 1 remained untouched from Phase 2 (See Table 3-2). NWRI (2005) observed that filters 2 and 4 did not drain well, which may have lead to anaerobic conditions in the filters during Phase 2. To mitigate this issue, NWRI modified the underdrain systems in filters 2 and 4 to incorporate three collection pipes prior to Phase 3. As a result of their observation of that some media were not accumulating biomass, NWRI also replaced the distribution pipes for RSF 2 with a distribution system having more pipes with downward facing orifices. Unfortunately, this modification resulted in freezing of the orifices due to drips sticking to the orifices and sewage pooling in the end of the pipe. As a result, the original distribution pipeline was reinstalled. The Grab sample methodology for collecting raw sewage samples was reinstated since the autosampler pump was frequently blocked with debris during cold weather.

The forward hydraulic loading and recycle ratio remained at 0.4 m/day and 500% respectively, for all RSFs. Alum addition was commenced to achieve the objective TP effluent criterion of less than 1 mg P/L. Alum was added to the raw sewage pipe in the main wet well using a peristaltic pump and a static mixer when the raw sewage pump was on. Phase 3 started on November 26, 2004 and ended on April 2, 2005. The purpose of Phase 3 was to assess the performance of the RSFs under cold weather condition, as well as the performance of 5 mm (d_{10}) media. This phase also assessed the removal of phosphorus with the addition of alum.

4.2.3.1 Phase 3 Ambient Temperature, Online Filter Temperatures and Flow

Clifford experienced an extremely cold winter in 2004. The Phase 3 ambient temperature and online filter temperatures are presented in Figure 4-22 and 4-23. In this period, the minimum ambient temperature was -31.1 °C, and the average monthly ambient temperature for December, January, February and March were -5.5 °C, -8.8 °C, -6.7 °C, -4.8 °C respectively. The online filter bed temperature data show an average decrease of approximately 7 °C from 9.8 °C to 2.7 °C, over this experimental period.

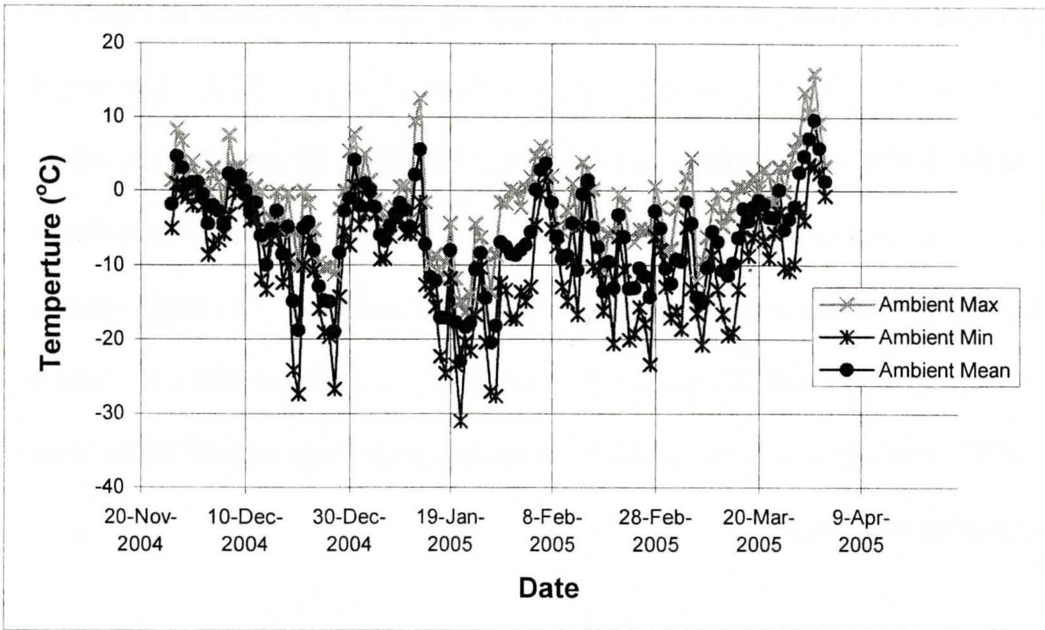


Figure 4-22. Phase 3: Ambient temperature.

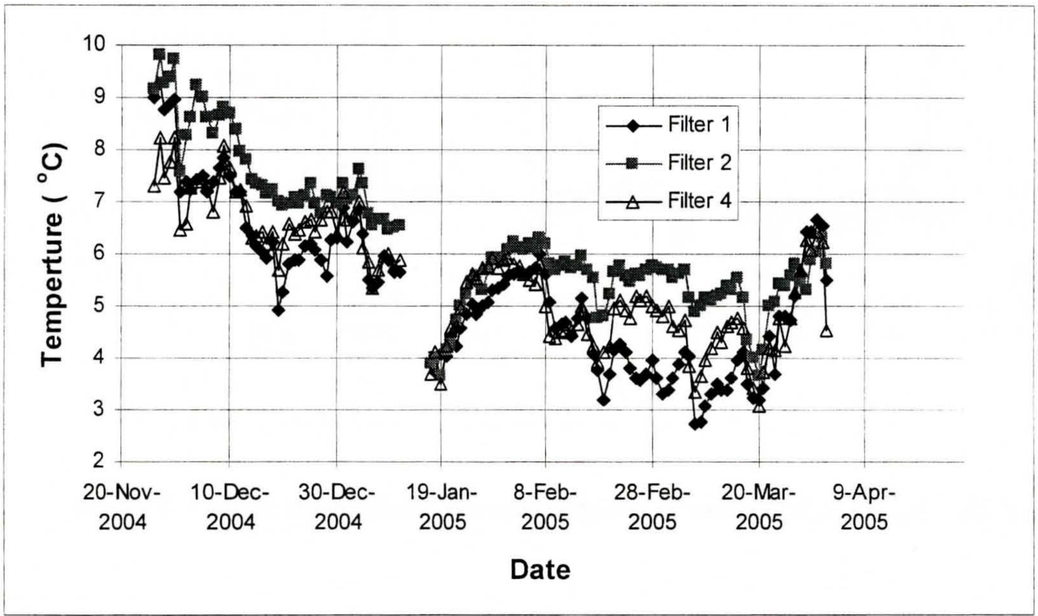


Figure 4-23. Phase 3: Online filter temperatures.

The daily RSF forward and total hydraulic loading rates are presented in Figure 4-24. The recycle ratios of RSFs 1, 2 and 4 are presented in Figure 4-25. The target influent hydraulic loading rate for RSFs was 0.4 m/day, however, the actual mean values were 0.4 m/day, 0.42 m/day and 0.41 m/day respectively. On several dates the influent flow was shut down for maintenances, these day flows were excluded. The target recycle ratio for all three RSFs was 500%, however, the actual recycle ratio for RSFs 1, 2 and 4 were 486%, 473% and 481%. Occasionally, those exceptionally high recycle ratios were due to debris fouling the pump.

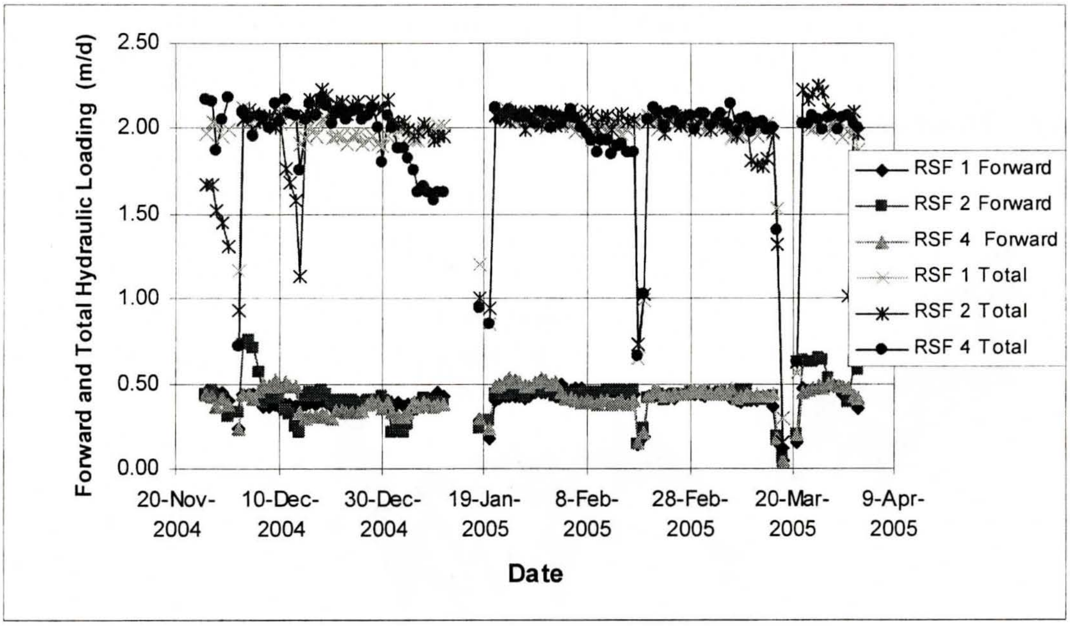


Figure 4-24. Phase 3: Summary of actual hydraulic loadings for RSFs 1, 2 and 4.

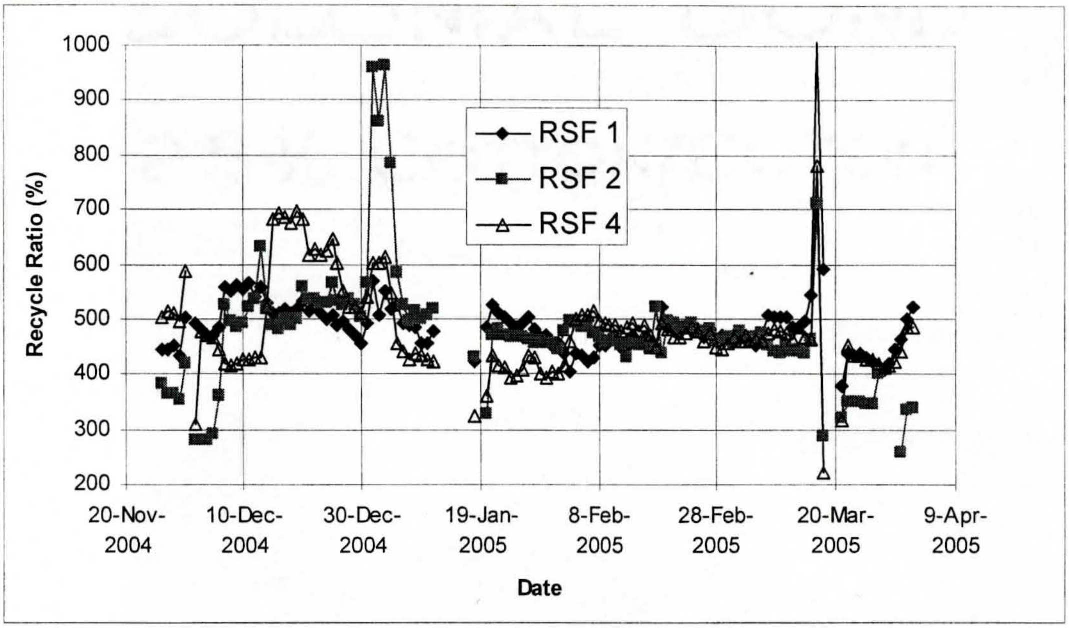


Figure 4-25. Phase 3: Actual recycle ratios for RSFs 1, 2 and 4.

4.2.3.2 Phase 3 Performance Results

Figure 4-26 shows operation of RSFs in winter.

Table 4-6 summarizes performance results from Phase 3. The data represent the average of all results collected throughout this phase. The RSF effluent parameters are presented as monthly averages of weekly samples in Table 4-7. The following paragraphs discuss each effluent parameter individually, and offer explanations for the differences observed between the three RSFs.

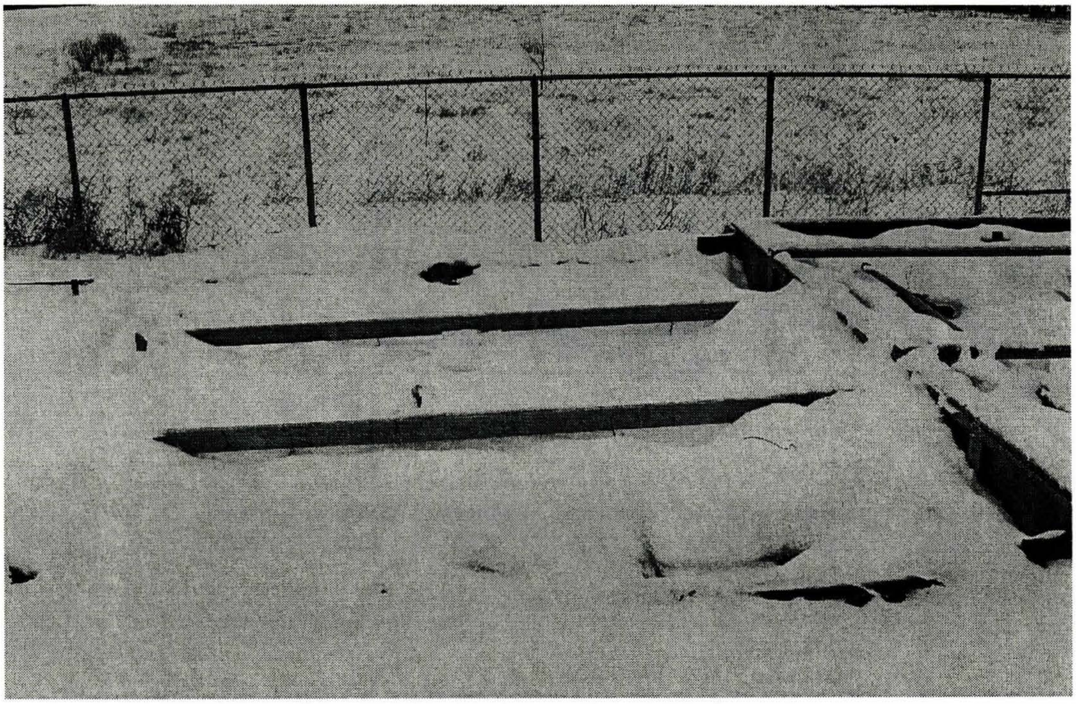


Figure 4-26. Snow and ice cover on the filters surface in during Phase 3.

Table 4-6. Phase 3 RSFs performance results (November, 2004 ~ March, 2005).

ITEM		RAW SEWAGE INFLUENT	PST EFFLUENT	SST 1 EFFLUENT	SST 2 EFFLUENT	SST 4 EFFLUENT	RSF 1 EFFLUENT	RSF 2 EFFLUENT	RSF 4 EFFLUENT
MEDIA SIZE (mm)							2.6	5	7.7
SEWAGE FLOWRATE (m/dayay)	DESIGN	1.2	1.2	2	2	2	0.4	0.4	0.4
	ACTUAL	1.23	1.23	1.94	1.92	1.93	0.40	0.42	0.41
RECYCLE RATIO (%)	DESIGN						500	500	500
	ACTUAL						486	474	481
Dosing Frequency (times/day)							48	48	48
TEMP (°C)		8.5	8.0	5.9	6.7	6.3	5.3	6.3	5.5
DO (mg/L O_2)		3.8	3.3	3.0	2.9	3.0	3.2	3.2	3.5
$cBOD_5$ (mg/L)		90.5	51.2	12.1	27.2	22.8	6.0	18.4	15.2
COD (mg/L)		314.6	146.1	63.6	102.2	88.7	35.4	81.9	70.8
TSS (mg/L)		194.9	49.5	21.1	38.8	35.5	14.5	37.6	32.1
TAN (mg N/L)		12.74	16.73	8.57	15.84	14.13	6.18	15.80	12.97
NO_2^- (mg N/L)		0.054	0.047	0.357	0.058	0.095	0.490	0.080	0.142
NO_3^- (mg N/L)		0.444	0.545	3.810	0.506	1.235	5.910	0.630	2.141
TN (mg N/L)		21.5	24.4	14.9	20.5	19.0	13.6	20.6	18.1
TP (mg P/L)		3.60	2.17	1.27	1.56	1.49	1.05	1.41	1.27
SO_4^{2-} (mg/L)		141.969	96.508	97.126	97.555	97.252	97.197	95.617	96.706
pH				6.69	6.83	6.86	6.82	7.01	7.07
CONDUCTIVITY (μs/cm)				1993	2021	1999	1924	1992	1949
ALKALINITY (mg $CaCO_3$/L)				284	320	308	268	315	300
E.coli (10^3cfu/100mL)				206	459	380	172	377	336

Table 4-7. Phase 3: RSF effluent parameters.

RSF	Month	cBOD5 (mg/L)	TSS (mg/L)	TAN (mg N/L)	TN (mg N/L)	TP (mg P/L)
RSF 1	Nov, 2004 (1)*	3.5	12.7	2.98	13.5	1.50
	Dec, 2004 (4)*	5.2	13.6	4.52	13.2	1.60
	Jan, 2005 (3)*	4.3	12.0	5.43	13.2	0.65
	Feb, 2005 (4)*	6.2	13.8	6.89	13.8	0.85
	Mar, 2005 (3)*	8.4	18.6	8.49	14.0	0.91
RSF 2	Nov, 2004 (1)*	17.5	19.2	14.90	18.6	1.10
	Dec, 2004 (4)*	21.5	59.0	17.03	21.3	2.20
	Jan, 2005 (3)*	15.3	26.3	15.87	20.2	0.97
	Feb, 2005 (4)*	16.4	32.3	15.43	21.1	1.18
	Mar, 2005 (3)*	20.6	33.6	14.90	20.3	1.19
RSF 4	Nov, 2004 (1)*	10.0	19.0	12.90	17.1	0.90
	Dec, 2004 (4)*	18.8	43.7	13.73	17.9	1.96
	Jan, 2005 (3)*	11.4	23.6	11.83	17.1	0.90
	Feb, 2005 (4)*	12.9	27.7	12.88	18.7	0.98
	Mar, 2005 (3)*	18.3	18.3	13.18	18.9	1.25

Note: 1. The effluent concentrations presented represent a monthly average based on weekly samples.

2. The shaded areas indicate effluent concentrations exceeding the MOE objective.

* This number indicates the number of sampling events incorporated into the average.

The overall $cBOD_5$ removal performance in Phase 3 was influenced by the addition of alum to the raw sewage. The average primary septic tank effluent $cBOD_5$ was only 51.2 mg/L whereas in phases 1 and it was 90.4 mg/L and 67.7 mg/L respectively. The Phase 3 effluent $cBOD_5$ and overall removal of $cBOD_5$ for all RSFs is presented in Figure 4-27. Generally, the effluent $cBOD_5$ from RSF 1 was lower than 10 mg/L. RSF 2 exceeded the effluent target throughout the entire phase, with a mean value of 18.4 mg/L. RSF 4 exceeded the effluent criteria on about half of the sampling occasions, with a mean value of 15.2 mg/L. The average overall removal of $cBOD_5$ for RSFs 1, 2 and 4 was 93.2%, 79.1% and 82.7% respectively.

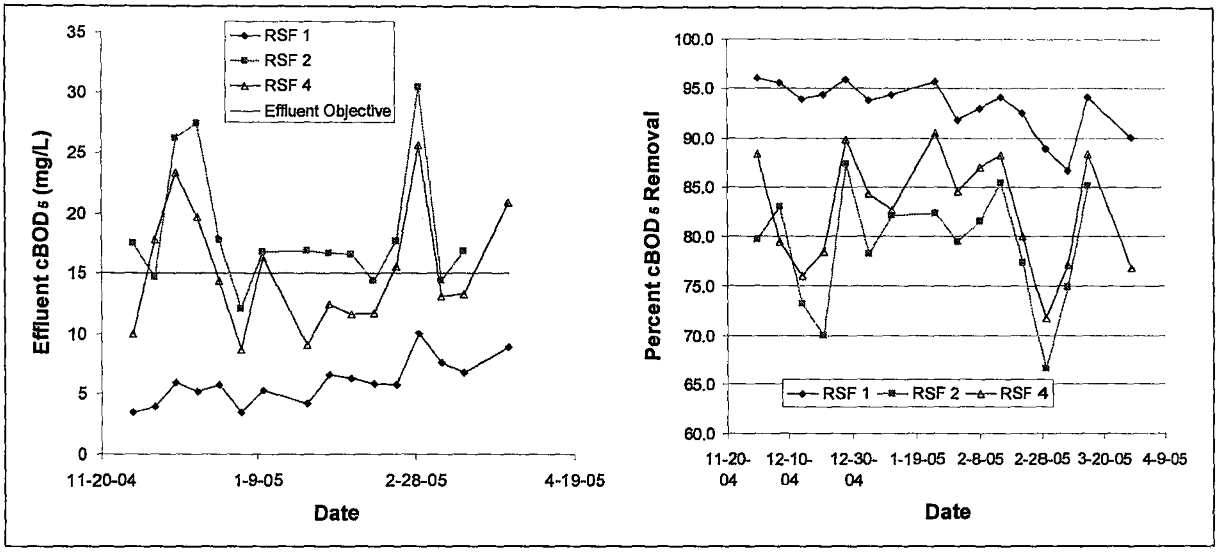


Figure 4-27. Phase 3: Effluent $cBOD_5$ concentration and overall $cBOD_5$ removal of RSFs.

The Effluent TSS concentrations and overall TSS removals by the RSFs in Phase 3 are presented in Figure 4-28. RSF 1 performed the best of the three RSFs, with the effluent TSS concentration meeting the objective in all months of this phase except for March 2005. The overall average TSS removal by RSF 1 declined to 92.2% in this phase. The effluent concentrations from RSFs 2 and 4 were consistently higher than the effluent target throughout this entire phase, with mean concentrations of 37.6 mg/L and 32.1 mg/L respectively. The overall average removal of TSS for RSFs 2 and 4 was 78.1% and 82.0% respectively. There was one occasion, December 14, 2004, when the TSS effluent concentrations from both RSF 2 and 4 were exceptionally high. On December 13, 2004, NWRI replaced the new dosing pipeline for RSF 2 with the original dosing pipe due to freezing of the orifices in the new dosing pipe. This resulted in some areas of filter 2 not being dosed and therefore freezing. This situation may have contributed to the scouring of solids from a particular zone of the filter, thereby resulting in higher effluent TSS concentrations in RSF 2. Adjustments to the filter 4 flow splitting tubes were also made on December 13, 2004, which likely upset the flowrate in the underdrain system of filter 4, resulting in the release of some solids. This likely caused the elevated TSS concentration in RSF 4.

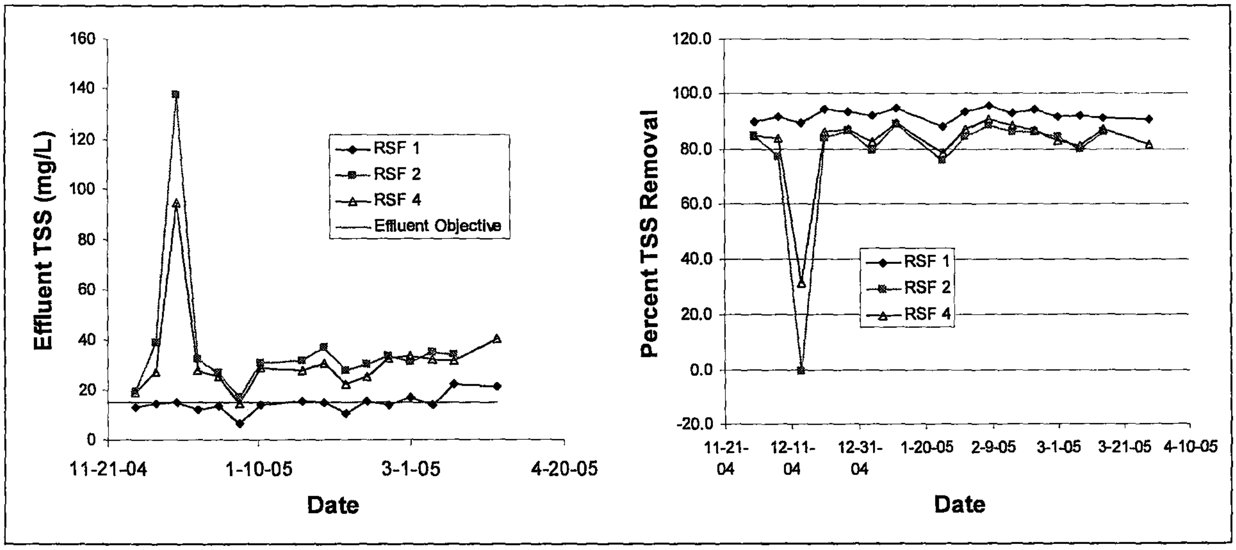


Figure 4-28. Phase 3: Effluent TSS concentration and overall TSS removal of RSFs.

The Phase 3 effluent nitrate and TAN concentrations from all RSFs are presented in Figure 4-29. Figure 4-29, together with Figure 4-23, clearly shows that as the temperature declined, the nitrification achieved by RSF 1 also declined. Since RSFs 2 and 4 only demonstrated weak nitrification throughout this phase, the temperature decline in Phase 3 had little effect on the nitrification performance of these RSFs. None of the three RSFs achieved the TAN effluent objective throughout Phase 3; however, RSF 1 did achieve the effluent objective in the first two months of this phase.

The average effluent TAN for RSFs 1, 2 and 4 were 6.18, 15.8 and 12.97 mg N/L respectively. The Phase 3 effluent TN concentration and overall TN reduction are presented in Figure 4-30. The effluent TN concentration from RSF 1, which ranged from 10 to 15 mg N/L (significantly higher than the previous two phases), demonstrates that temperature has a significant influence on the nitrification/denitrification process. The overall average TN removal by RSF 1 was 35.1 % in Phase 3, compared to 69.8% in Phase 2. RSF 2 removed little TN, with an average overall removal of 3.6%. RSF 4 achieved an overall TN removal of 13.2%.

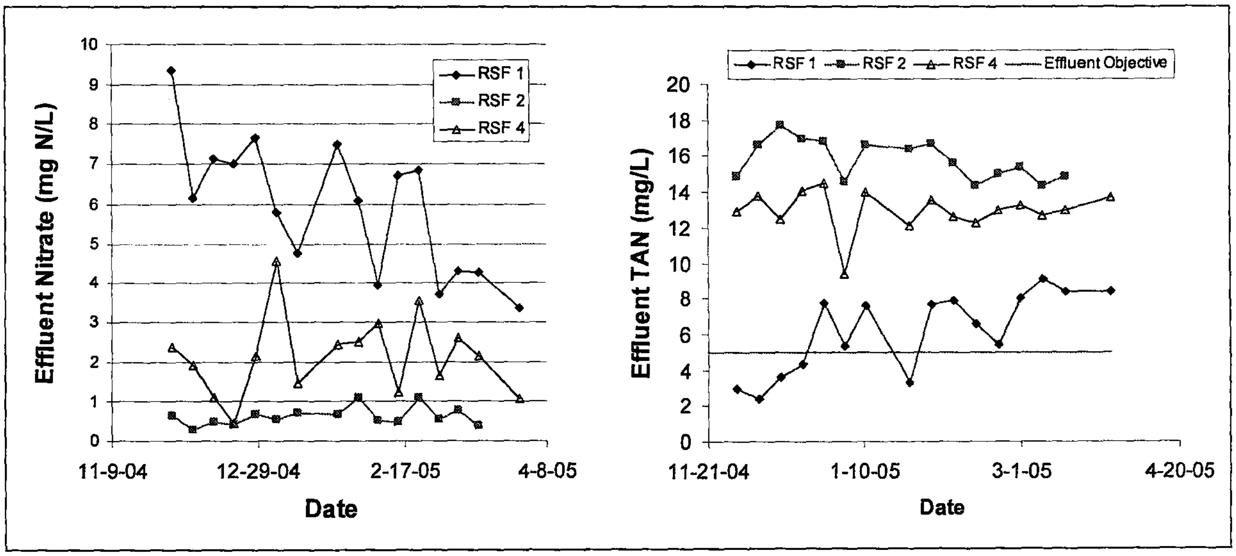


Figure 4-29. Phase 3: Nitrate and TAN concentration from RSFs 1, 2 and 4.

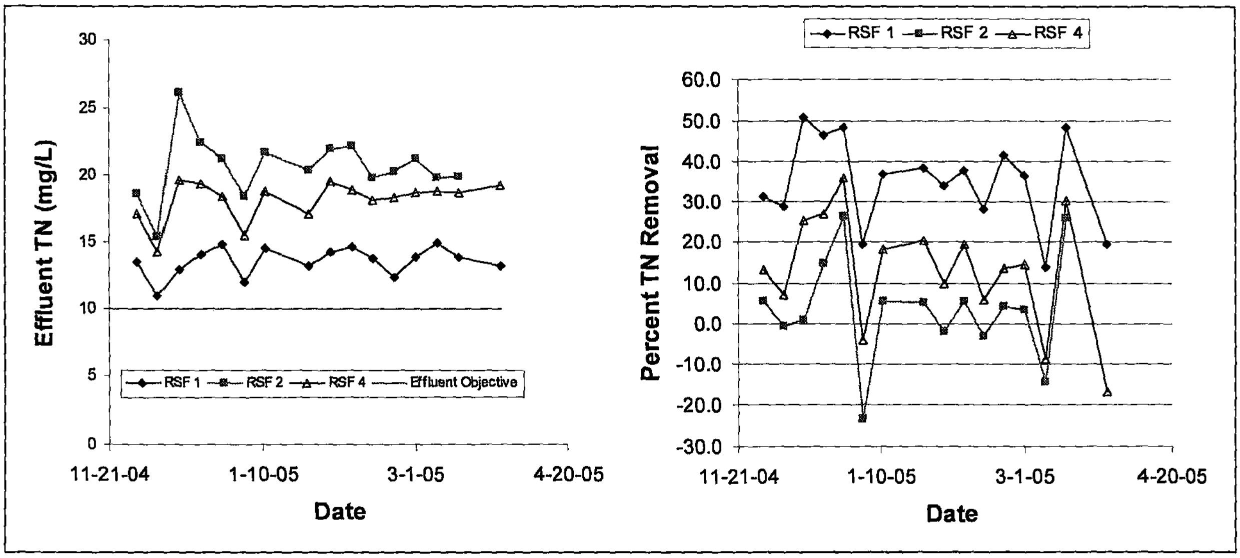


Figure 4-30. Phase 3: Effluent TN concentration and overall TN removal of RSFs.

The Phase 3 effluent TP concentration and overall TP removal from all three RSFs are presented in Figure 4-31. In this phase, with the addition of alum, the effluent TP concentration from all three RSFs was close to the effluent objective of 1.0 mg P/L. Alum addition, by a peristaltic pump, was implemented on November 25, 2004. The alum stock was a conventional 48% $Al_2(SO_4)_3 \cdot 14H_2O$ solution and the Al^{3+} dosage was approximately 7 mg Al^{3+} per liter of raw sewage. The alum pump malfunctioned on the next three sampling events, until it was replaced on December 26, 2004. Excluding data from the three occasions when the pump malfunctioned, the average effluent TP concentration for RSFs 1, 2 and 4 were 0.88, 1.13 and 1.0 mg P/L respectively. On March 1, 2005, the alum dosage was decreased to 5.3 mg Al^{3+} per liter of raw sewage. At this alum dosage, the average effluent TP concentration from RSFs 1, 2 and 4 were 0.83, 1.14 and 1.02 respectively. At the end of Phase 3, due to a mis-adjustment of the alum pump, the alum flowrate decreased causing the RSF effluent TP concentrations to increase.

Excluding the three pump malfunction occasions, and the mis-operation occasion, the average effluent TP concentrations from RSFs 1, 2 and 4 were 0.87, 1.13 and 1.00 mg P/L respectively, and the overall average removals were 75.8%, 68.7% and 72.5% respectively. RSFs 1 and 4 achieved the effluent criterion of 1.0 mg P/L, and RSF 2 is close to the criterion with the addition of alum.

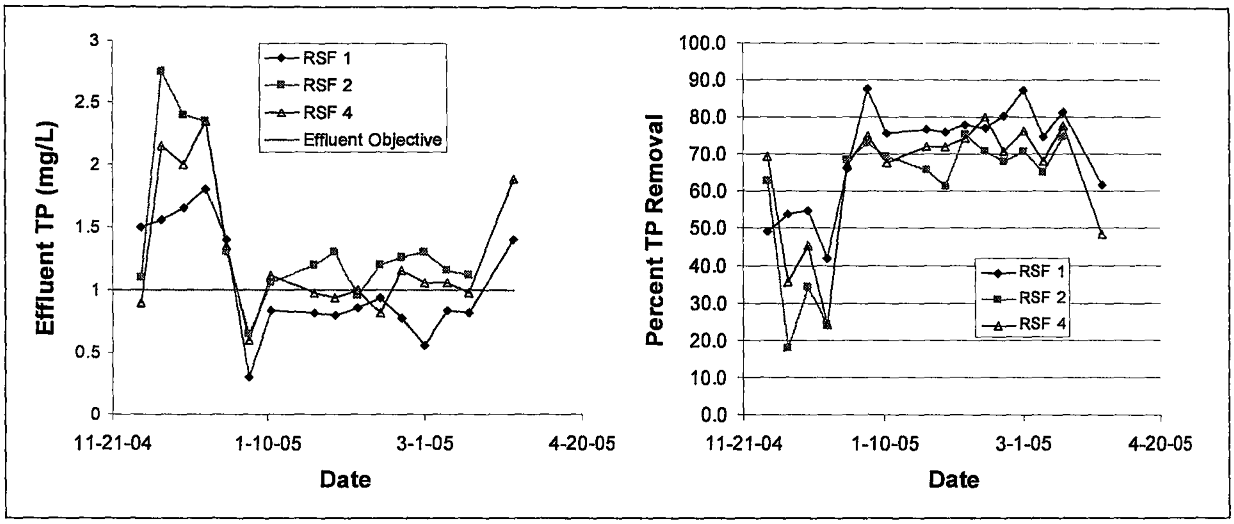


Figure 4-31. Phase 3: Effluent TP Concentration and Overall TP Removal of RSFs.

The phase 3 effluent E.coli concentrations from all three RSFs are presented in Figure 4-32. RSF 1 achieved the best performance in terms of E.coli removal. RSF 4 performed slightly better than RSF 2 due to the fact that the media in the filter 2 had not been given a chance to acclimatize prior to this phase, and therefore had not grown a consistent biofilm. The average effluent E.coli concentrations from RSFs 1, 2 and 4 were 172.4, 376.7 and 336.3×10^3 cfu/100 mL respectively. The difference in E.coli removal rates by the three RSFs was not as much as in previous phases, indicating that the various media sizes has a smaller impact on E.coli under cold weather conditions.

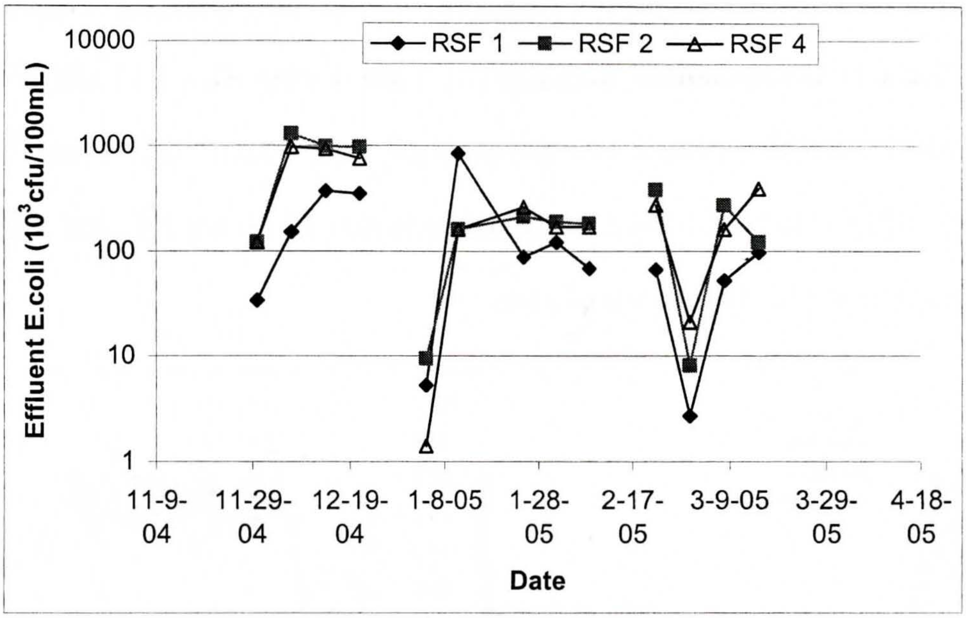


Figure 4-32. Phase 3: Effluent E.coli concentrations from RSFs 1, 2 and 4.

In summary, the results from this phase do not demonstrate adequate RSF performance under cold weather conditions. This result, however, is likely due to the fact that the media in two of the three filters was not properly acclimated prior to this phase. RSF 1 achieved the best performance followed by RSFs 4 and 2. The performance of all three RSFs was poorer throughout this phase than in previous phases, continued to decline with the temperature. RSF 1 achieved the effluent target for $cBOD_5$ and exceeded the effluent criteria for all other parameters (TSS, TAN, TN and TP) measured in this study for part of all of this phase. At the end of this phase, there was some ponding on the surface of RSF 1, however, the ponding disappeared in 1 minute and the DO in the filter effluent was over 3 mg/L, indicating that the ponding did not lead to anaerobic condition; RSFs 2 and 4 failed to achieve all of the effluent criteria throughout the majority of Phase 3. RSF 4, however, with 7.7 mm (d_{10}) media, achieved better performance than RSF 2 with 5 mm (d_{10}) media (all other operating parameters were identical). This is counter intuitive, however it may be attributed to the fact that although the media in filter 4 was washed prior to Phase 3, some microbes remained on the surface of the grains, whereas the 5 mm media in filter 2 were brand new. Under cold weather conditions, filter 2 was not able to acclimatize a steady population of microbes on the surface of its media. With the addition of alum, the effluent TP concentration met the effluent criteria in part of Phase 3. The alkalinity in the effluents of filters was not significantly depleted by the addition of alum since the sewage in this plant is high in alkalinity.

4.2.4 Phase 4 Performance

Because the biomass likely did not acclimate in filters 2 and 4 during Phase 3, all RSFs continued running under the same operating conditions in Phase 4 as they did in Phase 3 in order to further investigate the performance of the RSFs under these conditions (See Table 3-2). Phase 4 started on April 3, 2005 and ended on June 28, 2005. In this phase, the ponding on the surface of filter 1 became more serious. Although this situation in filter 1 improved after raking the surface, the improvement only lasted for two weeks. It was found that that the media in the filter 1 was infested with earth worms, suggesting that a heavy build up of organic material within the filter caused the ponding. RSF 1 ceased operation on June 7, 2005. NWRI dug out and washed the media, and modified the underdrain system to match that of filters 2 and 4. Filter 1 did not resume operation until the end of Phase 4. The 24 hour composite sampler was employed to collect the raw sewage samples throughout this phase.

4.2.4.1 Phase 4 Air Temperature, Online Filter Temperatures and Flow

The Phase 4 ambient temperature and online filter temperatures are presented in Figure 4-33 and 4-34 respectively. The average ambient temperature was 12.16 °C, and the online filter temperature data show an increase of approximately 15 °C, from 5 °C to 20 °C, over this experimental period.

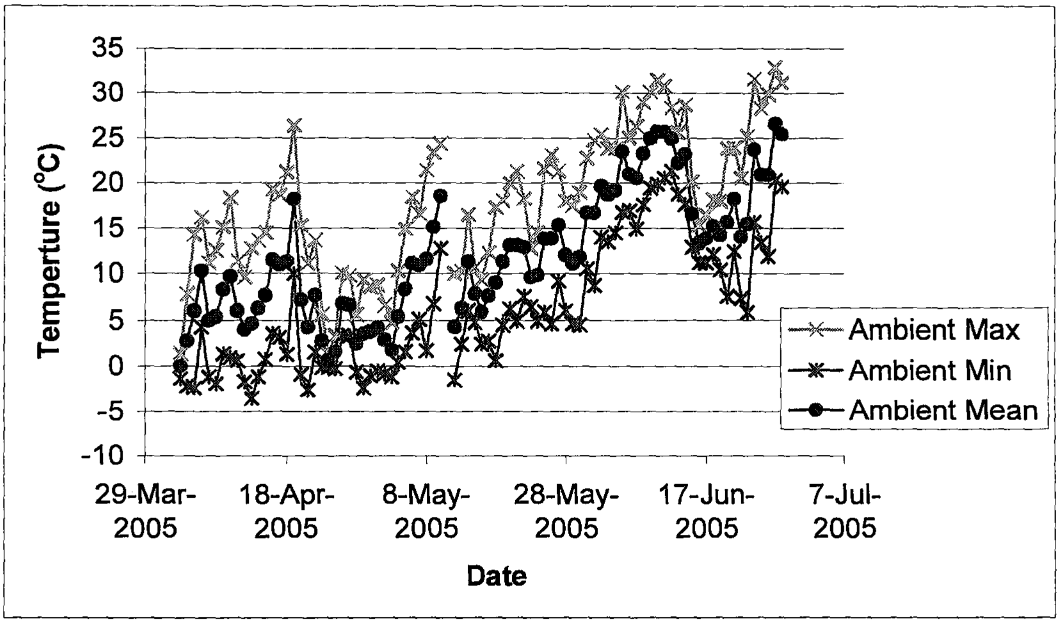


Figure 4-33. Phase 4: Ambient Temperature.

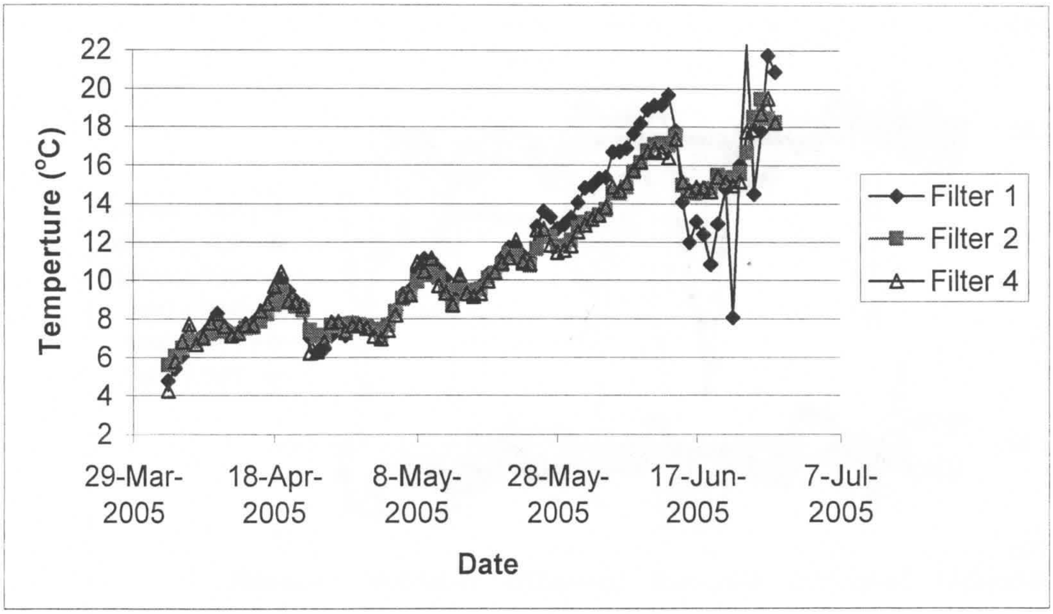


Figure 4-34. Phase 4: Online Filter Temperatures.

The daily filter forward and total hydraulic loading rates are presented in Figure 4-35. The RSF recycle ratios are presented in Figure 4-36. The design influent hydraulic loading rate for all RSFs was 0.4 m/day, and the actual average values were 0.42 m/day, 0.44 m/day and 0.45 m/day for RSFs 1, 2 and 4 respectively. On several dates the influent flow was shut down for maintenance; these day flows were excluded. The average recycle ratios for RSFs 1, 2 and 4 were 486%, 473% and 481%. Occasionally, those exceptional high recycle ratios were due to the debris fouling the pump.

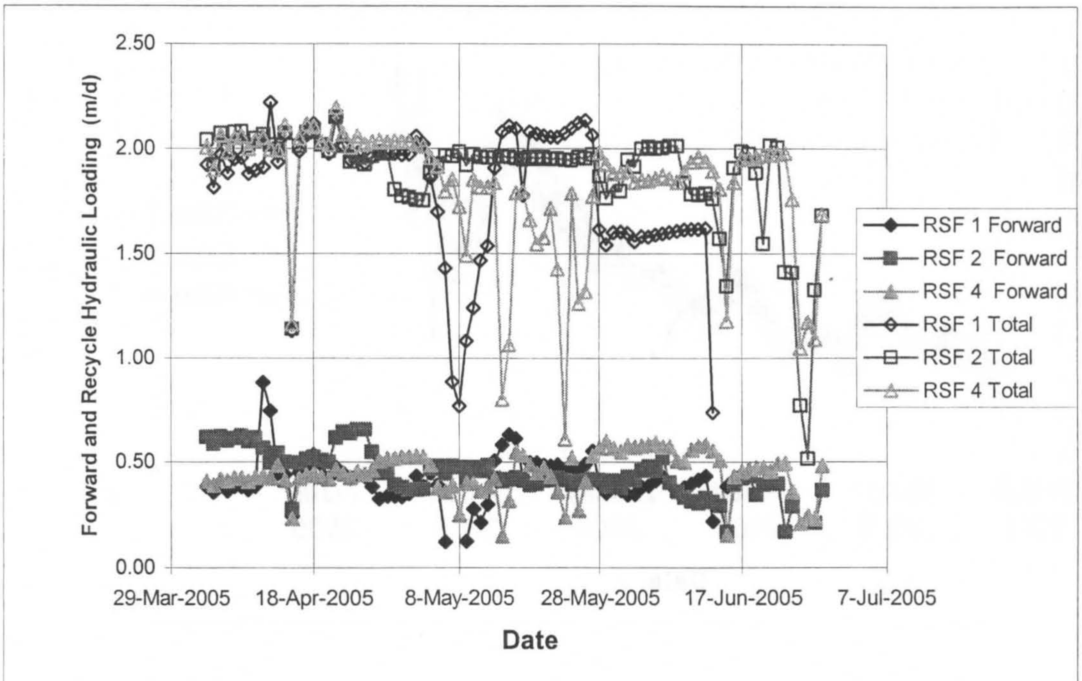


Figure 4-35. Phase 4: Summary of the actual hydraulic loadings for RSFs 1, 2 and 4.

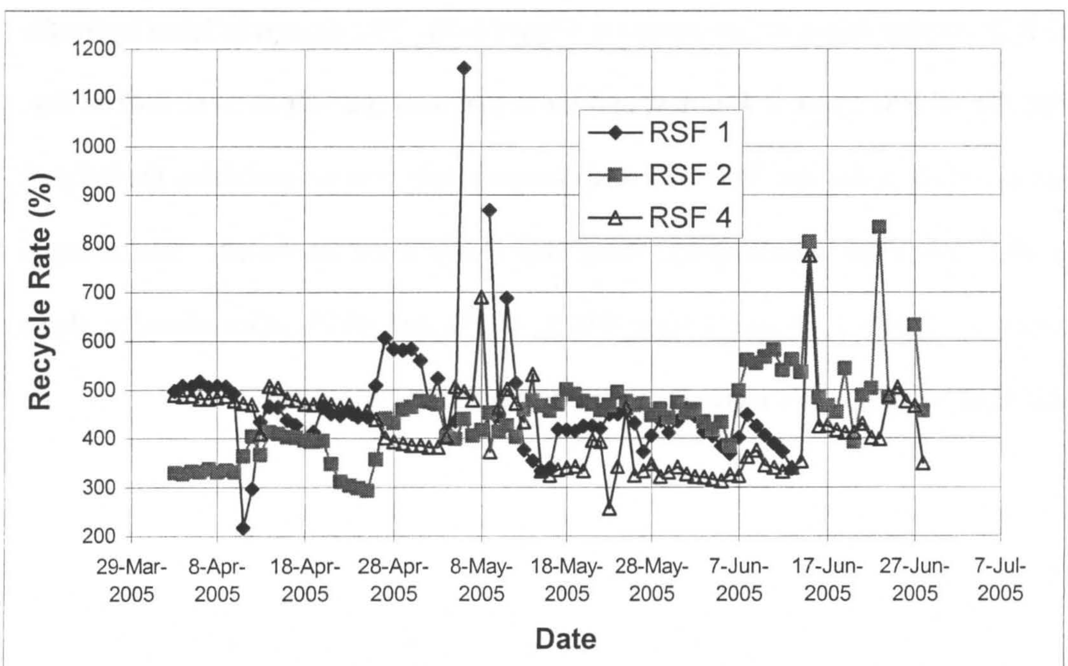


Figure 4-36. Phase 4: Actual recycle ratios for RSFs 1, 2 and 4.

4.2.4.2 Phase 4 Performance Results

Table 4-8 summarized the performance results from Phase 4. The data presented represent the average of all samples collected throughout this phase. The effluent quality parameters are presented as monthly averages of weekly samples in Table 4-9. The following paragraphs discuss each effluent parameter individually, and offer explanations for the differences observed between the three RSFs.

Table 4-8. Phase 4 RSFs performance results (April 2005 ~ June 2005).

ITEM		RAW SEWAGE INFLUENT	PST EFFLUENT	SST 1 EFFLUENT	SST 2 EFFLUENT	SST 4 EFFLUENT	RSF 1 EFFLUENT	RSF 2 EFFLUENT	RSF 4 EFFLUENT
MEDIA SIZE (mm)							2.6	5	7.7
SEWAGE FLOWRATE (m/day)	DESIGN	1.2	1.2	2	2	2	0.4	0.4	0.4
	ACTUAL	1.31	1.31	1.80	1.87	1.82	0.42	0.44	0.45
RECYCLE RATIO (%)	DESIGN						500	500	500
	ACTUAL						461	446	418
Dosing Frequency (times/day)							48	48	48
TEMP (°C)		11.0	9.4	9.2	9.8	9.8	9.3	10.9	11.0
DO (mg/L O_2)		5.6	3.0	2.7	2.0	2.0	3.8	3.7	3.7
$cBOD_5$ (mg/L)		71.9	52.7	13.9	20.0	19.5	4.0	10.4	9.8
COD (mg/L)		272.7	134.2	53.0	79.3	76.6	31.3	53.9	49.9
TSS (mg/L)		127.3	36.1	17.8	29.3	24.9	9.9	20.2	16.4
TAN (mg N/L)		15.57	18.12	8.06	11.43	11.25	4.95	9.49	9.30
NO_2^- (mg N/L)		0.093	0.062	0.250	0.199	0.179	0.351	0.227	0.186
NO_3^- (mg N/L)		0.292	0.278	2.111	0.772	1.257	4.672	2.365	3.011
TN (mg N/L)		27.2	25.2	12.8	16.3	16.1	10.6	15.1	14.1
TP (mg P/L)		4.33	1.74	0.93	1.12	1.01	0.71	0.83	0.68
SO_4^{2-} (mg/L)		54.592	89.502	86.966	88.216	87.964	86.894	87.424	87.754
pH				7.07	7.20	7.22	7.20	7.34	7.37
CONDUCTIVITY (μs/cm)				1590	1710	1630	1530	1660	1580
ALKALINITY (mg $CaCO_3$/L)				274	301	298	253	300	290
E.coli (10^3cfu/100mL)				56	130	90	11	110	74

Table 4-9. Phase 4: RSF effluent parameters.

RSF	Month	$cBOD_5$ (mg/L)	TSS (mg/L)	TAN (mg N/L)	TN (mg N/L)	TP (mg P/L)
RSF 1	Apr, 2005 (4)*	4.4	9.4	5.83	12.1	0.66
	May, 2005 (5)*	3.6	9.8	4.11	9.5	0.66
	Jun, 2005 (1)*	4.5	12.6	5.65	9.7	1.12
RSF 2	Apr, 2005 (4)*	13.8	28.1	12.95	18.4	1.08
	May, 2005 (5)*	9.4	16.0	9.46	15.8	0.69
	Jun, 2005 (4)*	9.1	17.6	6.06	11.0	0.75
RSF 4	Apr, 2005 (4)*	11.1	19.0	11.10	16.5	0.77
	May, 2005 (4)*	9.9	16.2	8.99	14.0	0.6
	Jun, 2005 (4)*	8.9	14.0	7.81	11.9	0.63

Note: 1. The effluent concentrations presented represent a monthly average based on weekly samples.

2. The shaded areas indicate effluent concentrations exceeding the MOE objective.

* This number indicates the number of sampling events incorporated into the average.

The phase 4 effluent $cBOD_5$ concentrations and overall removals of $cBOD_5$ for all RSFs are presented in Figure 4-37. As shown in Table 4-9, all three RSFs achieved the effluent objective for $cBOD_5$ throughout this experimental phase. The average $cBOD_5$ effluent concentrations were 4.0, 10.4 and 9.8 mg/L for RSFs 1, 2 and 4 respectively. All RSFs achieved better performance with the higher filter temperature except RSF 1. This may attributed to the ponding issue experienced by this filter. The performance of RSF 2 exceeded that of RSF 4 over time, indicating that the filter was continuing to develop a mature biofilm over this period. The average overall removal of $cBOD_5$ for RSFs 1, 2 and 4 was 93.2%, 84.0% and 84.3% respectively.

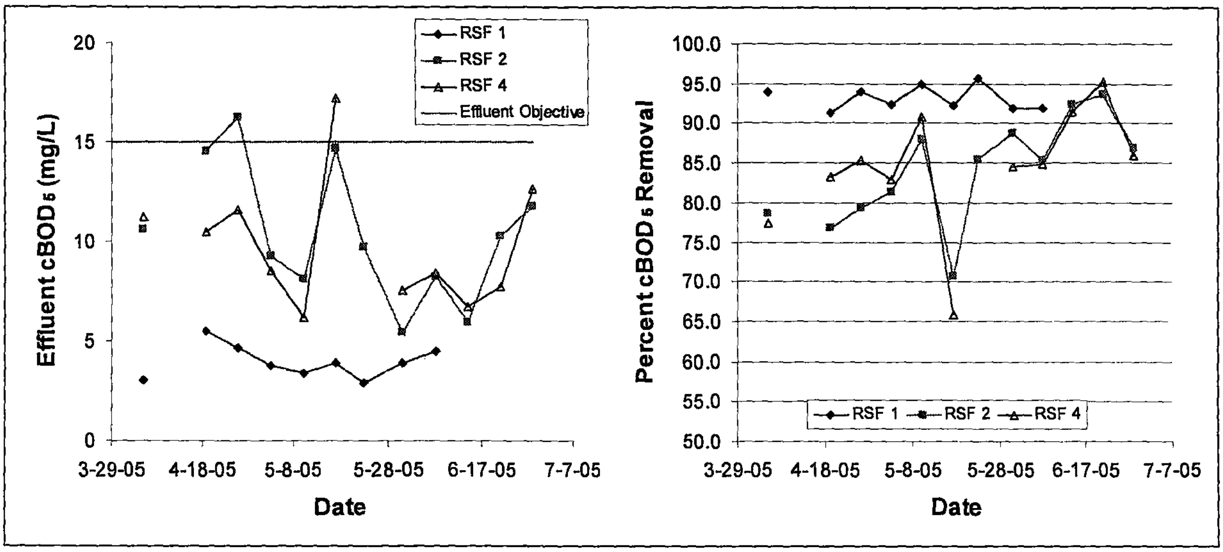


Figure 4-37. Phase 4: Effluent $cBOD_5$ concentration and overall $cBOD_5$ removal of RSFs

The effluent TSS concentration and overall TSS removal from all three RSFs in Phase 4 are presented in Figure 4-38. RSF 1 achieved the best performance in terms of TSS, meeting the effluent criteria with an average concentration of 9.9 mg/L. The performance deteriorated towards the end of this phase due to the ponding issue. The overall average TSS removal by RSF 1 was 91.3%. The effluent TSS concentration of RSF 2 was much higher than that of RSF 4 at the beginning of this phase, but approach to the performance of RSF 4 over time. As shown in Table 4-9, the RSF 2 effluent TSS concentration did not meet the effluent criteria over the entire experimental period; RSF 4 also exceeded the effluent TSS criteria until the last month of the experimental period. The effluent TSS concentrations from RSFs 2 and 4 were close to the effluent criteria in May and June, 2005, indicating that the increase in temperature encouraged the microbes to become more active, enabling these two RSFs to perform better in terms of TSS removal. The overall average TSS removal of RSF 2 and 4 was 82.9% and 86.2% respectively.

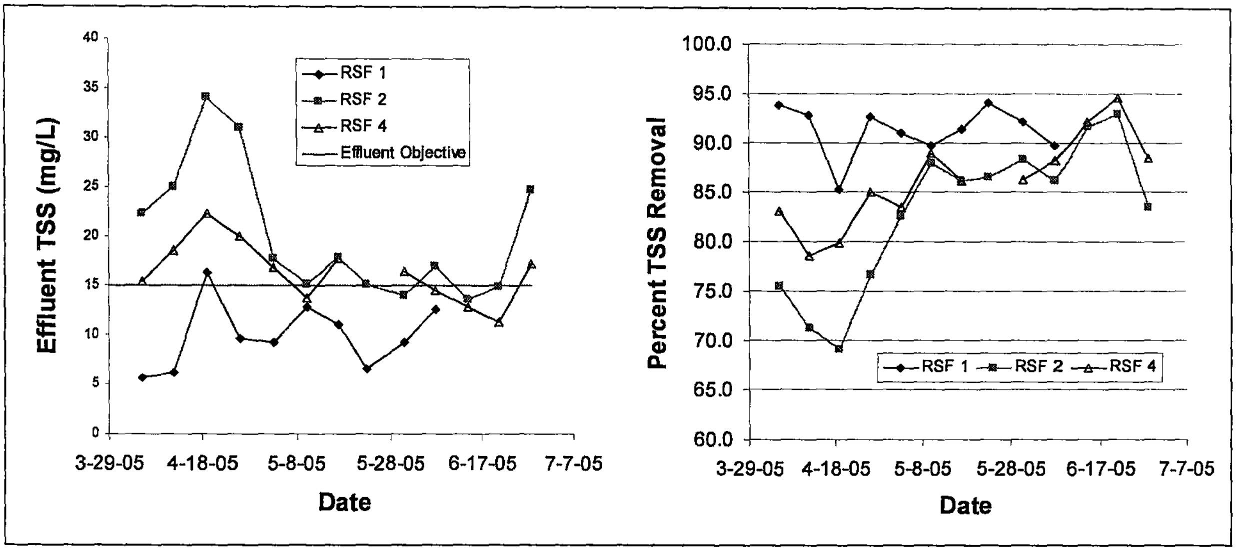


Figure 4-38. Phase 4: Effluent TSS concentration and overall TSS removal of RSFs.

The Phase 4 effluent nitrate and TAN concentrations from all three RSFs are presented in Figure 4-39. As shown in Table 4-9, the effluent TAN concentration from RSF 1 exceeded the effluent objective throughout this phase except in the second month, due to the ponding problem which lead to a deterioration of the filter's nitrification capacity. Neither RSFs 2 nor 4 achieved the effluent target throughout this phase; however, their performance approached the target as the temperature increased. As shown in Table 4-9, RSF 2 did perform better than RSF 4 in terms of effluent TAN as the temperature increased, which further demonstrates the fact that RSF 2 acclimated over time in the warmer temperatures. The average effluent TAN concentrations from RSFs 1, 2 and 4 were 4.95, 9.49 and 9.3 mg N/L respectively.

The Phase 4 effluent TN concentrations and overall TN reduction from all three RSFs are presented in Figure 4-40. The average effluent TN concentrations from for RSFs 1, 2 and 4 were 10.6, 15.1 and 14.1 mg N/L respectively. The effluent TN concentration from RSF 1 exceeded the effluent objective in the first month of this phase, but did achieve the objective in later months as the temperature increased. RSFs 2 and 4 did not achieve the TN effluent objective throughout this phase; however, they did perform better as the temperature increased, and RSF 2 out performed RSF 4 by the end of this phase. The overall average TN removal for RSFs 1, 2 and 4 was 56.2 %, 40.4% and 43.7% respectively.

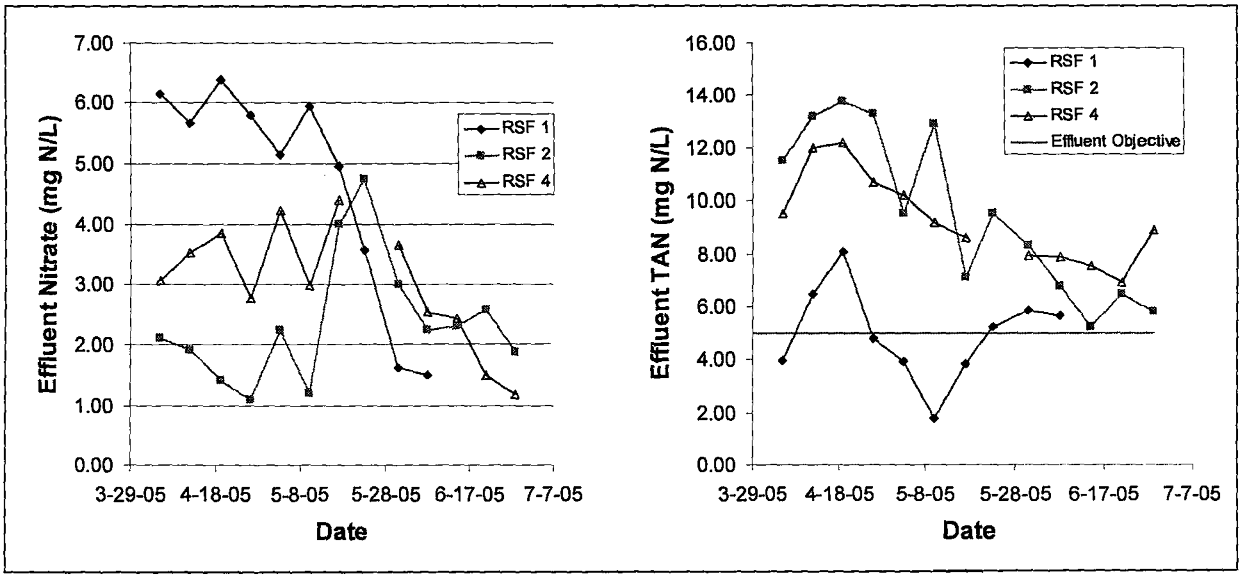


Figure 4-39. Phase 4: Nitrate and TAN effluent concentration from RSFs 1, 2 and 4.

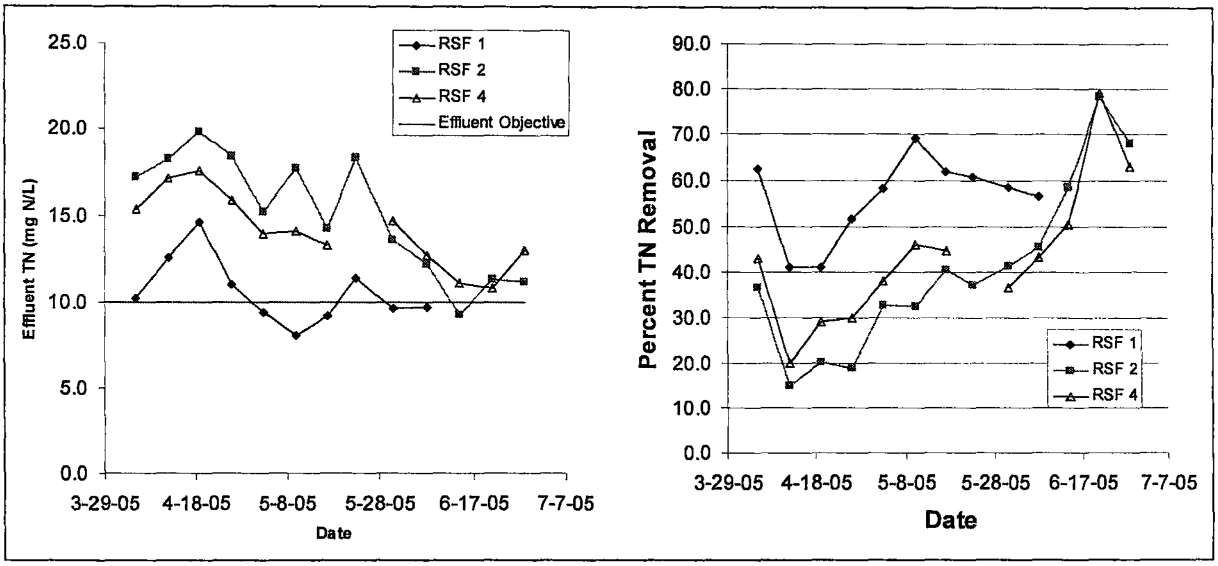


Figure 4-40. Phase 4: Effluent TN concentration and overall TN Removal of RSFs.

The Phase 4 effluent TP concentration and overall TP removal for all three RSFs are presented in Figure 4-41. In phase 4, alum was added at a concentration of approximately 7 mg Al^{3+} per liter of raw sewage. With the addition of alum, as shown in Table 4-9, the effluent TP concentration generally met the effluent objective for all three RSFs, with the exception of the last month for RSF 1 and the first month for RSF 2. The exceedences were likely due to the ponding issue for filter 1 and the acclimation issue for filter 2. The average effluent TP concentration for RSFs 1, 2 and 4 was 0.71, 0.83 and 0.68 mg P/L respectively. The overall average TP removal for RSFs 1, 2 and 4 was 81.9%, 79.9% and 83.6% respectively.

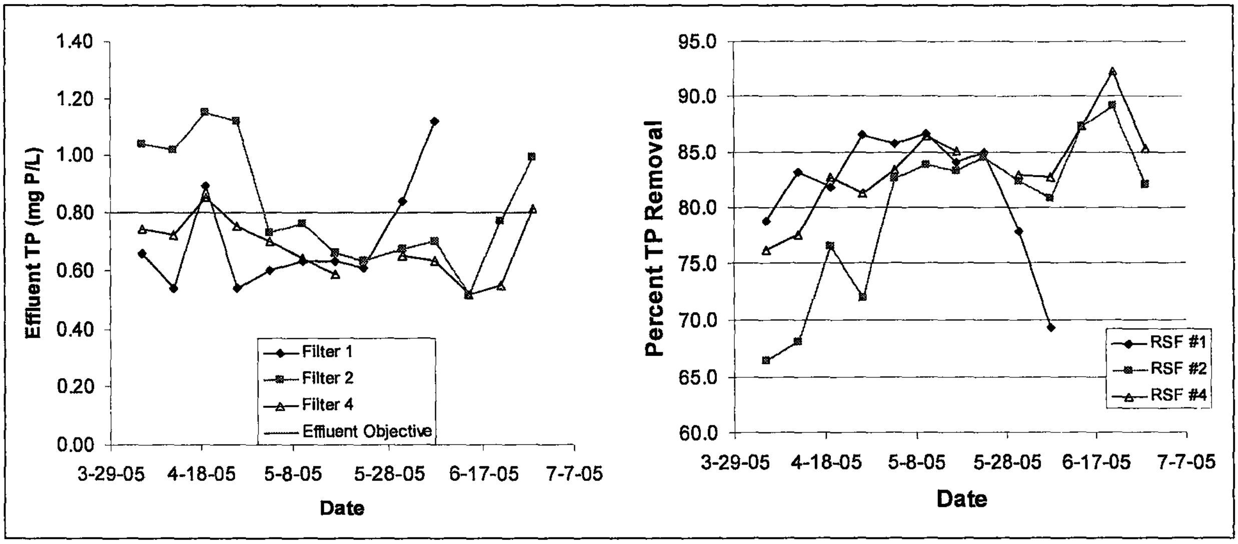


Figure 4-41. Phase 4: Effluent TP concentration and overall TP removal of RSFs.

The phase 4 effluent E.coli concentrations from all three RSFs are presented in Figure 4-42. RSF 1 maintained the best performance in terms of E.coli removal in this phase. The average effluent E.coli concentrations from RSFs 1, 2 and 4 were 43, 142 and 97×10^3 cfu/100mL respectively. The performance of RSF 2 was better than that of RSF 4 in terms of E.coli removal near the end of this phase, again likely due to the acclimation of filter 2 over the course of this phase.

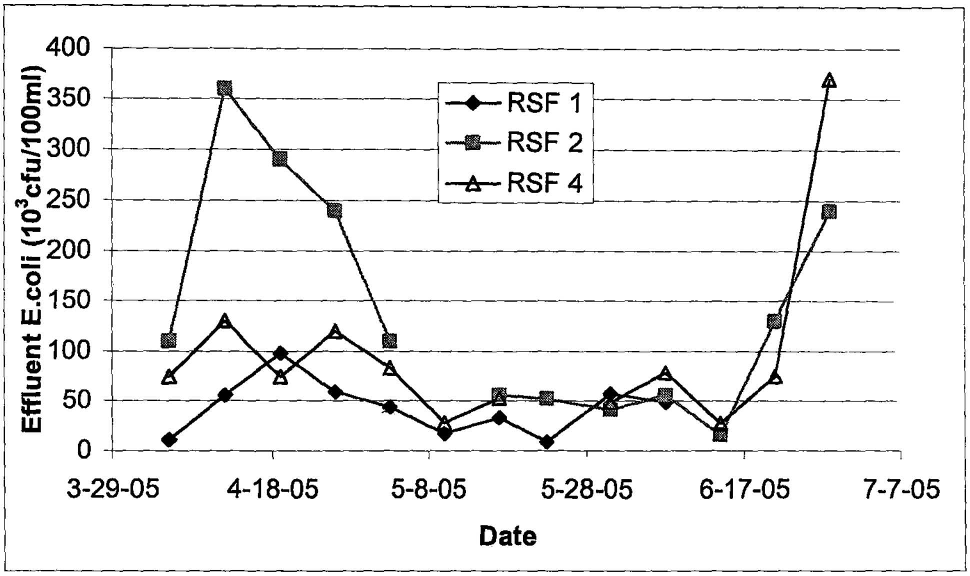


Figure 4-42. Phase 4 Effluent E.coli concentrations from RSFs 1, 2 and 4.

In summary, RSF 1 satisfied the effluent criteria most of the time, although it continued to experience a ponding problem throughout this phase. RSF 1 performed worse in Phase 4 than it did in Phase 2, in which it was operating under similar conditions and temperatures. This was likely due to the ponding issue. RSF 2 performed better than RSF 4 over time and with increasing temperatures, demonstrating the steady acclimation of biomass in filter 2. The alkalinity in the filter effluent was not significantly depleted by nitrification or the addition of alum, as raw sewage in this pilot plant contains high levels of alkalinity.

4.3 Coagulation Study

The purpose of this study was to optimize the coagulant application conditions for the influent loading on the RSFs. Jar tests were conducted during Phase 2 to analyze the concentration of total phosphorus (TP), total soluble phosphorus (TPf), and total suspended solids (TSS) in the sewage with the addition of alum. The raw sewage employed for these tests was collected from the Clifford wastewater treatment plant on October 19 and October 26, 2004. The results of these experiments are presented in Table 4-10.

Table 4-10. Jar test results.

Date	Alum dosage (mg Al^{3+}/L)	TP (mg P/L)	TPf (mg P/L)	TSS (mg/L)
October 19, 2004	0	3.5	1.85	120
	1	2.25	1.7	34
	2	1.9	1.45	29.9
	3	1.8	1.05	26.2
	4	1.3	0.78	23.6
	5	0.86	0.68	21.8
	6	0.82	0.44	20.2
	7	0.66	0.42	18.3
	8	0.6	0.4	17.2
	9	0.47	0.37	16.4
	10	0.42	0.36	15.6
October 26, 2004	0	3.45	2.35	108.4
	3	2.2	1.38	25.8
	3.5	1.82	1.1	23.9
	4	1.52	0.9	21.4
	4.5	1.48	0.72	23.8
	5	1.18	0.66	18
	5.5	1.08	0.62	17.1
	6	0.86	0.62	13.4
	6.5	0.84	0.45	12.1
	7	0.69	0.45	14.2
	7.5	0.59	0.38	12.2
	8	0.46	0.39	11.8
	8.5	0.5	0.39	14.1

A non-linear regression analysis was performed on the results of jar tests using an exponential decay function, giving:

$$TP / TP_0 = 1.00 * \exp[-0.69 * (Al^{3+} / TP_0)] - 0.039 \quad (4\text{-}1)$$

where: TP = the residual concentration of total phosphorus (mg P/L)

TP_0 = the initial concentration of total phosphorus (mg P/L)

Al^{3+} = the aluminum dosage (mg Al/L)

and $$TPf / TPf_0 = 0.98 * \exp[-0.58 * (Al^{3+} / TPf_0)] + 0.080 \quad (4\text{-}2)$$

where: TPf = the residual concentration of soluble phosphorus (mg P/L)

TPf_0 = the initial concentration of soluble phosphorus (mg P/L)

Al^{3+} = the aluminum dosage (mg Al/L)

The fitted models are presented in Figures 4-43 and 4-44. The historic data from Clifford wastewater treatment plant indicated the TP concentration in the raw sewage is about 5 mg P/L. To achieve the effluent TP concentration of 1.0 mg P/L, (4-1) indicates that the addition of alum is approximately 10 mg/L per liter raw sewage. (4-2) predicts that an Al^{3+} dosage of four times the initial soluble phosphorus concentration will remove approximately 82% of the soluble phosphorus. Previous research (Eastwood and Murphy 1996) has shown that alum addition at a concentration of four times the initial soluble phosphorus will remove approximately 90% of the soluble phosphorus. The current results differ slightly from the previous research, however, coagulation is influenced by factors such as pH, temperature, alkalinity, turbidity and agitation. Therefore, the results of the present work are still reasonable.

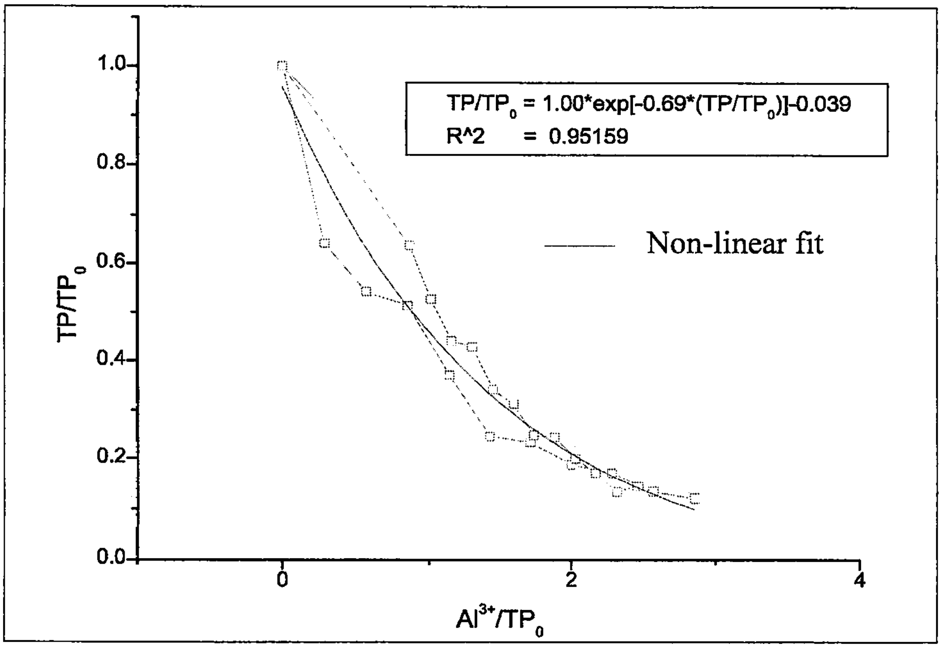


Figure 4-43. Residual concentration of total phosphorus with the addition of alum.

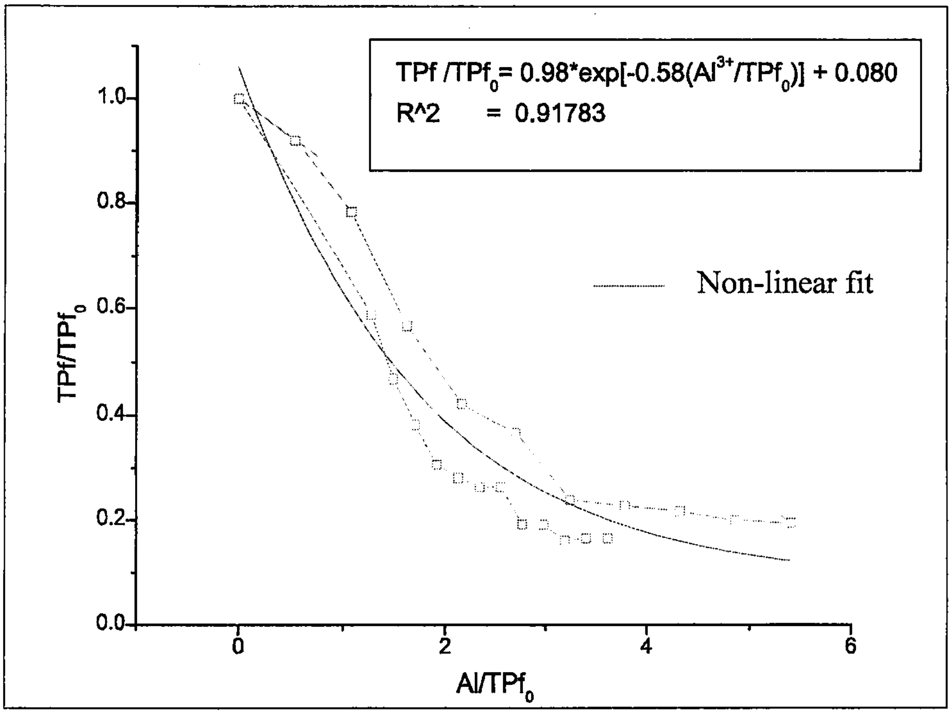


Figure 4-44. Residual concentration of soluble phosphorus with the addition of alum.

4.4 Discussion

The Wilcoxon Rank-Sum test was employed to determine whether the results of the various operating conditions from the three RSFs and four phases were statistically different. This nonparametric method was chosen due to the small sample sizes and non-normal distributions of the experimental results. 95% confidence levels were used for all comparisons.

4.4.1 The Effect of Recycle Ratio on RSF Performance

The effect of recycle ratio was evaluated in Phase 1 for RSFs 1 and 2 with 2.6 mm (d_{10}) sand, a dosing frequency of 48 times/day and an influent hydraulic loading of 0.2 m/day. The recycle ratios were 300% and 500% for RSFs 1 and 2 respectively. The effect of recycle ratio on performance is presented in Table 4-11. The $cBOD_5$, TAN and TN concentrations were statistically significantly lower when the recycle ratio increased from 300% to 500%. The TSS and TP concentrations in the effluent, however were not statistically different, when recycle ratio was increased. It should be noted, however, that both recycle ratios achieved the effluent targets for all parameters except TP. The recirculation of the treated effluent acts to dilute the influent sewage, resulting in better treatment efficiency (Venhuizen, 1997) as explained in Section 4.2.1.

Table 4-11. The effect of the recycle ratio on the RSFs treatment efficacy.

d_{10} = 2.6 mm, Dosing=48 times/day, HLR = 0.2m/day

Parameter	Effluent Concentration (mg/L)		Overall removal (%)	
	RSF 1 300%	RSF 2 500%	RSF 1 300%	RSF 2 500%
$cBOD_5$	2.1*	0.7*	97.1	99.2
TSS	6.6*	5.8*	95.4	95.7
TAN - N	1.38*	0.67*	90.2	95.3
TN – N	9.5*	7.9*	64.9	70.8
TP – P	3.89	3.90	20.5	21.1

Note: 1. The concentration is the average of all samples measurements collected throughout corresponding phase.
2. Shading of adjacent columns indicates that results exhibit a statistically significant difference.
3. * Effluent concentration achieves the MOE criterion.

4.4.2 The Effect of Dosing Frequency on RSF Performance

The effect of dosing frequency on RSFs performance was evaluated in Phase 2. The RSFs 1 and 2 contained 2.6 mm (d_{10}) sand and operated with a forward hydraulic loading rate of 0.4 m/day and a recycle ratio of 500%. The dosing frequency ranged from 24 to 48 times/day. The experiment results showed that decreasing the dosing frequency from 48 times/day to 24 times/day improved the RSF performance. The effluent quality of the RSF with a dosing frequency of 24 times/day had a statistically significant higher effluent quality in terms of $cBOD_5$, TSS, TAN and TN, but not in terms of TP. The effluent objectives for $cBOD_5$, TSS, TAN and TN were achieved by the RSF with a dosing frequency of 24 times/day (as shown in Table 4-5). The RSF with a dosing frequency of 48 times/day only achieve the effluent targets for $cBOD_5$ and TSS concentrations consistently, but did not achieve the effluent targets for TN-N, TAN-N and TP-P. The effect of dosing frequency on average effluent concentration and overall removal of various effluent parameters is shown in Table 4-12.

The US EPA (2002) recommends a dosing frequency of 48 times/day. Darby (1996) studied dosing frequencies of 4, 12 and 24 times/day for intermittent sand filters and found that increasing the dosing frequency generally improved the filter performance of the filters. However, Darby did not study dosing frequencies as high as 48 times/day. Darby explained that higher dosing frequencies result in smaller hydraulic loading rates on the filter bed for each dosing event. The smaller flows applied to the filter enables the sewage flow over the sand in a thin film, allowing maximum oxygen diffusion and maximum contact between the organics in the waste flows and the microbial growth on the media. In this study, it was found that RSF with a dosing frequency of 48 times/day required almost 40 minutes for the underdrain flow to decrease to a trickle. The longer drainage time lead to less air percolating through the filter, resulting in poorer performance.

Table 4-12. The effect of dosing frequency on the RSF treatment efficacy.

d_{10}=2.6 mm, HLR=0.4m/day, Recycle ratio=500%

Parameter	Effluent Concentration (mg/L)		Overall removal (%)	
	RSF 1 24 times/day	RSF 2 48 times/day	RSF 1 24 times/day	RSF 2 48 times/day
$cBOD_5$	2.9*	5.0*	97.8	96.2
TSS	5.2*	10.3*	97.1	95.0
TAN - N	2.6*	9.3	84.5	46.3
TN - N	8.9*	14.7	69.8	50.4
TP - P	3.1	3.9	35.8	20.1

Note: 1. The concentration is the average of all samples measurements collected throughout corresponding phase.

2. Shading of adjacent columns indicates that results exhibit a statistically significant difference.

3. * Effluent concentration achieves the MOE criterion.

4.4.3 The Effect of Forward hydraulic Loading Rate on RSF Performance

The effect of the forward hydraulic loading rate on RSF performance was evaluated for RSF 2 with 2.6 mm (d_{10}) media and RSF 4 with 7.7 mm (d_{10}) media at dosing frequency of 48 times/day and a recycle ratio of 500%. The effect of the increasing forward hydraulic loading rate on RSF performance is presented in Table 4-13. Increased forward flow loading rates had a significant effect on the RSF with 2.6 mm (d_{10}) media, and less of an effect on the RSF with the 7.7 mm (d_{10}) media. For RSF 2, with 2.6 mm diameter media, increasing the forward hydraulic loading rate from 0.2 m/day to 0.4 m/day caused a statistically significant decrease in RSF effluent quality and overall removals of $cBOD_5$, TSS, TAN and TN. There was, however, no statistically significant change in RSF effluent concentrations of TP, and the overall removal of TSS and TP. For RSF 4, with 7.7 mm diameter media, increasing the hydraulic loading rate only caused a statistically significant decrease in the RSF effluent quality with respect to TSS and TP. Increasing the hydraulic loading rate had a larger effect on the RSF with smaller media. The larger media have larger hydraulic conductivities and are therefore able to handle higher hydraulic loading rates, however, they do not provide the same degree of treatment as smaller media (Eastwood, 1995). Under a hydraulic loading rate of 0.2 m/day, RSF 2, with 2.6 mm diameter media, achieved the effluent objectives for all parameters except TP, whereas when hydraulic loading rate was increased to 0.4 m/day, the sewage was not well nitrified/denitrified and the effluent TN and TAN exceeded the target concentrations. On the other hand, the coarser media did not achieve satisfactory nitrification/denitrification at hydraulic loading rates of either 0.2 m/day or 0.4 m/day.

Table 4-13. The effect of the forward hydraulic loading rate on the RSF treatment efficacy

	d_{10}=2.6 mm, Recycle ratio=500%, Dosing=48 times/day				d_{10}=7.7 mm, Recycle ratio=500%, Dosing=48 times/day			
	Effluent Concentration (mg/L)		**Overall removal (%)**		**Effluent Concentration (mg/L)**		**Overall removal (%)**	
Parameter	RSF 2 0.2 m/day	RSF 2 0.4 m/day	RSF 2 0.2 m/day	RSF 2 0.4 m/day	RSF 4 0.2 m/day	RSF 4 0.4 m/day	RSF 4 0.2 m/day	RSF 4 0.4 m/day
cBOD5	0.7*	5.0*	99.2	96.2	8.7*	12.4*	89.4	90.1
TSS	5.8*	10.3*	95.7	95.0	13.5*	18.9	90.0	90.5
NH_3+NH_4^+ - N	0.67*	9.30	95.3	46.3	9.33	11.14	35.9	34.8
TN - N	7.9*	14.7	70.8	50.4	15.0	16.2	43.4	44.3
TP - P	3.90	3.89	21.1	20.1	4.14	3.33	16.5	31.2

Note: 1. The concentration is the average of all samples measurements collected throughout corresponding phase.

2. Shading of adjacent columns indicates that results exhibit a statistically significant difference.

3. * Effluent concentration achieves the MOE criterion.

4.4.4 Effect of Media Size on RSF Performance

The effect of media size on RSF performance was evaluated throughout the entire study period. The results of comparisons are presented in Table 4-14. In Phase 1, the effects of 2.6 and 7.7 mm diameter media were compared with a hydraulic loading rate of 0.2 m/day, a dosing frequency of 48 times/day and a recycle ratio of 500%. Statistically, the performance of the RSF with 2.6 mm diameter media was significantly better than the RSF with 7.7 mm media for all effluent parameters except TP. This can be explained by the fact that smaller sized media has more surface area and therefore a larger microbial population to treat the sewage, which leads to better performance as explained in Section 4.1.1. In Phase 2, the effect of 2.6 and 7.7 mm media sizes on RSF performance continued to be evaluated, with all other operating conditions remaining the same as Phase 1 except the hydraulic loading rate, which was adjusted to 0.4 m/day. Under these conditions, only differences in the effluent $cBOD_5$ and TSS concentrations and the overall removal of $cBOD_5$ were statistically significant. Under higher hydraulic loading rates and dosing frequencies, the drainage from the underdrain system was slow leading to less air percolating through the filter; this had larger effect on the smaller media since the coarser media can handle higher hydraulic loading rate (Eastwood, 1995). The effect of media size could not be compared under cold weather conditions (Phase 3), as the 5 and 7.7 mm diameter media were not well acclimated throughout this phase. The effects of three media sizes, 2.6, 5 and 7.7 mm (d_{10}) were compared in Phase 4. As shown in Table 4-14, with a hydraulic loading rate of 0.4 m/day, a recycle ratio of 500% and a dosing frequency of 24 times/day, the performance of the 2.6 mm diameter media was statistically superior for all parameters except TP. There were, however, no statistically significant differences between the 5 and 7.7 mm diameter media. The 2.6 mm media achieved all the effluent objectives with the exception of TAN and TN, which were just slightly higher than the target concentrations in some months.

Table 4-14. The effect of media size (d_{10}) on RSF treatment efficacy.

HLR=0.2m/day, Dosing=48 times/day, Recycle ratio=500% (Phase 1)				
	Effluent Concentration (mg/L)		**Overall removal (%)**	
	RSF 2	RSF 4	RSF 2	RSF 4
Parameter	2.6 mm	7.7 mm	2.6 mm	7.7 mm
$cBOD_5$	0.7*	8.7*	99.2	89.4
TSS	5.8*	13.5*	95.7	90.0
TAN - N	0.7*	9.3	95.3	35.9
TN - N	7.9*	15.0	70.8	43.4
TP - P	3.9	4.1	21.1	16.5

HLR=0.4m/day, Dosing=48 times/day, Recycle ratio=500% (Phase 2)				
	Effluent Concentration (mg/L)		**Overall removal (%)**	
	RSF 2	RSF 4	RSF 2	RSF 4
Parameter	2.6 mm	7.7 mm	2.6 mm	7.7 mm
$cBOD_5$	5.0*	12.4*	96.2	90.1
TSS	10.3*	18.9	95.0	90.5
TAN - N	9.30	11.1	46.3	34.8
TN - N	14.7	16.2	50.4	44.3
TP - P	3.89	3.3	20.1	31.2

HLR=0.4m/day, Dosing=24 times/day, Recycle ratio=500% (Phase 4)						
	Effluent Concentration (mg/L)			**Overall removal (%)**		
	RSF 1	RSF 2	RSF 4	RSF 1	RSF 2	RSF 4
Parameter	2.6 mm	5.0 mm	7.7 mm	2.6 mm	5.0 mm	7.7 mm
cBOD5	4.0*	10.4*	9.8*	93.2	84.0	84.3
TSS	9.9*	20.2	16.4	91.3	82.9	86.2
TAN - N	4.95	9.49	9.30	67.3	38.0	38.6
TN - N	10.6	15.1	14.1	56.2	40.4	43.7
TP - P	0.71*	0.83*	0.68*	81.9	79.9	83.6

Note: 1. The concentration is the average of all samples measurements collected throughout corresponding phase.
2. Shading of adjacent columns indicates that results exhibit a statistically significant difference.
3. Underlining in the RSF 1 and RSF 4 columns indicate that these results exhibit a statistically significant difference.
4. * Effluent concentration achieves the MOE criterion.

4.4.5 The Effect of Temperature on RSF Performance

The effect of temperature on RSF performance was investigated using RSF 1, which was operated with 2.6 mm diameter media, a hydraulic loading rate of 0.2 m/day, and a recycle ratio of 500% under Fall, Winter and Spring conditions; the Fall and Spring were replications of the same experiment to compare results over time. Comparisons of the winter and spring performance for RSF 2 with 5 mm (d_{10}) media and RSF 4 with 7.7 (d_{10}) mm were not conducted due to the fact that the media was not well acclimated during the winter months. The effect of temperature on RSF performance is presented in Table 4-15. As shown in this Table 4-15, RSF 1 performed statistically better in the fall than it did in the winter. Additionally, there were statistically significant differences in the effluent concentrations of $cBOD_5$, TSS, and TN, but not TAN and TP, between the Winter and Spring months. The superior RSF performance in the fall and spring months can be attributed to temperature effects, which have a significant impact on microbial activity (Metcalf & Eddy, 2003). The higher removal of TP in winter than in fall was due to the addition of alum in Phase 3. Temperature did not have a statistically significant impact on TP removal through a comparison of winter and spring performances.

Although the fall and spring performances of RSF 1 were supposed to be similar, the data show that they are actually statistically different. This can be attributed to the growth of earthworms in the filter 1, which lead to clogging and ponding, causing the filter to become anaerobic. Generally, in summer-fall and spring-summer, under a hydraulic loading rate of 0.4 m/day, a dosing frequency of 24 times/day, a recycle ratio of 500%, and 2.6 mm (d_{10}) media, RSF should achieve the MOE effluent criteria if the ponding problem is not an issue. In the winter months, however, these operating conditions cannot achieve the objective for nitrogen removal.

Table 4-15. The effect of temperature on RSF treatment efficacy.

HLR=0.4m/day, Dosing=24times/day, Recycle ratio=500%, d_{10}=2.6 mm						
	Effluent Concentration (mg/L)			**Overall removal (%)**		
Parameter	RSF 1 Fall	RSF 1 Winter	RSF 1 Spring	RSF 1 Fall	RSF 1 Winter	RSF 1 Spring
$cBOD_5$	2.9*	6.0*	4.0*	97.1	93.2	93.2
TSS	5.2*	14.5*	9.9*	95.4	92.2	91.3
TAN - N	2.62*	6.18	4.95	84.5	62.9	67.3
TN - N	8.9*	13.6	10.6	64.9	35.1	56.2
TP - P	3.13	0.86*	0.71*	20.5	70.1	81.9

Note: 1. The concentration is the average of all samples measurements collected throughout corresponding phase.
2. Shading of adjacent columns indicate that results exhibit a statistically significant difference.
3. Underlining in the Fall and Spring columns indicate that these results exhibit a statistically significant difference.
4. TP concentration and overall removal in Winter were calculated after alum was added.
5. * Effluent concentration achieved the target.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions

The overall goal of this research was to generate optimum design and operational parameters for recirculating sand filters for the south-western Ontario climate. The study involved evaluating the effect of media size, dosing frequency, recycle ratio, hydraulic loading rate and temperature on effluent quality, as well as the removal of total phosphorus by alum addition. The results of this research will be used by the MOE to develop a guideline for the operation of recirculating sand filters in Ontario.

This study concludes that:

1. RSFs in series with septic tanks may produce a high quality effluent achieving the effluent criteria set by the MOE.
2. To achieve the effluent objectives provided by the MOE, the optimum operating conditions for RSFs are 2.6 mm (d_{10}) media, a 500% recycle ratio, a dosing frequency of 24 times/day and a forward hydraulic loading rate of 0.2 m/day.
3. Under cold weather conditions and a hydraulic loading rate of 0.4 m/day, the RSF with 2.6 mm (d_{10}) media, a 500% recycle ratio and a dosing frequency of 24 times/day, still performed well, achieving the effluent objectives for all effluent criteria except the TN and TAN concentration due to the cold temperatures affecting the nitrification/denitrification process. This fact showed that the RSFs

were stressed in terms of TN and TAN removal under low operating temperatures in combination with high hydraulic loading rates.

4. The RSFs, with coarser media (d_{10} = 5 and 7.7 mm) can achieve the effluent criteria in terms of $cBOD_5$ and TSS under optimum operating conditions, however, they did not demonstrate the capability of achieving effluent criteria in terms of TN and TAN.

5. In Phase 4 it was found that the media in filter 1 was infested with earth worms, which heavily affected the RSF treatment efficiency. This phenomenon has never been reported in existing literature.

6. With the proper addition of alum, the effluent total phosphorus was easily reduced to the effluent objective of 1.0 mg/L.

5.2 Recommendations for future work

This study has demonstrated that the optimum operating conditions for RSFs in Ontario is 2.6 mm (d_{10}) media, a 500% recycle ratio, a dosing frequency of 24 times/day and a hydraulic loading rate of 0.2 m/day. However, it has not been proven that RSFs with these operating conditions will achieve the effluent criteria in terms of TN and TAN under cold weather conditions. Further work should be conducted to determine the maximum hydraulic loading to achieve the effluent criterion in terms of TN under cold weather conditions.

This study was negatively impacted by the lack of raw sewage screening and degritting at the Clifford Wastewater Treatment Plant. The impeller on the raw sewage centrifugal pump was frequently fouled by concrete, plastic and wood debris, and those debris passed through the septic tanks and fouled the dosing pumps, flow throttling valves and dosing orifices. Although a grinder pump replaced the original raw sewage pump, the situation was not significantly improved. A screening system should be installed upstream of the raw sewage pump to reduce fouling in the pilot plant and to help regulate the flowrate.

With the low levels of effluent TSS achieved in this work, a disinfection study using UV lights should be conducted to evaluate the feasibility of UV disinfection to further improve effluent quality, thereby permitting surface water discharge.

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Appendix A
Analytical Results

Table A - 1. Phase 1 $cBOD_5$ results.

PROJECT	SAMPLING	$cBOD_5$ (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 1	04-07-04																		
Phase 1	04-27-04																		
Phase 1	05-11-04																		
Phase 1	05-14-04																		
Phase 1	05-18-04																		
Phase 1	05-25-04	71.5	68.9	62.3	11.5	15.2	3.6	1.1	8.1	3.6	9.6	83.3	77.9	94.2	90.4	46.7	95.0	98.5	88.7
Phase 1	06-01-04	137	110	5.3	13	35	0.7	1.3	14.4	19.7	95.2	88.2	68.2	86.8	90.0	58.9	99.5	99.1	89.5
Phase 1	06-08-04	112	88.4	57.7	16.2	27.3	2.2	0.2	11.7	21.1	34.7	81.7	69.1	96.2	98.8	57.1	98.0	99.8	89.6
Phase 1	06-15-04	68.4	126	35.4	6.4	20.2	2.3	0.3	4.2	-84.2	71.9	94.9	84.0	93.5	95.3	79.2	96.6	99.6	93.9
Phase 1	06-22-04	84.8	95.8	40.1	10.4	34.9	0.7	1.1	10.1	-13.0	58.1	89.1	63.6	98.3	89.4	71.1	99.2	98.7	88.1
Phase 1	06-29-04	45.5	52.9	17.5	6.3	12.2	1.6	0.2	2.8	-16.3	66.9	88.1	76.9	90.9	96.8	77.0	96.5	99.6	93.8
Phase 1	07-06-04	44.1	105	25.7	16.1	33.5	2.1	0.3	9.2	-138.1	75.5	84.7	68.1	91.8	98.1	72.5	95.2	99.3	79.1
Phase 1	07-13-04	112	76.2	24.4	31.3	24.1	3.4	1	8.7	32.0	68.0	58.9	68.4	86.1	96.8	63.9	97.0	99.1	92.2
Phase 1	07-20-04																		
Number		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Mean		84.4	90.4	33.6	13.9	25.3	2.1	0.7	8.7	-21.9	60.0	83.6	72.0	92.2	94.5	65.8	97.1	99.2	89.4
Standard Deviation		33.5	23.8	19.5	8.0	8.9	1.1	0.5	3.8	59.3	26.5	10.8	6.8	4.3	3.9	11.2	1.7	0.5	4.7
Max		137.0	126.0	62.3	31.3	35.0	3.6	1.3	14.4	32.0	95.2	94.9	84.0	98.3	98.8	79.2	99.5	99.8	93.9
Min		44.1	52.9	5.3	6.3	12.2	0.7	0.2	2.8	-138.1	9.6	58.9	63.6	86.1	89.4	46.7	95.0	98.5	79.1

Note: Overall removal is based on raw sewage concentration.

Table A - 2. Phase 1 TSS results.

PROJECT	SAMPLING	TSS (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 1	04-07-04	191.7	69.5	17.9	31.8	26.6	3.6	2.5	12.1	63.8	74.2	54.2	61.7	80.1	92.1	54.4	98.1	98.7	93.7
Phase 1	04-27-04	103.9	38.3	26.9	19.0	31.8	4.2	7.7	13.5	63.2	29.8	50.4	16.8	84.2	59.4	57.5	95.9	92.6	87.0
Phase 1	05-11-04		46.7	23.6	21.3	18.8	7.6	8.3	8.7		49.4	54.4	59.7	67.8	60.9	53.7			
Phase 1	05-14-04	194.5	36.8	25.3	15.1	22.9	19.5	5.7	16.2	81.1	31.3	59.0	37.6	23.1	62.6	29.4	90.0	97.1	91.7
Phase 1	05-18-04	172.8	40.1	23.9	16.5	23.1	3.9	6.5	18.1	76.8	40.4	59.0	42.5	83.9	60.8	21.5	97.8	96.3	89.5
Phase 1	05-25-04	63.2	42.8	51.9	15.7	15.8	6.9	6.6	11.5	32.3	-21.3	63.4	63.2	86.7	58.1	27.0	89.1	89.6	81.8
Phase 1	06-01-04	187.5	62.0	13.0	18.0	31.4	7.1	5.3	18.8	67.0	79.0	70.9	49.2	45.4	70.3	40.2	96.2	97.1	90.0
Phase 1	06-08-04	221.2	59.7	31.7	22.8	26.0	11.2	5.4	16.3	73.0	46.9	61.8	56.4	64.8	76.5	37.3	95.0	97.6	92.6
Phase 1	06-15-04	132.0	56.0	31.8	21.8	21.5	8.5	7.3	13.1	57.6	43.2	61.0	61.7	73.3	66.5	38.9	93.6	94.5	90.1
Phase 1	06-22-04	218.3	47.1	27.7	18.6	22.6	6.1	8.9	13.1	78.4	41.3	60.5	52.0	77.9	52.4	42.0	97.2	95.9	94.0
Phase 1	06-29-04	70.8	51.0	25.4	18.2	19.6	4.3	4.7	9.5	28.0	50.2	64.4	61.5	82.8	74.4	51.5	93.9	93.4	86.6
Phase 1	07-06-04	113.4	43.8	29.7	19.1	21.3	3.9	2.1	16.7	61.4	32.1	56.3	51.3	86.9	88.7	21.8	96.6	98.1	85.3
Phase 1	07-13-04	235.0	52.1	23.6	29.4	22.7	4.2	5.5	13.0	77.8	54.7	43.6	56.4	82.2	81.3	42.7	98.2	97.7	94.5
Phase 1	07-20-04	116.6	36.3	18.4	23.8	17.1	2.1	5.4	8.2	68.9	49.3	34.4	52.9	88.6	77.3	52.0	98.2	95.4	93.0
Number		13	14	14	14	14	14	14	14	13.0	14.0	14.0	14.0	14.0	14.0	14.0	13.0	13.0	13.0
Mean		155.4	48.7	26.5	20.8	22.9	6.6	5.8	13.5	63.8	42.9	56.7	51.6	73.4	70.1	40.7	95.4	95.7	90.0
Standard Deviation		58.4	10.2	9.0	4.9	4.8	4.4	1.9	3.4	16.6	23.4	9.2	12.5	18.5	12.0	12.2	3.0	2.6	3.9
Max		235.0	69.5	51.9	31.8	31.8	19.5	8.9	18.8	81.1	79.0	70.9	63.2	88.6	92.1	57.5	98.2	98.7	94.5
Min		63.2	36.3	13.0	15.1	15.8	2.1	2.1	8.2	28.0	-21.3	34.4	16.8	23.1	52.4	21.5	89.1	89.6	81.8

Note: Overall removal is based on raw sewage concentration.

Table A - 3. Phase 1 TAN results.

PROJECT	SAMPLING	TAN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 1	04-07-04	8.35	5.75	2.83	3.68	4.6	0.56	0.85	2.65	31.1	50.9	36.1	20.0	80.2	76.9	42.4	93.3	89.8	68.3
Phase 1	04-27-04	20.5	14.9	9.05	7.40	7.55	1.3	1.6	4.08	27.3	39.3	50.3	49.3	85.6	78.4	46.0	93.7	92.2	80.1
Phase 1	05-11-04		12.4	7.6	2.95	6.5	2.1	0.38	4.26		38.7	76.2	47.6	72.4	87.1	34.5			
Phase 1	05-14-04	12.8	12.3	7.75	2.75	7.65	2.5	0.24	4.42	4.3	36.7	77.6	37.6	67.7	91.3	42.2	80.5	98.1	65.5
Phase 1	05-18-04	8.1	12.6	7.45	2.55	10.5	1.42	0.23	7.95	-55.6	40.9	79.8	16.7	80.9	91.0	24.3	88.7	98.2	36.9
Phase 1	05-25-04	8.95	11.1	12.5	2.80	9.9	4.54	0.27	8.6	-23.5	-12.7	74.7	10.4	63.5	90.4	13.1	58.9	97.6	22.2
Phase 1	06-01-04	16.8	16.6	2.75	4.50	12.3	0.34	0.34	11.8	1.2	83.4	72.9	26.2	87.6	92.4	4.1	98.0	98.0	30.1
Phase 1	06-08-04	14.1	14.7	11.5	4.30	12.4	1.02	0.18	14	-4.3	22.1	70.7	15.6	91.1	95.8	-12.9	93.1	98.8	4.8
Phase 1	06-15-04	18.7	14.3	10.5	4.45	12.3	1.62	0.25	11.8	23.5	26.6	68.9	14.3	84.6	94.4	4.1	91.3	98.7	37.2
Phase 1	06-22-04	10.8	15.8	10.5	3.65	12.7	0.53	0.96	12.2	-47.0	33.5	76.9	19.9	95.0	73.7	3.6	96.6	93.9	22.8
Phase 1	06-29-04	16	14.8	7.9	4.70	11.3	0.17	0.13	11.2	7.5	46.6	68.2	24.0	97.8	97.2	0.4	98.9	99.2	30.0
Phase 1	07-06-04	17.8	18.8	8.05	6.05	14.4	1.23	0.3	13.6	-5.6	57.2	67.8	23.4	84.7	95.0	5.6	93.5	98.4	27.7
Phase 1	07-13-04	16.5	16	7.45	7.60	12.3	0.71	1.99	13.7	3.0	53.4	52.5	23.1	90.5	73.8	-11.4	95.7	87.9	17.0
Phase 1	07-20-04	10.6	13.7	8.4	9.55	11.7	1.34	1.71	10.4	-29.2	38.7	30.3	14.6	84.0	82.1	11.1	90.2	87.5	24.1
Number		13	14	14	14	14	14	14	14	13	14	14	14	14	14	14	13	13	13
Mean		13.84	13.83	8.15	4.78	10.42	1.38	0.67	9.33	-5.2	39.7	64.5	24.5	83.3	87.1	14.8	90.2	95.3	35.9
Standard Deviation		4.21	3.08	2.78	2.12	2.81	1.12	0.64	4.00	27.0	21.2	15.9	12.1	9.8	8.4	19.8	10.5	4.4	22.1
Max		20.50	18.80	12.45	9.55	14.40	4.54	1.99	14.00	31.1	83.4	79.8	49.3	97.8	97.2	46.0	98.9	99.2	80.1
Min		8.10	5.75	2.75	2.55	4.60	0.17	0.13	2.65	-55.6	-12.7	30.3	10.4	63.5	73.7	-12.9	58.9	87.5	4.8

Note: Overall removal is based on raw sewage or primary septic tank sewage concentration which ever is higher.

Table A - 4. Phase 1 TN results.

PROJECT	SAMPLING	TN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 1	04-07-04	19.4	18.9	13.1	14.2	15.8	9.8	11	12.4	2.6	30.7	24.9	16.4	25.2	22.5	21.5	49.5	43.3	36.1
Phase 1	04-27-04	34.2	18.6	13.2	12.7	12.7	9.2	9.2	9.4	45.6	29.0	31.7	31.7	30.3	27.6	26.0	73.1	73.1	72.5
Phase 1	05-11-04		38.4	11.2	10.1	10	8.4	9.7	8.5		70.8	73.7	74.0	25.0	4.0	15.0			
Phase 1	05-14-04	29.8	19.8	11.3	8.5	8	8.6	8.4	7.9	33.6	42.9	57.1	59.6	23.9	1.2	1.3	71.1	71.8	73.5
Phase 1	05-18-04	38.2	21.6	13.4	8.9	16.6	8.5	7.2	14.6	43.5	38.0	58.8	23.1	36.6	19.1	12.0	77.7	81.2	61.8
Phase 1	05-25-04	18.2	20.9	11.6	9.8	14.2	10.2	8.8	11.8	-14.8	44.5	53.1	32.1	12.1	10.2	16.9	44.0	51.6	35.2
Phase 1	06-01-04	29.2	24.5	8.3	7.5	18.8	7.3	6.3	18	16.1	66.1	69.4	23.3	12.0	16.0	4.3	75.0	78.4	38.4
Phase 1	06-08-04	28.6	23.2	18.1	7.8	19.9	11	7.2	17.9	18.9	22.0	66.4	14.2	39.2	7.7	10.1	61.5	74.8	37.4
Phase 1	06-15-04	30.4	24.8	15.9	7.5	20.9	10.4	6.2	19.3	18.4	35.9	69.8	15.7	34.6	17.3	7.7	65.8	79.6	36.5
Phase 1	06-22-04	36	24.7	17.8	7.8	19.9	11.4	6	18.2	31.4	27.9	68.4	19.4	36.0	23.1	8.5	68.3	83.3	49.4
Phase 1	06-29-04	30.1	26.2	14	9.1	19.1	10.5	6.9	18.6	13.0	46.6	65.3	27.1	25.0	24.2	2.6	65.1	77.1	38.2
Phase 1	07-06-04	21	25.3	13	8.8	21.7	9	5.4	18.5	-20.5	48.6	65.2	14.2	30.8	38.6	14.7	57.1	74.3	11.9
Phase 1	07-13-04	35	25.7	12.8	14.6	20.4	9.7	9.1	18.8	26.6	50.2	43.2	20.6	24.2	37.7	7.8	72.3	74.0	46.3
Phase 1	07-20-04	22.4	23.1	12.6	14.7	17.9	8.4	9.3	16.2	-3.1	45.5	36.4	22.5	33.3	36.7	9.5	62.5	58.5	27.7
Number		13	14	14	14	14	14	14	14	13	14	14	14	14	14	14	13	13	13
Mean		28.7	24.0	13.3	10.1	16.9	9.5	7.9	15.0	16.2	42.8	55.9	28.1	27.7	20.4	11.3	64.9	70.8	43.4
Standard Deviation		6.6	4.9	2.6	2.7	4.2	1.2	1.7	4.2	20.7	13.9	15.8	17.6	8.4	12.1	7.0	10.0	12.1	17.4
Max		38.2	38.4	18.1	14.7	21.7	11.4	11.0	19.3	45.6	70.8	73.7	74.0	39.2	38.6	26.0	77.7	83.3	73.5
Min		18.2	18.6	8.3	7.5	8.0	7.3	5.4	7.9	-20.5	22.0	24.9	14.2	12.0	1.2	1.3	44.0	43.3	11.9

Note: Overall removal is based on raw sewage concentration.

Table A - 5. Phase 1 TP results.

PROJECT	SAMPLING	TP (mg P/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 1	04-07-04	3.8	4.25	3.15	3.00	3.6	2.35	2.25	2.6	-11.8	25.9	29.4	15.3	25.4	25.0	27.8	38.2	40.8	31.6
Phase 1	04-27-04	4.8	4.65	4.90	4.80	4.15	3.9	3.8	4.35	3.1	-5.4	-3.2	10.8	20.4	20.8	-4.8	18.8	20.8	9.4
Phase 1	05-11-04		4.3	4.10	3.80	4.85	3.65	3.9	3.95		4.7	11.6	-12.8	11.0	-2.6	18.6			
Phase 1	05-14-04	6.55	4.1	5.25	1.09	4.65	3.55	4.5	5.05	37.4	-28.0	73.4	-13.4	32.4	-312.8	-8.6	45.8	31.3	22.9
Phase 1	05-18-04	6.1	4.95	3.60	4.60	4.45	4.6	3.75	4.95	18.9	27.3	7.1	10.1	-27.8	18.5	-11.2	24.6	38.5	18.9
Phase 1	05-25-04	5.5	4	4.55	4.70	4.6	3.95	4.6	4.2	27.3	-13.8	-17.5	-15.0	13.2	2.1	8.7	28.2	16.4	23.6
Phase 1	06-01-04	5	4.95	4.20	4.15	4.65	4.25	4.35	4.9	1.0	15.2	16.2	6.1	-1.2	-4.8	-5.4	15.0	13.0	2.0
Phase 1	06-08-04	5.95	3.7	3.85	3.80	4.25	3.25	3.75	3.8	37.8	-4.1	-2.7	-14.9	15.6	1.3	10.6	45.4	37.0	36.1
Phase 1	06-15-04	4.85	4.9	4.45	3.90	4.55	4.25	4.3	4.35	-1.0	9.2	20.4	7.1	4.5	-10.3	4.4	12.4	11.3	10.3
Phase 1	06-22-04	4.9	4.85	3.95	3.90	4.5	4	3.8	3.9	1.0	18.6	19.6	7.2	-1.3	2.6	13.3	18.4	22.4	20.4
Phase 1	06-29-04	4.8	4.7	3.90	3.90	4.45	3.95	4	3.85	2.1	17.0	17.0	5.3	-1.3	-2.6	13.5	17.7	16.7	19.8
Phase 1	07-06-04	3.3	5.75	5.00	4.60	4.3	4.8	4.45	4.3	-74.2	13.0	20.0	25.2	4.0	3.3	0.0	-45.5	-34.8	-30.3
Phase 1	07-13-04	6.85	4.3	4.75	4.85	3.6	4.45	3.9	4.05	37.2	-10.5	-12.8	16.3	6.3	19.6	-12.5	35.0	43.1	40.9
Phase 1	07-20-04	4	3.7	3.60	3.45	3.6	3.5	3.3	3.65	7.5	2.7	6.8	2.7	2.8	4.3	-1.4	12.5	17.5	8.8
Number		13	14	14	14	14	14	14	14	13	14	14	14	14	14	14	13	13	13
Mean		5.11	4.51	4.23	3.90	4.30	3.89	3.90	4.14	6.6	5.1	13.2	3.6	7.4	-16.8	3.8	20.5	21.1	16.5
Standard Deviation		1.06	0.56	0.61	0.97	0.42	0.62	0.60	0.63	29.5	16.0	22.0	12.8	14.5	85.9	12.1	23.1	20.2	18.0
Max		6.85	5.75	5.25	4.85	4.85	4.80	4.60	5.05	37.8	27.3	73.4	25.2	32.4	25.0	27.8	45.8	43.1	40.9
Min		3.30	3.70	3.15	1.09	3.60	2.35	2.25	2.60	-74.2	-28.0	-17.5	-15.0	-27.8	-312.8	-12.5	-45.5	-34.8	-30.3

Note: Overall removal is based on raw sewage concentration.

Table A - 6. Phase 1 E.coli results.

PROJECT PHASE	SAMPLING DATE	E.coli (10^3 cfu/100mL) McMaster Lab data					
		SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4
Phase 1	04-07-04						
Phase 1	04-27-04						
Phase 1	05-11-04						
Phase 1	05-14-04						
Phase 1	05-18-04						
Phase 1	05-25-04		670.0	890.0	45.0	2.8	260.0
Phase 1	06-01-04	750.0	1100.0	2800.0	49.0	7.3	1100.0
Phase 1	06-08-04						
Phase 1	06-15-04						
Phase 1	06-22-04	1500.0	750.0	1200.0	5.3	20.0	730.0
Phase 1	06-29-04						
Phase 1	07-06-04	2300.0	1500.0	1900.0	6.4	3.8	1800.0
Phase 1	07-13-04	1900.0	1600.0	1600.0	27.0	3.1	870.0
Phase 1	07-20-04		2000.0	2200.0			
Number		4	6	6	5	5	5
Mean		1612.5	1270.0	1765.0	26.5	7.4	952.0
Standard Deviation		661.3	520.4	691.5	20.6	7.3	564.8
Max		2300.0	2000.0	2800.0	49.0	20.0	1800.0
Min		750.0	670.0	890.0	5.3	2.8	260.0

Table A - 7. Phase 2 $cBOD_5$ results.

PROJECT PHASE	SAMPLING DATE	$cBOD_5$ (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 2	08-17-04	112.0	70.90	17.90	25.10	27.90	2.80	5.00	6.00	36.7	74.8	64.6	60.6	84.4	80.1	78.5	97.5	95.5	94.6
Phase 2	08-24-04	88.0	94.00	21.50	43.80	41.80	2.30	4.70	21.40	-6.8	77.1	53.4	55.5	89.3	89.3	48.8	97.4	94.7	75.7
Phase 2	09-08-04	83.4	54.50	16.20	26.50	36.00	3.30	4.10	14.10	34.7	70.3	51.4	33.9	79.6	84.5	60.8	96.0	95.1	83.1
Phase 2	09-14-04																		
Phase 2	09-21-04	308.0	55.40	15.30	19.60	25.30	3.00	4.20	8.80	82.0	72.4	64.6	54.3	80.4	78.6	65.2	99.0	98.6	97.1
Phase 2	09-28-04	113.0	84.10	21.90	32.80	33.50	3.60	5.20	20.20	25.6	74.0	61.0	60.2	83.6	84.1	39.7	96.8	95.4	82.1
Phase 2	10-05-04	158.0	69.30	4.00	35.80	36.70	2.60	7.10	16.40	56.1	94.2	48.3	47.0	35.0	80.2	55.3	98.4	95.5	89.6
Phase 2	10-12-04	502.0	73.10	17.10	36.10	34.60	3.90	5.50	11.10	85.4	76.6	50.6	52.7	77.2	84.8	67.9	99.2	98.9	97.8
Phase 2	10-19-04	103.0	51.20	29.30	30.60	33.70	3.60	6.50	10.90	50.3	42.8	40.2	34.2	87.7	78.8	67.7	96.5	93.7	89.4
Phase 2	10-26-04	89.8	67.80	14.50	19.20	20.40	2.00	3.40	5.80	24.5	78.6	71.7	69.9	86.2	82.3	71.6	97.8	96.2	93.5
Phase 2	11-02-04	366.0	57.10	12.90	15.20	17.40	2.00	4.40	8.80	84.4	77.4	73.4	69.5	84.5	71.1	49.4	99.5	98.8	97.6
Number		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Mean		192.3	67.7	17.1	28.5	30.7	2.9	5.0	12.4	47.3	73.8	57.9	53.8	78.8	81.4	60.5	97.8	96.2	90.1
Standard Deviation		147.0	13.8	6.6	9.0	7.7	0.7	1.1	5.5	30.4	12.7	10.8	12.6	15.8	4.9	12.0	1.2	1.9	7.6
Max		502.0	94.0	29.3	43.8	41.8	3.9	7.1	21.4	85.4	94.2	73.4	69.9	89.3	89.3	78.5	99.5	98.9	97.8
Min		83.4	51.2	4.0	15.2	17.4	2.0	3.4	5.8	-6.8	42.8	40.2	33.9	35.0	71.1	39.7	96.0	93.7	75.7

Note: Overall removal is based on raw sewage concentration.

Table A - 8. Phase 2 TSS results.

PROJECT	SAMPLING	TSS (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 2	08-17-04	151.6	41.7	21.6	27.3	27.5	4.7	9.5	12.7	72.5	48.2	34.5	34.1	78.2	65.2	53.8	96.9	93.7	91.6
Phase 2	08-24-04	172.0	60.8	27.5	44.7	45.6	5.2	10.8	29.4	64.7	54.8	26.5	25.0	81.1	75.8	35.5	97.0	93.7	82.9
Phase 2	09-08-04	152.2	48.0	26.7	35.5	34.5	9.0	9.8	24.8	68.5	44.4	26.0	28.1	66.3	72.4	28.1	94.1	93.6	83.7
Phase 2	09-14-04	138.6	56.3	40.4	39.5	40.8	6.2	12.4	23.4	59.4	28.2	29.8	27.5	84.7	68.6	42.6	95.5	91.1	83.1
Phase 2	09-21-04	595.6	60.5	27.2	26.4	28.6	2.9	5.8	16.9	89.8	55.0	56.4	52.7	89.3	78.0	40.9	99.5	99.0	97.2
Phase 2	09-28-04	149.4	74.7	26.8	31.9	30.7	4.4	5.3	18.5	50.0	64.1	57.3	58.9	83.6	83.4	39.7	97.1	96.5	87.6
Phase 2	10-05-04	216.8	59.4	4.6	33.8	32.5	2.0	10.7	13.0	72.6	92.3	43.1	45.3	56.5	68.3	60.0	99.1	95.1	94.0
Phase 2	10-12-04	876.8	48.8	19.5	19.2	45.6	2.1	17.8	23.8	94.4	60.0	60.7	6.6	89.2	7.3	47.8	99.8	98.0	97.3
Phase 2	10-19-04	167.8	68.8	49.2	37.5	39.4	8.6	11.8	16.8	59.0	28.5	45.5	42.7	82.5	68.5	57.4	94.9	93.0	90.0
Phase 2	10-26-04	162.0	56.0	23.0	26.0	30.0	7.0	12.0	15.0	65.4	58.9	53.6	46.4	69.6	53.8	50.0	95.7	92.6	90.7
Phase 2	11-02-04	514.4	51.9	17.3	19.0	24.9	4.9	7.8	13.6	89.9	66.7	63.4	52.0	71.7	58.9	45.4	99.0	98.5	97.4
Number		11	11	11	11	11	11	11	11	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Mean		299.7	57.0	25.8	31.0	34.6	5.2	10.3	18.9	71.5	54.6	45.2	38.1	77.5	63.7	45.6	97.1	95.0	90.5
Standard Deviation		248.7	9.5	11.6	8.2	7.2	2.4	3.4	5.6	14.4	18.0	14.1	15.4	10.3	20.5	9.5	2.0	2.6	5.6
Max		876.8	74.7	49.2	44.7	45.6	9.0	17.8	29.4	94.4	92.3	63.4	58.9	89.3	83.4	60.0	99.8	99.0	97.4
Min		138.6	41.7	4.6	19.0	24.9	2.0	5.3	12.7	50.0	28.2	26.0	6.6	56.5	7.3	28.1	94.1	91.1	82.9

Note: Overall removal is based on raw sewage concentration.

Table A - 9. Phase 2 TAN results.

PROJECT	SAMPLING	TAN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 2	08-17-04	16.90	15.50	8.15	10.25	11.70	4.30	5.60	9.40	8.3	47.4	33.9	24.5	47.2	45.4	19.7	74.6	66.9	44.4
Phase 2	08-24-04	14.70	15.90	7.75	11.90	12.75	2.52	7.10	10.25	-8.2	51.3	25.2	19.8	67.5	40.3	19.6	84.2	55.3	35.5
Phase 2	09-08-04	14.10	13.50	6.50	9.50	12.60	2.85	5.80	10.30	4.3	51.9	29.6	6.7	56.2	38.9	18.3	79.8	58.9	27.0
Phase 2	09-14-04	12.30	16.40	6.55	10.50	11.05	2.51	6.35	9.70	-33.3	60.1	36.0	32.6	61.7	39.5	12.2	84.7	61.3	40.9
Phase 2	09-21-04	14.30	13.50	6.30	9.10	10.05	2.14	6.15	8.95	5.6	53.3	32.6	25.6	66.0	32.4	10.9	85.0	57.0	37.4
Phase 2	09-28-04	16.20	17.40	6.95	13.70	15.00	2.80	9.60	13.00	-7.4	60.1	21.3	13.8	59.7	29.9	13.3	83.9	44.8	25.3
Phase 2	10-05-04	16.30	17.60	2.75	13.60	15.10	1.04	12.90	13.90	-8.0	84.4	22.7	14.2	62.2	5.1	7.9	94.1	26.7	21.0
Phase 2	10-12-04	19.10	23.50	8.70	18.60	18.20	3.26	14.00	15.40	-23.0	63.0	20.9	22.6	62.5	24.7	15.4	86.1	40.4	34.5
Phase 2	10-19-04	15.30	17.90	3.60	13.40	11.90	2.14	10.95	11.40	-17.0	79.9	25.1	33.5	40.6	18.3	4.2	88.0	38.8	36.3
Phase 2	10-26-04	15.00	17.10	8.30	15.50	13.20	3.26	14.90	11.90	-14.0	51.5	9.4	22.8	60.7	3.9	9.8	80.9	12.9	30.4
Phase 2	11-02-04	13.90	16.50	5.95	11.20	10.90	1.98	8.90	8.30	-18.7	63.9	32.1	33.9	66.7	20.5	23.9	88.0	46.1	49.7
Number		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Mean		15.28	16.80	6.50	12.48	12.95	2.62	9.30	11.14	-10.1	60.6	26.2	22.7	59.2	27.2	14.1	84.5	46.3	34.8
Standard Deviation		1.81	2.68	1.88	2.85	2.36	0.84	3.45	2.22	12.8	12.0	7.7	8.8	8.4	14.1	5.9	5.0	16.1	8.5
Max		19.10	23.50	8.70	18.60	18.20	4.30	14.90	15.40	8.3	84.4	36.0	33.9	67.5	45.4	23.9	94.1	66.9	49.7
Min		12.30	13.50	2.75	9.10	10.05	1.04	5.60	8.30	-33.3	47.4	9.4	6.7	40.6	3.9	4.2	74.6	12.9	21.0

Note: Overall removal is based on raw sewage or primary septic tank sewage concentration which ever is higher.

Table A - 10. Phase 2 TN results.

PROJECT	SAMPLING	TN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 2	08-17-04	30.2	24.5	11.8	15.8	18.0	9.1	12.5	10.4	18.9	51.8	35.5	26.5	22.9	20.9	42.2	69.9	58.6	65.6
Phase 2	08-24-04	26.2	26.6	12.0	19.1	20.9	7.4	15.3	18.3	-1.5	54.9	28.2	21.4	38.3	19.9	12.4	71.8	41.6	30.2
Phase 2	09-08-04	24.0	22.2	11.2	17.3	19.7	8.4	11.5	19.5	7.5	49.5	22.1	11.3	25.0	33.5	1.0	65.0	52.1	18.8
Phase 2	09-14-04	20.8	27.3	11.8	17.8	19.8	7.9	13.4	17.5	-31.3	56.8	34.8	27.5	33.1	24.7	11.6	62.0	35.6	15.9
Phase 2	09-21-04	44.0	23.2	11.3	16.4	19.1	7.9	13.0	17.2	47.3	51.3	29.3	17.7	30.1	20.7	9.9	82.0	70.5	60.9
Phase 2	09-28-04	25.6	22.1	10.9	16.5	17.6	8.7	13.2	16.1	13.7	50.7	25.3	20.4	20.2	20.0	8.5	66.0	48.4	37.1
Phase 2	10-05-04	26.2	23.7	8.3	18.6	20.4	8.9	16.5	18.2	9.5	65.0	21.5	13.9	-7.2	11.3	10.8	66.0	37.0	30.5
Phase 2	10-12-04	55.6	30.8	11.3	20.3	19.2	8.6	17.6	16.8	44.6	63.3	34.1	37.7	23.9	13.3	12.5	84.5	68.3	69.8
Phase 2	10-19-04	29.6	26.9	15.4	19.4	17.3	9.9	17.1	15.5	9.1	42.8	27.9	35.7	35.7	11.9	10.4	66.6	42.2	47.6
Phase 2	10-26-04	27.8	24.9	14.6	20.7	18.6	10.5	18.7	15.3	10.4	41.4	16.9	25.3	28.1	9.7	17.7	62.2	32.7	45.0
Phase 2	11-02-04	38.4	23.5	13.5	15.4	15.1	11.0	12.6	13.1	38.8	42.6	34.5	35.7	18.5	18.2	13.2	71.4	67.2	65.9
Number		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Mean		31.7	25.1	12.0	17.9	18.7	8.9	14.7	16.2	15.2	51.8	28.2	24.8	24.4	18.5	13.7	69.8	50.4	44.3
Standard Deviation		10.3	2.6	1.9	1.8	1.6	1.1	2.5	2.6	22.5	7.9	6.3	8.9	12.2	6.9	10.3	7.4	13.9	19.4
Max		55.6	30.8	15.4	20.7	20.9	11.0	18.7	19.5	47.3	65.0	35.5	37.7	38.3	33.5	42.2	84.5	70.5	69.8
Min		20.8	22.1	8.3	15.4	15.1	7.4	11.5	10.4	-31.3	41.4	16.9	11.3	-7.2	9.7	1.0	62.0	32.7	15.9

Note: Overall removal is based on raw sewage concentration.

Table A - 11. Phase 2 TP results.

PROJECT PHASE	SAMPLING DATE	TP (mg P/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 2	08-17-04	5.20	4.30	3.80	3.70	3.90	3.80	3.80	3.85	17.3	11.6	14.0	9.3	0.0	-2.7	1.3	26.9	26.9	26.0
Phase 2	08-24-04	4.30	4.00	4.15	4.30	4.00	3.40	4.55	3.30	7.0	-3.7	-7.5	0.0	18.1	-5.8	17.5	20.9	-5.8	23.3
Phase 2	09-08-04	3.60	4.05	3.60	3.95	3.70	3.30	3.90	3.50	-12.5	11.1	2.5	8.6	8.3	1.3	5.4	8.3	-8.3	2.8
Phase 2	09-14-04	2.45	4.00	3.65	3.70	3.50	3.10	3.80	3.40	-63.3	8.8	7.5	12.5	15.1	-2.7	2.9	-26.5	-55.1	-38.8
Phase 2	09-21-04	10.20	3.30	3.25	4.15	3.30	3.05	4.25	2.95	67.6	1.5	-25.8	0.0	6.2	-2.4	10.6	70.1	58.3	71.1
Phase 2	09-28-04	4.70	3.75	3.25	4.45	3.80	3.15	4.05	3.45	20.2	13.3	-18.7	-1.3	3.1	9.0	9.2	33.0	13.8	26.6
Phase 2	10-05-04	5.20	4.00	3.25	3.85	3.55	3.20	4.05	3.75	23.1	18.8	3.8	11.3	1.5	-5.2	-5.6	38.5	22.1	27.9
Phase 2	10-12-04	12.20	3.70	3.25	3.90	3.30	2.95	3.95	3.05	69.7	12.2	-5.4	10.8	9.2	-1.3	7.6	75.8	67.6	75.0
Phase 2	10-19-04	4.60	4.10	3.30	3.50	3.15	2.50	3.50	3.05	10.9	19.5	14.6	23.2	24.2	0.0	3.2	45.7	23.9	33.7
Phase 2	10-26-04	4.20	3.70	3.20	3.90	3.35	3.20	4.15	3.35	11.9	13.5	-5.4	9.5	0.0	-6.4	0.0	23.8	1.2	20.2
Phase 2	11-02-04	11.90	3.60	3.20	2.90	2.85	2.75	2.80	2.95	69.7	11.1	19.4	20.8	14.1	3.4	-3.5	76.9	76.5	75.2
Number		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Mean		6.23	3.86	3.45	3.85	3.49	3.13	3.89	3.33	20.2	10.7	-0.1	9.5	9.1	-1.2	4.4	35.8	20.1	31.2
Standard Deviation		3.46	0.28	0.31	0.42	0.34	0.34	0.45	0.31	39.4	6.8	14.1	7.9	8.0	4.5	6.6	31.1	38.1	33.8
Max		12.20	4.30	4.15	4.45	4.00	3.80	4.55	3.85	69.7	19.5	19.4	23.2	24.2	9.0	17.5	76.9	76.5	75.2
Min		2.45	3.30	3.20	2.90	2.85	2.50	2.80	2.95	-63.3	-3.7	-25.8	-1.3	0.0	-6.4	-5.6	-26.5	-55.1	-38.8

Note: Overall removal is based on raw sewage concentration.

Table A - 12. Phase 2 E.coli results.

PROJECT PHASE	SAMPLING DATE	E.coli (10^3 cfu/100mL) McMaster Lab data					
		SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4
Phase 2	08-17-04	1200.0	2000.0	2500.0	1.3	28.0	820.0
Phase 2	08-24-04	720.0	3400.0	2600.0	2.0	110.0	1800.0
Phase 2	09-08-04	670.0	860.0	2600.0	4.6	41.0	1100.0
Phase 2	09-14-04						
Phase 2	09-21-04	730.0	900.0	1300.0	1.0	88.0	800.0
Phase 2	09-28-04	1800.0	2700.0	2300.0	55.0	150.0	1300.0
Phase 2	10-05-04	10.0	1600.0	2000.0	0.6	780.0	1200.0
Phase 2	10-12-04	1300.0	2800.0	3400.0	24.0	1000.0	2200.0
Phase 2	10-19-04	1400.0	2400.0	2700.0	17.0	570.0	800.0
Phase 2	10-26-04	1100.0	1400.0	1500.0	2.0	380.0	580.0
Phase 2	11-02-04	540.0	570.0	790.0	3.7	260.0	330.0
Number		10	10	10	10	10	10
Mean		947.0	1863.0	2169.0	11.1	340.7	1093.0
Standard Deviation		512.5	950.8	776.6	17.3	338.2	564.8
Max		1800.0	3400.0	3400.0	55.0	1000.0	2200.0
Min		10.0	570.0	790.0	0.6	28.0	330.0

Table A - 13. Phase 3 $cBOD_5$ results.

PROJECT	SAMPLING	$cBOD_5$ (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 3	11-30-04	86	35.7	7.9	19.6	15	3.5	17.5	10	58.5	77.9	45.1	58.0	55.7	10.7	33.3	95.9	79.7	88.4
Phase 3	12-7-04	86.7	57.3	13	35.3	29.9	3.9	14.7	17.8	33.9	77.3	38.4	47.8	70.0	58.4	40.5	95.5	83.0	79.5
Phase 3	12-14-04	97.6	84.2	12	29.2	38.6	6	26.2	23.4	13.7	85.7	65.3	54.2	50.0	10.3	39.4	93.9	73.2	76.0
Phase 3	12-21-04	91.2	66.2	15	40.3		5.2	27.4	19.7	27.4	77.3	39.1		65.3	32.0		94.3	70.0	78.4
Phase 3	12-28-04	141	55.2	13	34.1	25.6	5.8	17.8	14.4	60.9	76.4	38.2	53.6	55.4	47.8	43.8	95.9	87.4	89.8
Phase 3	1-4-05	55.6	34.8	8.5	17.2	13.6	3.5	12.1	8.7	37.4	75.6	50.6	60.9	58.8	29.7	36.0	93.7	78.2	84.4
Phase 3	1-11-05	93.9	34.6	10.2	22.6	22.6	5.3	16.8	16.3	63.2	70.5	34.7	34.7	48.0	25.7	27.9	94.4	82.1	82.6
Phase 3	1-25-05	95.7	31	10.2	22.8	23.5	4.2	16.9	9.1	67.6	67.1	26.5	24.2	58.8	25.9	61.3	95.6	82.3	90.5
Phase 3	2-1-05	81.3	48.5	16.1	36.4	25.3	6.6	16.7	12.5	40.3	66.8	24.9	47.8	59.0	54.1	50.6	91.9	79.5	84.6
Phase 3	2-8-05	89.8	41.8	12.6	23.1	17.1	6.3	16.6	11.6	53.5	69.9	44.7	59.1	50.0	28.1	32.2	93.0	81.5	87.1
Phase 3	2-15-05	99.4	50.9	8.2	18.6	14.5	5.9	14.4	11.7	48.8	83.9	63.5	71.5	28.0	22.6	19.3	94.1	85.5	88.2
Phase 3	2-22-05	78	48.8	12.4	26.5	23.5	5.8	17.7	15.6	37.4	74.6	45.7	51.8	53.2	33.2	33.6	92.6	77.3	80.0
Phase 3	3-1-05	91	83.4	16.2	35.7	27.3	10.1	30.4	25.7	8.4	80.6	57.2	67.3	37.7	14.8	5.9	88.9	66.6	71.8
Phase 3	3-8-05	57.3	37.7	10.9	22.3	17.7	7.6	14.4	13.1	34.2	71.1	40.8	53.1	30.3	35.4	26.0	86.7	74.9	77.1
Phase 3	3-15-05	114	43.8	11.6	23.9	17.5	6.8	16.9	13.3	61.6	73.5	45.4	60.0	41.4	29.3	24.0	94.0	85.2	88.3
Phase 3	3-29-05	90	65.8	16.2		30.2	8.9		20.9	26.9	75.4		54.1	45.1		30.8	90.1		76.8
Number		16	16	16	15	15	16	15	16	16	16	15	15	16	15	15	16	15	16
Mean		90.5	51.2	12.1	27.2	22.8	6.0	18.4	15.2	42.1	75.2	44.0	53.2	50.4	30.5	33.6	93.2	79.1	82.7
Standard Deviation		19.8	16.6	2.8	7.4	7.0	1.8	5.3	5.1	18.0	5.4	11.7	11.8	11.7	14.2	13.1	2.6	5.9	5.8
Max		141.0	84.2	16.2	40.3	38.6	10.1	30.4	25.7	67.6	85.7	65.3	71.5	70.0	58.4	61.3	95.9	87.4	90.5
Min		55.6	31.0	7.9	17.2	13.6	3.5	12.1	8.7	8.4	66.8	24.9	24.2	28.0	10.3	5.9	86.7	66.6	71.8

Note: Overall removal is based on raw sewage concentration.

Table A - 14. Phase 3 TSS results.

PROJECT	SAMPLING	TSS (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 3	11-30-04	126	35.3	14.3	26.8	20.9	12.7	19.2	19	72.0	59.5	24.1	40.8	11.2	28.4	9.1	89.9	84.8	84.9
Phase 3	12-7-04	170.4	56.5	21.2	38.7	36.5	14.4	38.9	27.1	66.8	62.5	31.5	35.4	32.1	-0.5	25.8	91.5	77.2	84.1
Phase 3	12-14-04	137	47.7	20.7	41.7	33.4	14.8	137.9	94.4	65.2	56.6	12.6	30.0	28.5	-230.7	-182.6	89.2	-0.7	31.1
Phase 3	12-21-04	199.8	43.3	19.1	35.3		11.7	32.4	27.8	78.3	55.9	18.5		38.7	8.2		94.1	83.8	86.1
Phase 3	12-28-04	200.2	46.5	20	44.7	33.8	13.4	26.8	25.4	76.8	57.0	3.9	27.3	33.0	40.0	24.9	93.3	86.6	87.3
Phase 3	1-4-05	82.8	35.2	12.8	20.7	17.7	6.5	16.8	14.5	57.5	63.6	41.2	49.7	49.2	18.8	18.1	92.1	79.7	82.5
Phase 3	1-11-05	274.4	45	21.2	37	37.9	14	30.5	28.5	83.6	52.9	17.8	15.8	34.0	17.6	24.8	94.9	88.9	89.6
Phase 3	1-25-05	130.8	44.4	21.9	40.1	44.8	15.6	31.6	27.9	66.1	50.7	9.7	-0.9	28.8	21.2	37.7	88.1	75.8	78.7
Phase 3	2-1-05	236.4	57.2	21.1	53.6	36.8	15	37.3	30.9	75.8	63.1	6.3	35.7	28.9	30.4	16.0	93.7	84.2	86.9
Phase 3	2-8-05	243.6	50.7	19.4	34.5	27.2	10.4	27.9	22.3	79.2	61.7	32.0	46.4	46.4	19.1	18.0	95.7	88.5	90.8
Phase 3	2-15-05	222.2	47.8	23.2	45	30.2	15.5	30.4	25.2	78.5	51.5	5.9	36.8	33.2	32.4	16.6	93.0	86.3	88.7
Phase 3	2-22-05	247.2	50.9	23.3	41.9	40.9	14.1	33.5	32.5	79.4	54.2	17.7	19.6	39.5	20.0	20.5	94.3	86.4	86.9
Phase 3	3-1-05	202.2	54.3	27.1	44.4	44.9	17	31.3	33.8	73.1	50.1	18.2	17.3	37.3	29.5	24.7	91.6	84.5	83.3
Phase 3	3-8-05	173.4	42	19	37	37.1	14	35.1	32.4	75.8	54.8	11.9	11.7	26.3	5.1	12.7	91.9	79.8	81.3
Phase 3	3-15-05	246.6	56.2	20.7	40.6	39.6	22.1	34.4	31.5	77.2	63.2	27.8	29.5	-6.8	15.3	20.5	91.0	86.1	87.2
Phase 3	3-29-05	225.4	79.2	32.8		51.5	21.3		40.8	64.9	58.6		35.0	35.1		20.8	90.6		81.9
Number		16	16	16	15	15	16	15	16	16.0	16.0	15.0	15.0	16.0	15.0	15.0	16.0	15.0	16.0
Mean		194.9	49.5	21.1	38.8	35.5	14.5	37.6	32.1	73.1	57.2	18.6	28.7	31.0	3.7	7.2	92.2	78.1	82.0
Standard Deviation		53.8	10.4	4.6	7.8	9.0	3.7	28.4	17.7	7.1	4.7	10.9	13.8	13.2	65.7	52.9	2.1	22.1	13.9
Max		274.4	79.2	32.8	53.6	51.5	22.1	137.9	94.4	83.6	63.6	41.2	49.7	49.2	40.0	37.7	95.7	88.9	90.8
Min		82.8	35.2	12.8	20.7	17.7	6.5	16.8	14.5	57.5	50.1	3.9	-0.9	-6.8	-230.7	-182.6	88.1	-0.7	31.1

Note: Overall removal is based on raw sewage concentration.

Table A - 15. Phase 3 TAN results.

PROJECT PHASE	SAMPLING DATE	TAN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 3	11-30-04	12.4	15.6	7	15.2	13.3	2.98	14.9	12.9	-25.8	55.1	2.6	14.7	57.4	2.0	3.0	80.9	4.5	17.3
Phase 3	12-7-04	13.7	18.6	6.5	16.7	15.3	2.38	16.6	13.8	-35.8	65.1	10.2	17.7	63.4	0.6	9.8	87.2	10.8	25.8
Phase 3	12-14-04	17.4	17.1	6.1	15.8	13.8	3.62	17.7	12.5	1.7	64.3	7.6	19.3	40.7	-12.0	9.4	79.2	-1.7	28.2
Phase 3	12-21-04	17.3	16.9	7.55	17.4		4.36	17	14.1	2.3	55.3	-3.0		42.3	2.3		74.8	1.7	18.5
Phase 3	12-28-04	16.3	17.3	8.85	16.9	16.4	7.7	16.8	14.5	-6.1	48.8	2.3	5.2	13.0	0.6	11.6	55.5	2.9	16.2
Phase 3	1-4-05	8.5	14.9	6.3	14	11	5.35	14.6	9.4	-75.3	57.7	6.0	26.2	15.1	-4.3	14.5	64.1	2.0	36.9
Phase 3	1-11-05	11.8	16.2	9.6	16.6	14.9	7.6	16.6	14	-37.3	40.7	-2.5	8.0	20.8	0.0	6.0	53.1	-2.5	13.6
Phase 3	1-25-05	13.1	17.1	6.85	16.5	14.6	3.35	16.4	12.1	-30.5	59.9	3.5	14.6	51.1	0.6	17.1	80.4	4.1	29.2
Phase 3	2-1-05	12.5	18.6	10.5	16.9	15.2	7.65	16.7	13.6	-48.8	43.5	9.1	18.3	27.1	1.2	10.5	58.9	10.2	26.9
Phase 3	2-8-05	12.6	17.5	9.85	16	14.3	7.85	15.6	12.6	-38.9	43.7	8.6	18.3	20.3	2.5	11.9	55.1	10.9	28.0
Phase 3	2-15-05	11	14.6	8.5	15.2	13.6	6.6	14.4	12.3	-32.7	41.8	-4.1	6.8	22.4	5.3	9.6	54.8	1.4	15.8
Phase 3	2-22-05	11.3	16.8	7.75	15.1	13.7	5.45	15	13	-48.7	53.9	10.1	18.5	29.7	0.7	5.1	67.6	10.7	22.6
Phase 3	3-1-05	10.7	17.1	9.7	15.1	13.7	8.05	15.4	13.3	-59.8	43.3	11.7	19.9	17.0	-2.0	2.9	52.9	9.9	22.2
Phase 3	3-8-05	9.1	16	10.5	14.8	13.6	9.1	14.4	12.7	-75.8	34.7	7.5	15.0	12.9	2.7	6.6	43.1	10.0	20.6
Phase 3	3-15-05	13.6	17.5	11.4	15.4	14.2	8.4	14.9	13	-28.7	34.9	12.0	18.9	26.3	3.2	8.5	52.0	14.9	25.7
Phase 3	3-29-05	12.6	15.8	10.2		14.4	8.4		13.7	-25.4	35.4		8.9	17.6		4.9	46.8		13.3
Number		16	16	16	15	15	16	15	16	16	16	15	15	16	15	15	16	15	16
Mean		12.74	16.73	8.57	15.84	14.13	6.18	15.80	12.97	-35.3	48.6	5.4	15.4	29.8	0.2	8.8	62.9	6.0	22.5
Standard Deviation		2.56	1.15	1.73	0.96	1.20	2.24	1.08	1.18	23.3	10.3	5.4	5.8	16.2	4.1	4.1	13.7	5.3	6.6
Max		17.40	18.60	11.40	17.40	16.40	9.10	17.70	14.50	2.3	65.1	12.0	26.2	63.4	5.3	17.1	87.2	14.9	36.9
Min		8.50	14.60	6.10	14.00	11.00	2.38	14.40	9.40	-75.8	34.7	-4.1	5.2	12.9	-12.0	2.9	43.1	-2.5	13.3

Note: Overall removal is based on raw sewage or primary septic tank sewage concentration which ever is higher.

Table A - 16. Phase 3 TN results.

PROJECT PHASE	SAMPLING DATE	TN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 3	11-30-04	19.7	20.9	13.8	18.4	18	13.5	18.6	17.1	-6.1	34.0	12.0	13.9	2.2	-1.1	5.0	31.5	5.6	13.2
Phase 3	12-7-04	15.3	18	11.5	15.7	14.5	10.9	15.4	14.2	-17.6	36.1	12.8	19.4	5.2	1.9	2.1	28.8	-0.7	7.2
Phase 3	12-14-04	26.3	23.2	13.7	21.2	19.6	12.9	26.1	19.6	11.8	40.9	8.6	15.5	5.8	-23.1	0.0	51.0	0.8	25.5
Phase 3	12-21-04	26.4	23.6	15.9	22.4		14.1	22.5	19.3	10.6	32.6	5.1		11.3	-0.4		46.6	14.8	26.9
Phase 3	12-28-04	28.8	24.3	15.7	22.3	19	14.8	21.2	18.4	15.6	35.4	8.2	21.8	5.7	4.9	3.2	48.6	26.4	36.1
Phase 3	1-4-05	14.9	22.7	15.1	18.1	16.8	12	18.4	15.5	-52.3	33.5	20.3	26.0	20.5	-1.7	7.7	19.5	-23.5	-4.0
Phase 3	1-11-05	23	25.6	16.3	21.8	20.5	14.5	21.7	18.8	-11.3	36.3	14.8	19.9	11.0	0.5	8.3	37.0	5.7	18.3
Phase 3	1-25-05	21.5	25.1	15.4	20.5	19.4	13.2	20.4	17.1	-16.7	38.6	18.3	22.7	14.3	0.5	11.9	38.6	5.1	20.5
Phase 3	2-1-05	21.6	27.2	15.9	22.7	20.7	14.2	22	19.5	-25.9	41.5	16.5	23.9	10.7	3.1	5.8	34.3	-1.9	9.7
Phase 3	2-8-05	23.5	28.1	15.5	22.2	20.8	14.6	22.2	18.9	-19.6	44.8	21.0	26.0	5.8	0.0	9.1	37.9	5.5	19.6
Phase 3	2-15-05	19.2	22.6	14.4	20	18.9	13.8	19.8	18.1	-17.7	36.3	11.5	16.4	4.2	1.0	4.2	28.1	-3.1	5.7
Phase 3	2-22-05	21.2	25.6	14.4	21.6	19.2	12.4	20.3	18.3	-20.8	43.8	15.6	25.0	13.9	6.0	4.7	41.5	4.2	13.7
Phase 3	3-1-05	21.9	27.8	15.3	20.6	19.7	13.9	21.2	18.7	-26.9	45.0	25.9	29.1	9.2	-2.9	5.1	36.5	3.2	14.6
Phase 3	3-8-05	17.3	26.8	15.3	19.9	19.6	14.9	19.8	18.8	-54.9	42.9	25.7	26.9	2.6	0.5	4.1	13.9	-14.5	-8.7
Phase 3	3-15-05	26.9	27.2	15.6	20.2	19.2	13.9	19.9	18.7	-1.1	42.6	25.7	29.4	10.9	1.5	2.6	48.3	26.0	30.5
Phase 3	3-29-05	16.4	22.1	14.7		19.3	13.2		19.2	-34.8	33.5		12.7	10.2		0.5	19.5		-17.1
Number		16	16	16	15	15	16	15	16	16	16	15	15	16	15	15	16	15	16
Mean		21.5	24.4	14.9	20.5	19.0	13.6	20.6	18.1	-16.7	38.6	16.1	21.9	9.0	-0.6	4.9	35.1	3.6	13.2
Standard Deviation		4.2	2.8	1.2	1.9	1.6	1.1	2.4	1.5	20.4	4.4	6.6	5.4	4.9	6.6	3.2	11.1	12.9	14.3
Max		28.8	28.1	16.3	22.7	20.8	14.9	26.1	19.6	15.6	45.0	25.9	29.4	20.5	6.0	11.9	51.0	26.4	36.1
Min		14.9	18.0	11.5	15.7	14.5	10.9	15.4	14.2	-54.9	32.6	5.1	12.7	2.2	-23.1	0.0	13.9	-23.5	-17.1

Note: Overall removal is based on raw sewage concentration.

Table A - 17. Phase 3 TP results.

PROJECT PHASE	SAMPLING DATE	TP (mg P/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 3	11-30-04	2.95	1.3	1	1.25	1.1	1.5	1.1	0.9	55.9	23.1	3.8	15.4	-50.0	12.0	18.2	49.2	62.7	69.5
Phase 3	12-7-04	3.35	3.8	1.55	2.35	2.65	1.55	2.75	2.15	-13.4	59.2	38.2	30.3	0.0	-17.0	18.9	53.7	17.9	35.8
Phase 3	12-14-04	3.65	3.4	2.25	2.15	2.2	1.65	2.4	2	6.8	33.8	36.8	35.3	26.7	-11.6	9.1	54.8	34.2	45.2
Phase 3	12-21-04	3.1	3	2.15	2.7		1.8	2.35	2.35	3.2	28.3	10.0		16.3	13.0		41.9	24.2	24.2
Phase 3	12-28-04	4.1	1.5	1.45	1.8	1.95	1.4	1.3	1.35	63.4	3.3	-20.0	-30.0	3.4	27.8	30.8	65.9	68.3	67.1
Phase 3	1-4-05	2.4	1.55	0.8	0.7	0.8	0.3	0.65	0.6	35.4	48.4	54.8	48.4	62.5	7.1	25.0	87.5	72.9	75.0
Phase 3	1-11-05	3.45	2.15	1.02	1.36	1.36	0.84	1.06	1.12	37.7	52.6	36.7	36.7	17.6	22.1	17.6	75.7	69.3	67.5
Phase 3	1-25-05	3.5	2.15	1.06	1.34	1.4	0.82	1.2	0.98	38.6	50.7	37.7	34.9	22.6	10.4	30.0	76.6	65.7	72.0
Phase 3	2-1-05	3.35	1.9	1	1.6	1.22	0.8	1.3	0.94	43.3	47.4	15.8	35.8	20.0	18.8	23.0	76.1	61.2	71.9
Phase 3	2-8-05	3.9	2.1	1.04	1.24	1.14	0.86	0.96	1	46.2	50.5	41.0	45.7	17.3	22.6	12.3	77.9	75.4	74.4
Phase 3	2-15-05	4.1	1.5	1.18	1.36	1.22	0.94	1.2	0.82	63.4	21.3	9.3	18.7	20.3	11.8	32.8	77.1	70.7	80.0
Phase 3	2-22-05	3.95	2.06	1	1.58	1.36	0.78	1.26	1.16	47.8	51.5	23.3	34.0	22.0	20.3	14.7	80.3	68.1	70.6
Phase 3	3-1-05	4.45	1.74	1.12	1.26	1.26	0.56	1.3	1.06	60.9	35.6	27.6	27.6	50.0	-3.2	15.9	87.4	70.8	76.2
Phase 3	3-8-05	3.3	2.08	1.02	1.52	1.4	0.84	1.16	1.06	37.0	51.0	26.9	32.7	17.6	23.7	24.3	74.5	64.8	67.9
Phase 3	3-15-05	4.4	1.58	0.94	1.22	1.1	0.82	1.12	0.98	64.1	40.5	22.8	30.4	12.8	8.2	10.9	81.4	74.5	77.7
Phase 3	3-29-05	3.65	2.86	1.78		2.2	1.4		1.88	21.6	37.8		23.1	21.3		14.5	61.6		48.5
Number		16	16	16	15	15	16	15	16	16	16	15	15	16	15	15	16	15	16
Mean		3.60	2.17	1.27	1.56	1.49	1.05	1.41	1.27	38.2	39.7	24.3	27.9	17.5	11.1	19.9	70.1	60.1	64.0
Standard Deviation		0.54	0.73	0.44	0.51	0.52	0.43	0.59	0.52	23.3	14.8	18.5	18.3	23.6	13.0	7.5	13.9	18.6	16.4
Max		4.45	3.80	2.25	2.70	2.65	1.80	2.75	2.35	64.1	59.2	54.8	48.4	62.5	27.8	32.8	87.5	75.4	80.0
Min		2.40	1.30	0.80	0.70	0.80	0.30	0.65	0.60	-13.4	3.3	-20.0	-30.0	-50.0	-17.0	9.1	41.9	17.9	24.2

Note: Overall removal is based on raw sewage concentration.

Table A - 18. Phase 3 E.coli results.

PROJECT PHASE	SAMPLING DATE	E.coli (10^3 cfu/100mL) McMaster Lab data					
		SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4
Phase 3	11-30-04	70	80	60	34	120	120
Phase 3	12-7-04	650	1500	1200	150	1300	970
Phase 3	12-14-04	470	970	1300	370	980	930
Phase 3	12-21-04	510	1000		350	970	750
Phase 3	12-28-04						
Phase 3	1-4-05	11	8.3	6.1	5.3	9.5	1.4
Phase 3	1-11-05	110	230	220	840	160	160
Phase 3	1-25-05	190	390	330	87	210	260
Phase 3	2-1-05	170	270	260	120	190	170
Phase 3	2-8-05	90	220	190	68	180	170
Phase 3	2-15-05						
Phase 3	2-22-05	130	340	220	66	380	270
Phase 3	3-1-05	40	220	200	2.7	8.1	21
Phase 3	3-8-05	96	210	230	52	270	160
Phase 3	3-15-05	140	530	340	96	120	390
Phase 3	3-29-05						
Number		13	13	12	13	13	13
Mean		205.9	459.1	379.7	172.4	376.7	336.3
Standard Deviation		202.0	435.2	418.0	231.9	421.4	330.9
Max		650.0	1500.0	1300.0	840.0	1300.0	970.0
Min		11.0	8.3	6.1	2.7	8.1	1.4

Table A - 19. Phase 4 cBOD$_5$ results.

PROJECT PHASE	SAMPLING DATE	cBOD$_5$ (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	49.6	25.6	6.8	15.8	11.1	3	10.6	11.2	48.4	73.4	38.3	56.6	55.9	32.9	-0.9	94.0	78.6	77.4
Phase 4	4-12-05																		
Phase 4	4-19-05	62.9	41.3	13.2	25.6	17.2	5.5	14.6	10.5	34.3	68.0	38.0	58.4	58.3	43.0	39.0	91.3	76.8	83.3
Phase 4	4-26-05	79	40.2	10.5	27.1	17.6	4.7	16.3	11.6	49.1	73.9	32.6	56.2	55.2	39.9	34.1	94.1	79.4	85.3
Phase 4	5-3-05	50	78.6	25.2	15.4	15.2	3.8	9.3	8.5	-57.2	67.9	80.4	80.7	84.9	39.6	44.1	92.4	81.4	83.0
Phase 4	5-10-05	67.2	60.8	8.7	21.2	11.5	3.4	8.1	6.2	9.5	85.7	65.1	81.1	60.9	61.8	46.1	94.9	87.9	90.8
Phase 4	5-17-05	50.2	32.8	29.3	26.5	40.3	3.9	14.7	17.2	34.7	10.7	19.2	-22.9	86.7	44.5	57.3	92.2	70.7	65.7
Phase 4	5-23-05	67.1	51.4	11.1	17.4		2.9	9.7		23.4	78.4	66.1		73.9	44.3		95.7	85.5	
Phase 4	5-31-05	48.5	41.2	9.3	10.9	14.8	3.9	5.4	7.5	15.1	77.4	73.5	64.1	58.1	50.5	49.3	92.0	88.9	84.5
Phase 4	6-7-05	55.7	34.9	11.4	15.7	16.2	4.5	8.2	8.4	37.3	67.3	55.0	53.6	60.5	47.8	48.1	91.9	85.3	84.9
Phase 4	6-14-05	78	57.3		12.7	15.7		5.9	6.7	26.5		77.8	72.6		53.5	57.3		92.4	91.4
Phase 4	6-21-05	164	85.9		21.8	18.6		10.3	7.7	47.6		74.6	78.3		52.8	58.6		93.7	95.3
Phase 4	6-28-05	90.2	82.6		29.6	36.4		11.8	12.7	8.4		64.2	55.9		60.1	65.1		86.9	85.9
Number		12	12	9	12	11	9	12	11	12	9	12	11	9	12	11	9	12	11
Mean		71.9	52.7	13.9	20.0	19.5	4.0	10.4	9.8	23.1	67.0	57.1	57.7	66.0	47.5	45.3	93.2	84.0	84.3
Standard Deviation		32.0	20.5	7.8	6.2	9.6	0.8	3.4	3.2	29.1	21.9	20.2	28.8	12.5	8.6	17.8	1.5	6.8	7.8
Max		164.0	85.9	29.3	29.6	40.3	5.5	16.3	17.2	49.1	85.7	80.4	81.1	86.7	61.8	65.1	95.7	93.7	95.3
Min		48.5	25.6	6.8	10.9	11.1	2.9	5.4	6.2	-57.2	10.7	19.2	-22.9	55.2	32.9	-0.9	91.3	70.7	65.7

Note: Overall removal is based on raw sewage concentration.

Table A - 20. Phase 4 TSS results.

PROJECT	SAMPLING	TSS (mg/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	90.8	31.4	11.8	28.6	19.7	5.6	22.2	15.4	65.4	62.4	8.9	37.3	52.5	22.4	21.8	93.8	75.6	83.0
Phase 4	4-12-05	86.6	38.6	17	32.1	23.3	6.2	24.9	18.5	55.4	56.0	16.8	39.6	63.5	22.4	20.6	92.8	71.2	78.6
Phase 4	4-19-05	110.2	49.7	21.8	42.2	30.3	16.3	34.1	22.2	54.9	56.1	15.1	39.0	25.2	19.2	26.7	85.2	69.1	79.9
Phase 4	4-26-05	133	41.6	15.2	37.7	25.1	9.7	31	20	68.7	63.5	9.4	39.7	36.2	17.8	20.3	92.7	76.7	85.0
Phase 4	5-3-05	101.8	35.3	14	25.4	21	9.2	17.7	16.8	65.3	60.3	28.0	40.5	34.3	30.3	20.0	91.0	82.6	83.5
Phase 4	5-10-05	125.6	40.8	20.8	30.3	20.4	12.9	15.2	13.8	67.5	49.0	25.7	50.0	38.0	49.8	32.4	89.7	87.9	89.0
Phase 4	5-17-05	128.8	34.8	17.3	25.7	26.1	11	17.9	17.8	73.0	50.3	26.1	25.0	36.4	30.4	31.8	91.5	86.1	86.2
Phase 4	5-23-05	112.6	34.1	14	22		6.6	15.2		69.7	58.9	35.5		52.9	30.9		94.1	86.5	
Phase 4	5-31-05	119.8	42.9	22.3	26.7	27.6	9.3	14	16.4	64.2	48.0	37.8	35.7	58.3	47.6	40.6	92.2	88.3	86.3
Phase 4	6-7-05	122.4	32.9	24	28.5	31.5	12.6	17	14.5	73.1	27.1	13.4	4.3	47.5	40.4	54.0	89.7	86.1	88.2
Phase 4	6-14-05	163	25.8		18.2	20.4		13.6	12.8	84.2		29.5	20.9		25.3	37.3		91.7	92.1
Phase 4	6-21-05	210.4	23.2		25.9	18.6		14.9	11.3	89.0		-11.6	19.8		42.5	39.2		92.9	94.6
Phase 4	6-28-05	149.4	37.8		38.2	35.1		24.7	17.2	74.7		-1.1	7.1		35.3	51.0		83.5	88.5
Number		13	13	10	13	12	10	13	12	13.0	10.0	13.0	12.0	10.0	13.0	12.0	10.0	13.0	12.0
Mean		127.3	36.1	17.8	29.3	24.9	9.9	20.2	16.4	69.6	53.2	18.0	29.9	44.5	31.9	33.0	91.3	82.9	86.2
Standard Deviation		32.8	7.1	4.2	6.8	5.3	3.4	6.7	3.1	9.7	10.7	14.4	14.3	12.2	10.6	11.8	2.6	7.6	4.7
Max		210.4	49.7	24.0	42.2	35.1	16.3	34.1	22.2	89.0	63.5	37.8	50.0	63.5	49.8	54.0	94.1	92.9	94.6
Min		86.6	23.2	11.8	18.2	18.6	5.6	13.6	11.3	54.9	27.1	-11.6	4.3	25.2	17.8	20.0	85.2	69.1	78.6

Note: Overall removal is based on raw sewage concentration.

Table A - 21. Phase 4 TAN results

PROJECT	SAMPLING	TAN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	13.20	12.90	6.20	12.30	10.40	3.95	11.50	9.50	2.3	51.9	4.7	19.4	36.3	6.5	8.7	70.1	12.9	28.0
Phase 4	4-12-05	14.80	17.40	8.65	13.30	12.30	6.50	13.20	12.00	-17.6	50.3	23.6	29.3	24.9	0.8	2.4	56.1	10.8	18.9
Phase 4	4-19-05	15.70	17.80	11.40	14.60	12.90	8.05	13.80	12.20	-13.4	36.0	18.0	27.5	29.4	5.5	5.4	48.7	12.1	22.3
Phase 4	4-26-05	14.90	16.10	6.70	14.40	12.40	4.80	13.30	10.70	-8.1	58.4	10.6	23.0	28.4	7.6	13.7	67.8	10.7	28.2
Phase 4	5-3-05	15.90	16.30	8.05	12.60	11.20	3.90	9.50	10.20	-2.5	50.6	22.7	31.3	51.6	24.6	8.9	75.5	40.3	35.8
Phase 4	5-10-05	16.60	22.00	4.40	14.50	11.60	1.80	12.90	9.20	-32.5	80.0	34.1	47.3	59.1	11.0	20.7	89.2	22.3	44.6
Phase 4	5-17-05	15.50	19.40	9.00	11.50	11.60	3.80	7.10	8.60	-25.2	53.6	40.7	40.2	57.8	38.3	25.9	75.5	54.2	44.5
Phase 4	5-23-05	18.50	18.40	9.50	12.70		5.20	9.50		0.5	48.4	31.0		45.3	25.2		71.9	48.6	
Phase 4	5-31-05	14.70	21.40	8.50	9.60	10.80	5.85	8.30	7.95	-45.6	60.3	55.1	49.5	31.2	13.5	26.4	60.2	43.5	45.9
Phase 4	6-7-05	13.40	16.90	8.15	8.65	9.90	5.65	6.75	7.90	-26.1	51.8	48.8	41.4	30.7	22.0	20.2	57.8	49.6	41.0
Phase 4	6-14-05	13.50	17.00		7.00	10.20		5.20	7.55	-25.9		58.8	40.0		25.7	26.0		61.5	44.1
Phase 4	6-21-05	14.10	14.10		8.65	9.10		6.50	6.90	0.0		38.7	35.5		24.9	24.2		53.9	51.1
Phase 4	6-28-05	21.60	25.90		8.75	12.60		5.80	8.90	-19.9		66.2	51.4		33.7	29.4		73.1	58.8
Number		13	13	10	13	12	10	13	12	13	10	13	12	10	13	12	10	13	12
Mean		15.57	18.12	8.06	11.43	11.25	4.95	9.49	9.30	-16.5	54.1	34.8	36.3	39.4	18.4	17.7	67.3	38.0	38.6
Standard Deviation		2.32	3.44	1.93	2.60	1.19	1.72	3.14	1.70	14.6	11.2	18.9	10.4	12.9	11.7	9.4	11.8	21.6	12.1
Max		21.60	25.90	11.40	14.60	12.90	8.05	13.80	12.20	2.3	80.0	66.2	51.4	59.1	38.3	29.4	89.2	73.1	58.8
Min		13.20	12.90	4.40	7.00	9.10	1.80	5.20	6.90	-45.6	36.0	4.7	19.4	24.9	0.8	2.4	48.7	10.7	18.9

Note: Overall removal is based on raw sewage or primary septic tank sewage concentration which ever is higher.

Table A - 22. Phase 4 TN Results.

PROJECT PHASE	SAMPLING DATE	TN (mg N/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
		Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	27.1	21.8	11.8	17.8	15.8	10.2	17.2	15.4	19.6	45.9	18.3	27.5	13.6	3.4	2.5	62.4	36.5	43.2
Phase 4	4-12-05	21.4	24.7	14.0	18.5	17.4	12.6	18.2	17.1	-15.4	43.3	25.1	29.6	10.0	1.6	1.7	41.1	15.0	20.1
Phase 4	4-19-05	24.8	26.5	16.5	20.9	18.9	14.6	19.8	17.6	-6.9	37.7	21.1	28.7	11.5	5.3	6.9	41.1	20.2	29.0
Phase 4	4-26-05	22.7	24.5	11.9	19.0	17.0	11.0	18.4	15.9	-7.9	51.4	22.4	30.6	7.6	3.2	6.5	51.5	18.9	30.0
Phase 4	5-3-05	22.6	24.2	11.1	16.3	15.6	9.4	15.2	14.0	-7.1	54.1	32.6	35.5	15.3	6.7	10.3	58.4	32.7	38.1
Phase 4	5-10-05	26.2	29.6	10.5	19.7	17.1	8.1	17.7	14.1	-13.0	64.5	33.4	42.2	22.9	10.2	17.5	69.1	32.4	46.2
Phase 4	5-17-05	24.1	25.6	12.5	15.9	15.1	9.2	14.3	13.3	-6.2	51.2	37.9	41.0	26.4	10.1	11.9	61.8	40.7	44.8
Phase 4	5-23-05	29.2	25.0	15.1	19.4		11.4	18.3		14.4	39.6	22.4		24.5	5.7		61.0	37.3	
Phase 4	5-31-05	23.2	27.8	11.7	14.2	15.5	9.6	13.6	14.7	-19.8	57.9	48.9	44.2	17.9	4.2	5.2	58.6	41.4	36.6
Phase 4	6-7-05	22.4	22.7	12.5	13.5	15.1	9.7	12.2	12.7	-1.3	44.9	40.5	33.5	22.4	9.6	15.9	56.7	45.5	43.3
Phase 4	6-14-05	22.5	21.5		10.5	13.4		9.3	11.1	4.4		51.2	37.7		11.4	17.2		58.7	50.7
Phase 4	6-21-05	52.0	18.1		13.0	12.7		11.3	10.8	65.2		28.2	29.8		13.1	15.0		78.3	79.2
Phase 4	6-28-05	35.2	35.0		13.4	19.1		11.2	13.0	0.6		61.7	45.4		16.4	31.9		68.2	63.1
Number		13	13	10	13	12	10	13	12	13	10	13	12	10	13	12	10	13	12
Mean		27.2	25.2	12.8	16.3	16.1	10.6	15.1	14.1	2.0	49.1	34.1	35.5	17.2	7.8	11.9	56.2	40.4	43.7
Standard Deviation		8.3	4.2	1.9	3.2	2.0	1.9	3.4	2.1	22.0	8.4	13.3	6.5	6.6	4.4	8.4	9.1	18.8	15.8
Max		52.0	35.0	16.5	20.9	19.1	14.6	19.8	17.6	65.2	64.5	61.7	45.4	26.4	16.4	31.9	69.1	78.3	79.2
Min		21.4	18.1	10.5	10.5	12.7	8.1	9.3	10.8	-19.8	37.7	18.3	27.5	7.6	1.6	1.7	41.1	15.0	20.1

Note: Overall removal is based on raw sewage concentration.

Table A - 23. Phase 4 TP results.

PROJECT	SAMPLING	TP (mg P/L) McMaster Lab data								Removal (%)							Overall Removal (%)		
PHASE	DATE	Raw	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	PST	SST 1	SST 2	SST 4	Filter 1	Filter 2	Filter 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	3.10	1.54	0.84	1.20	1.00	0.66	1.04	0.74	50.3	45.5	22.1	35.1	21.4	13.3	26.0	78.7	66.5	76.1
Phase 4	4-12-05	3.20	2.16	0.92	1.32	1.02	0.54	1.02	0.72	32.5	57.4	38.9	52.8	41.3	22.7	29.4	83.1	68.1	77.5
Phase 4	4-19-05	4.90	2.12	1.28	1.52	1.34	0.89	1.15	0.85	56.7	39.6	28.3	36.8	30.5	24.3	36.6	81.8	76.5	82.7
Phase 4	4-26-05	4.00	2.12	0.86	1.66	1.18	0.54	1.12	0.75	47.0	59.4	21.7	44.3	37.2	32.5	36.4	86.5	72.0	81.3
Phase 4	5-3-05	4.20	1.80	0.88	1.10	0.94	0.60	0.73	0.70	57.1	51.1	38.9	47.8	31.8	33.6	25.5	85.7	82.6	83.3
Phase 4	5-10-05	4.70	1.92	0.96	1.30	0.98	0.63	0.76	0.64	59.1	50.0	32.3	49.0	34.4	41.5	34.7	86.6	83.8	86.4
Phase 4	5-17-05	3.95	1.62	0.76	0.94	0.91	0.63	0.66	0.59	59.0	53.1	42.0	43.8	17.1	29.8	35.2	84.1	83.3	85.1
Phase 4	5-23-05	4.05	1.52	0.74	0.83		0.61	0.63		62.5	51.3	45.4		17.6	24.1		84.9	84.4	
Phase 4	5-31-05	3.80	1.64	0.99	0.96	0.98	0.84	0.67	0.65	56.8	39.6	41.5	40.2	15.2	30.2	33.7	77.9	82.4	82.9
Phase 4	6-7-05	3.65	1.82	1.10	0.93	0.98	1.12	0.70	0.63	50.1	39.6	48.9	46.2	-1.8	24.7	35.7	69.3	80.8	82.7
Phase 4	6-14-05	4.10	1.46		0.71	0.69		0.52	0.52	64.4		51.4	52.7		26.8	24.6		87.3	87.3
Phase 4	6-21-05	7.10	0.94		0.93	0.74		0.77	0.55	86.8		1.1	21.3		17.2	25.7		89.2	92.3
Phase 4	6-28-05	5.50	1.90		1.19	1.34		0.99	0.81	65.5		37.4	29.5		16.8	39.6		82.0	85.3
Number		13	13	10	13	12	10	13	12	13	10	13	12	10	13	12	10	13	12
Mean		4.33	1.74	0.93	1.12	1.01	0.71	0.83	0.68	57.5	48.7	34.6	41.6	24.5	26.0	31.9	81.9	79.9	83.6
Standard Deviation		1.06	0.34	0.16	0.28	0.20	0.19	0.21	0.10	12.4	7.3	13.7	9.5	13.0	7.7	5.3	5.4	7.1	4.3
Max		7.10	2.16	1.28	1.66	1.34	1.12	1.15	0.85	86.8	59.4	51.4	52.8	41.3	41.5	39.6	86.6	89.2	92.3
Min		3.10	0.94	0.74	0.71	0.69	0.54	0.52	0.52	32.5	39.6	1.1	21.3	-1.8	13.3	24.6	69.3	66.5	76.1

Note: Overall removal is based on raw sewage concentration.

Table A - 24. Phase 4 E.coli results.

PROJECT PHASE	SAMPLING DATE	E.coli (10^3 cfu/100mL) McMaster Lab data					
		SST 1	SST 2	SST 4	RSF 1	RSF 2	RSF 4
Phase 4	4-5-05	56	130	90	11	110	74
Phase 4	4-12-05	120	350	170	56	360	130
Phase 4	4-19-05	110	210	130	98	290	74
Phase 4	4-26-05	73	300	190	59	240	120
Phase 4	5-3-05	90	140	100	44	110	83
Phase 4	5-10-05	61	150	76	17		28
Phase 4	5-17-05	70	100	95	33	56	53
Phase 4	5-23-05	56	80		9	52	
Phase 4	5-31-05	110	76	80	57	41	48
Phase 4	6-7-05	180	210	270	49	56	79
Phase 4	6-14-05		51	62		16	27
Phase 4	6-21-05		240	160		130	75
Phase 4	6-28-05		310	500		240	370
Number		10	13	12	10	12	12
Mean		93	181	160	43	142	97
Standard Deviation		39	98	123	27	113	92
Max		180	350	500	98	360	370
Min		56	51	62	9	16	27

Appendix B
Comparison of analytical results with MOE Lab

To compare the agreement of analytical results between McMaster Lab and MOE Lab, nonparametric method Wilcoxon Rank-Sum test was employed due to non-normal distribution of test results. Confidence levels used in all comparisons were 95%.

B.1 Total Suspended Solids

There are not statistically significant difference between McMaster Lab results and MOE Lab results. As shown in Figure B-!, the McMaster Lab results have a good agreement with the MOE Lab results.

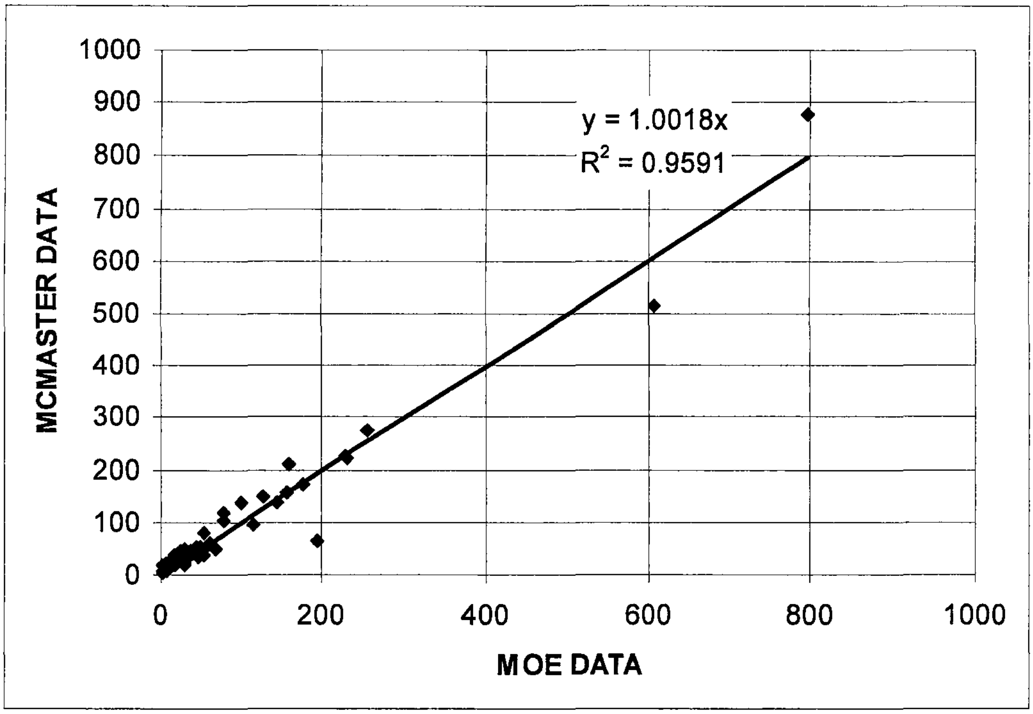

Figure B - 1. Total Suspended Solids Comparison.

B.2 Nitrate

For Nitrate examination results, the McMaster Lab is statistically significant different from the MOE Lab. But as presented in Figure B-2, the McMaster values were just slightly higher than MOE values.

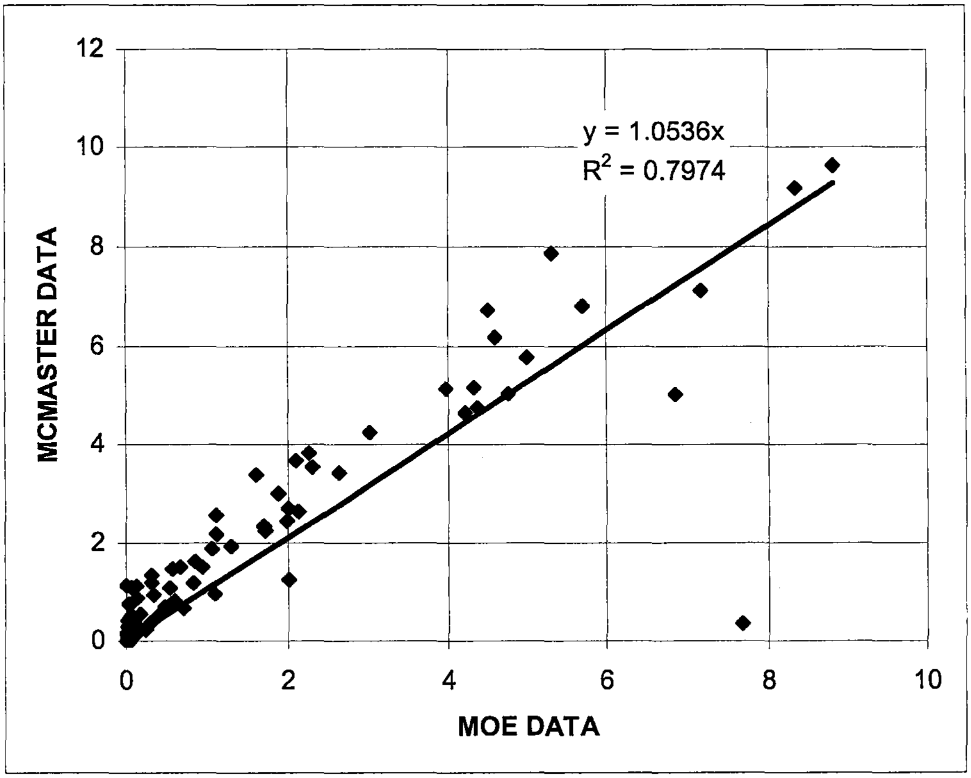

Figure B - 2. Nitrate Comparison.

B.3 TAN

For the TAN examination, the McMaster results were also statistically significant different from the MOE Lab results. The comparison is presented in Figure B-3; the

MOE values were higher than the McMaster values. Actually, the collected samples were examined by the McMaster Lab in 24 hours, whereas the MOE Lab performed the examinations in 48 hours. The later examination resulted in organic nitrogen being decomposed to TAN which may attribute the higher TAN value in MOE Lab results.

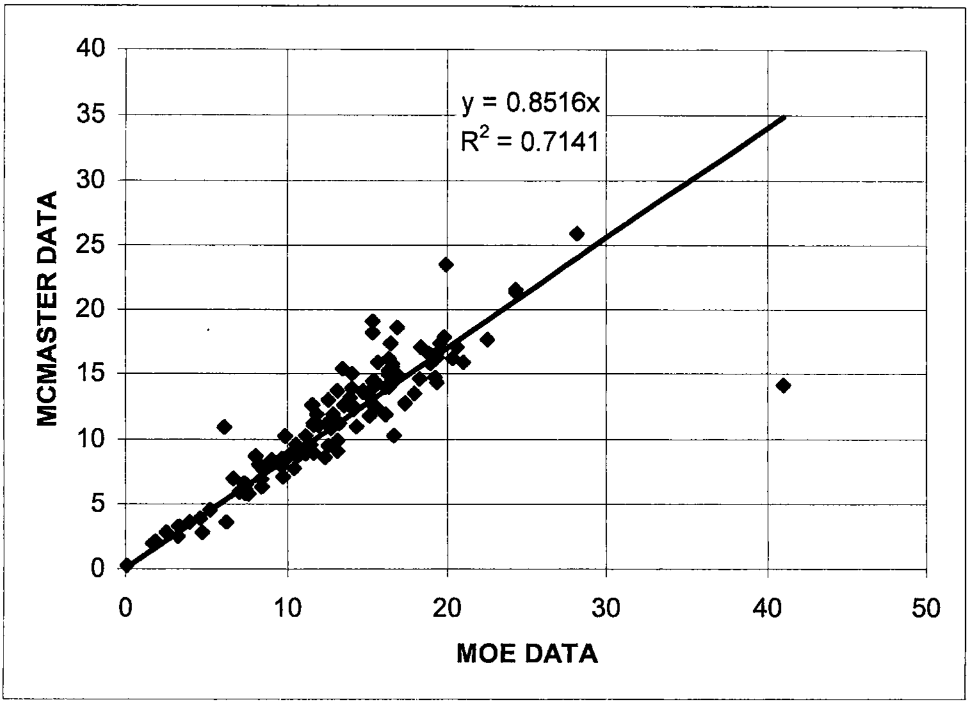

Figure B - 3. TAN Comparison.

B.4 Total Nitrogen

The examination results of Total Nitrogen between the McMaster Lab and the MOE Lab were not statistically significant different. As shown in Figure B-4, the McMaster values were close to those obtained by the MOE Lab.

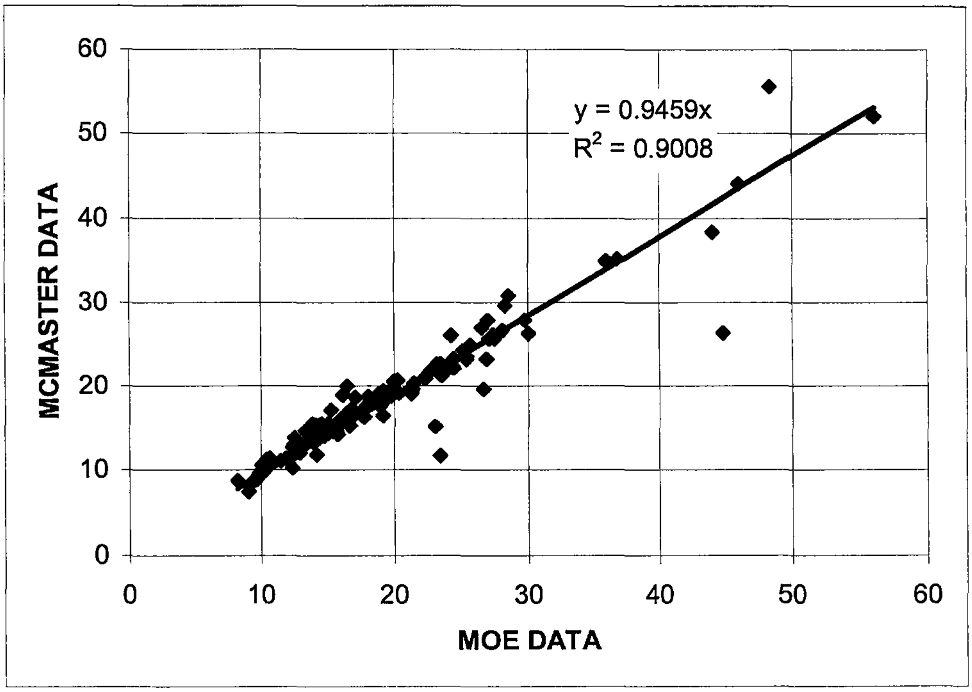

Figure B - 4. Total Nitrogen Comparison.

B.5 Total Phosphorus

There are statistically significant difference between the McMaster Lab and the MOE Lab for total phosphorus examination results. But as shown in Figure B-5, the values of McMaster Lab were just slightly higher than those obtained by MOE Lab.

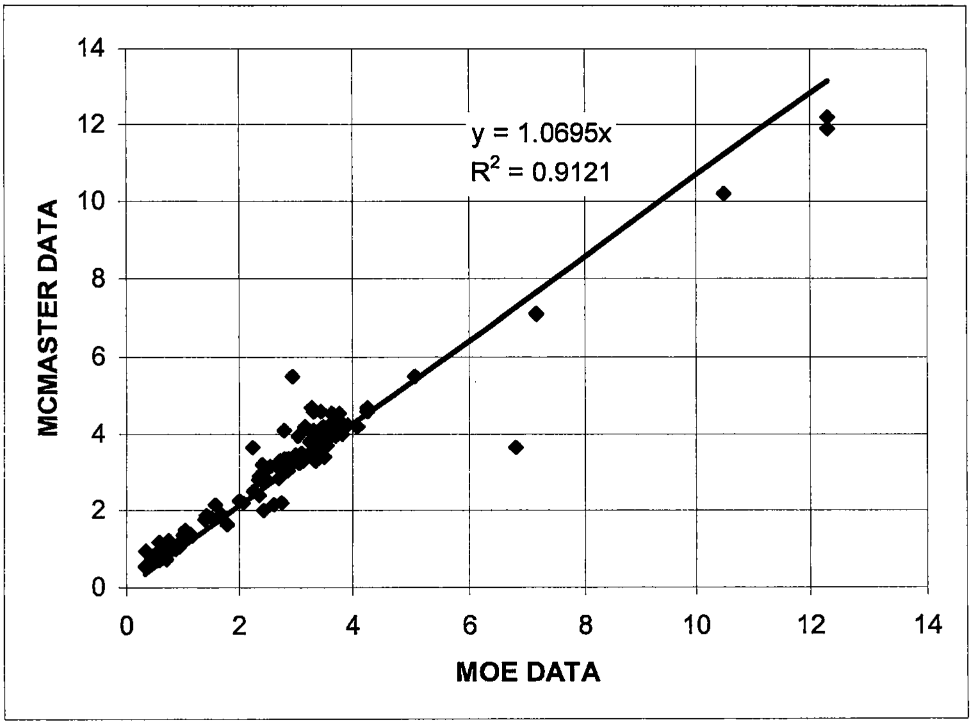

Figure B - 5. Total Phosphorus.

B.6 Alkalinity

The analytical results of Alkalinity between McMaster Lab and MOE Lab were not statistically significant different. They have a good agreement which can be seen from the Figure B-6.

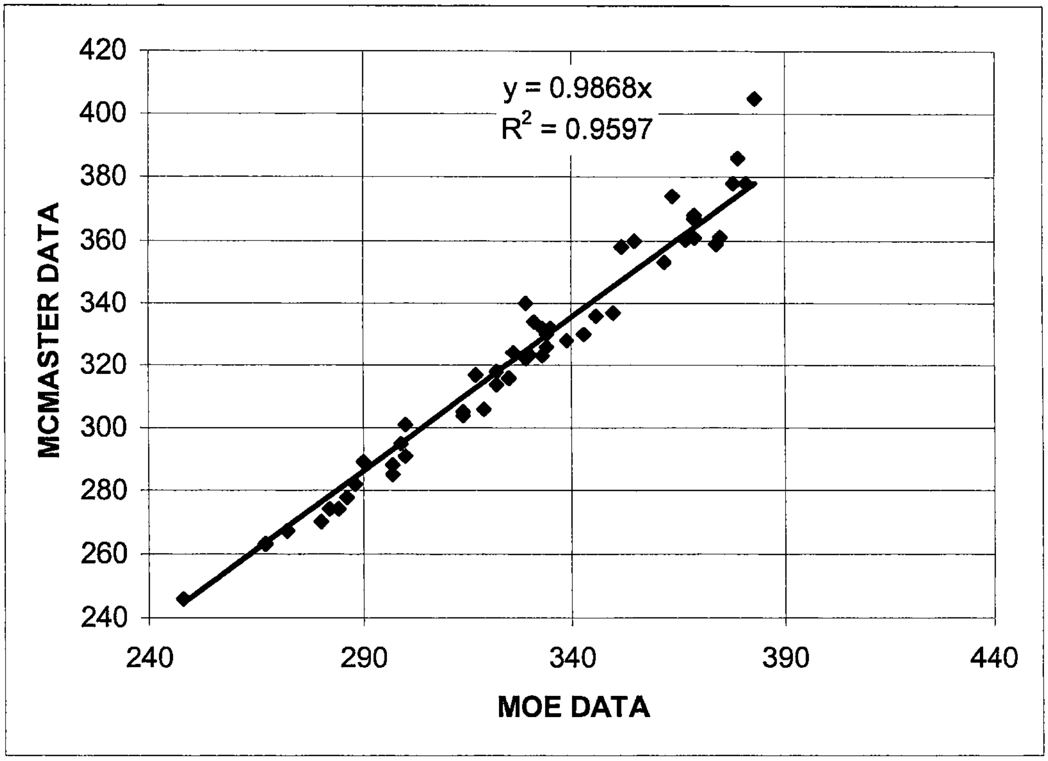

Figure B - 6. Alkalinity Comparison.

B.7 Conductivity

For analytical results of conductivity, there are not statistically significant difference between McMaster Lab and MOE Lab. As shown in, the McMaster Lab results have a good agreement with the MOE Lab results.

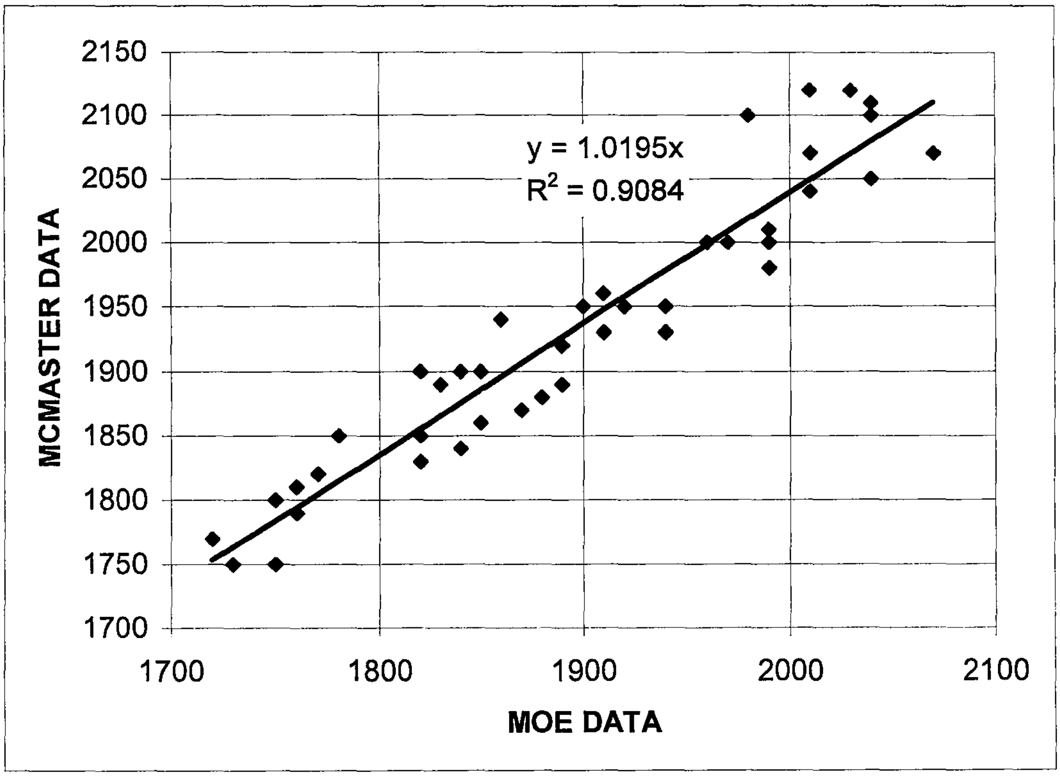

Figure B - 7. Conductivity Comparison.