Faculty of Resource Science and Technology

WATER QUALITY OF RUNOFF FROM SOIL APPLIED WITH PRAWN POND SLUDGE

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Water Quality of Runoff from Soil Applied with Prawn Pond Sludge

by

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DECLARATION

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other University.

Signed...

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ABSTRACT

Prawn aquaculture has become one of the most profitable of aquaculture food industries. Increasing amount of aquaculture shrimp ponds is causing a lot of impact especially on the mangrove ecosystems. Sludge from the bottom pond of prawn aquaculture is one of the potential sources of environmental problems since a lot of nutrients and other pollutants may accumulate there. Farmers usually dried the sludge and remove it to an unknown location. Possible leaching of the pollutants from the sludge may cause a clear detrimental effect on the environment, especially the surrounding water bodies. Leaching of nutrients from tiger prawn aquaculture (*penaeus monodon*) sludge through runoff are around 10 to 15% of the total nutrients. The leaching of nitrate and nitrite are quite low but a relatively high ammonia and orthophosphate concentration are monitored from the runoff. Solids effluents through runoff are quite high. The second rainfall on the same sludge residue shows less amount of pollutants but significantly higher amount of oxygen demand. The range of nutrients are 0.23 to 0.36 mg/l (ammonia), 0.57 to 0.90 (nitrate), 0.03 to 0.06 (nitrites) and 0.79 to 1.23 (reactive phosphorus) in the first rainfall simulations while in the second rainfall, the concentration decreases to 0.3 (ammonia), 0.30 to 0.43 (nitrate), 0.005 to 0.007 (nitrite) and 0.35 to 0.39 (reactive phosphorus)

Keywords: prawn pond sludge, leeching, runoff, water quality, *penaeus monodon*

Abstrak

Penternakan udang adalah salah satu industri akuakultur yang sangat menguntungkan. Pertambahan kolam- kolam akuakultur udang memberikan banyak impak terutamanya ke atas ekosistem paya bakau. Selut (sludge) di bawah kolam akuakultur udang adalah salah satu punca masalah alam sekitar yang berpotensi, memandangkan kebanyakan nutrien dan bahan pencemar lain terkumpul di bahagian tersebut. Penternak udang biasanya mengeringkan selut tersebut dan membuangnya di kawasan yang tidak diketahui. Resapan bahan pencemar daripada selut tersebut boleh mendatangkan kesan terhadap alam sekitar, terutamanya kawasan tadahan air yang berdekatan. Peresapan keluar nutrien daripada selut kolam akuakultur udang harimau (penaeus monodon) adalah kira- kira 10 hingga 15% daripada keseluruhan jumlah nutrien yang dikandungi oleh lumpur tersebut. Peresapan keluar nitrat dan nitrit adalah agak sedikit tetapi kepekatan ammonia dan orthophosphat telah diperhatikan daripada aliran permukaan air hujan (runoff). Kandungan pepejal (pepejal keseluruhan dan pepejal terampai) di dalam aliran tersebut adalah sangat tinggi. Penurunan hujan kedua ke atas selut yang sama memberikan kandungan pencemar yang lebih sedikit tetapi aliran permukaan air hujan tersebut mempunyai permintaan oxigen (oxygen demand) yang lebih tinggi. Julat kepekatan nutrien di dalam aliran tersebut adalah 0.23 ke 0.36 mg/l (ammonia), 0.57 ke 0.90 mg/l (nitrat), 0.03 ke 0.06 mg/l (nitrit) dan 0.79 ke 1.23 mg/l (ortophosphat) di dalam simulasi hujan yang pertama manakala pada simulasi hujan ke dua, kepekatan tersebut berkurangan kepada 0.3 mg/l (ammonia), 0.30 ke 0.43 mg/l (nitrat), 0.005 ke 0.007 (nitrit) dan 0.35 ke 0.39 mg/l (ortophosphat)

Kata kunci: selut *kolam udang, resepan keluar, kualiti air, penaeus monodon,*

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CHAPTER 1

INTRODUCTION

1.1. Aquaculture

Asians have been farming fish and crustaceans in coastal areas using traditional techniques for at least 3000 years (Stickney, 1979). New aquaculture technologies and a rising international demand for seafood products have, however, altered the basic character of aquaculture in coastal areas of Asia. Low intensity traditional forms of aquaculture that supported local food production are being replaced by resource intensive, high intensity systems that cater to international seafood markets (Stonich *et, al.*, 1997). Shrimp is by far the most valuable aquatic species currently being produced using high intensity aquaculture techniques, and the total value of global farmed shrimp production was approximately $7 billion USD in 2000 (FAO, 2002).

The history of prawn culture in Malaysia begins in 1980's following the success in neighboring countries like Thailand, Indonesia, and Philippines. In the early 1990's, the government identified 110,000 hectares of mangrove forest suitable for tiger prawn rearing and allocated RM15.38 million for aquaculture development in the Sixth Malaysia Plan. By the year 2000, there are about 5100 hectares of land used for prawn culture (from 2627 in 1995) and the Malaysian government is proud to claim that the country average production (metric tones/ hectare) is are the third highest in the world after Taiwan and Thailand (Raman, 2001). By the end of 2004, Malaysia is estimated to attain around RM 30 billion from prawn industry by utilizing the local disused pond rehabilitation technology through ionization (Business Times, 2004).

The prawn industry in Sarawak started in 1980's after the successful stories from Thailand and Taiwan. As Sarawak is the only state in Malaysia that imposes the licensing of prawn farms, it receives great attention from entrepreneur state wide. Land usage for prawn ponds increases rapidly in 1998 caused by the high prices of prawn in the world market. In 2001, there were 1652 prawn farm operators in the state (Singham and Wong, 2004). Sarawak now has 600 hectares of prawn farms, producing some 2,000 tones of prawns yearly worth RM80 million for the export markets. The annual state production of prawn product were estimated for about 4000 million tones (about RM 100 million) (Singham and Wong, 2004). In international markets, the average price of prawn can still reach to US$ 3 for each pound.

1.2. Prawn Pond Sludge

Sludge are waste particles that is obtained from two sources that is biological and chemical. Both of the sludge has different properties and effect on the environment (Carberry and England, 1983). The sludge from prawn farms are a mix of biological treatment and physical land erosion of ponds and generally are rich in nutrient (Shigeno, 1978). They are accumulated at the bottom of the pond and are usually black in color, with semi solid appearance. Farmers usually dumped the wastes to unknown locations to sustain the aquaculture pond and the water quality of the pond (Kurian and Sebastian, 1993). Some researchers (for example Boyd and Tucker, 1998) mentioned that the removal of sludge from the prawn pond is unnecessary and expensive (since there is no apparent and scientific results that shows that the production and motility of prawn being retarded by accumulation of sludge). However, removals of sludge from the ponds have been practiced by farmers for some reason such as to maintain the pond's area. Usually the sludge are flushed out from the ponds or manually removed from the pond to a different area.

Introduction of the sludge into the environment can cause toxic effect in the food chain and also euthrophication problems. High nutrient content can cause high microbial growth and reproduction, causes competition over space and resources with other aquatic organisms (Carberry and England, 1983).

It is important to know the source and characteristic of sludge for treatment, storage, disposal, or reuse (Carberry and England, 1983). As both the ways to remove the sludge (dry and wet methods) involves introduction of the sludge into the environment, the question of where to dump the sludge is still uncertain. If we spread it on land, it will pollute the land on which it is spread. It is also found that nutrients leaches can go into the soils and pollute groundwater (Singham and Wong, 2004).This happened because when too much nutrients are added to the water, aquatic plants will bloom. It would use up oxygen in the water leaving little oxygen for the other aquatic animals to breathe (Singham and Wong, 2004).

Since prawn aquaculture pond sludge are usually dumped after it is dried (Chanratchakool et. al.., 2004), the sludge dumping may cause detrimental effect to the environment. Leaching of nutrients or other pollutant particularly will cause environmental hazards to the surrounding water bodies. Boyd and Tucker (1998) mentioned that the sludge from prawn aquaculture ponds can potentially leach a great amount of nutrients and salinity into the groundwater.

1.2. Objectives

The objective of this study was to investigate the water quality of runoff from soil plots applied with prawn pond sludge.

CHAPTER 2

LITERATURE REVIEW

2.1. Sludge

Sludge can be divided into two categories that are the biological (or biological treatment) sludge and chemical sludge. Chemical sludge is generally emphasized for their toxic properties, while biological sludge is observed for their nutrient content (Carberry and England, 1983). Prawn sludge (biological treatment sludge) is rich in nutrient, especially nitrogen and phosphorus, and their constituent (Shigeno, 1978). Some countries like the US reuses sludge as nutrient rich fertilizers, but the use of prawn sludge is still not practiced worldwide (Carberry and England, 1983). Usually, the sludge is dumped elsewhere using dry method or wet method into the environment (Chanratchakool et, al.., 2004). Some of them are also using natural ways (tide) to clean the pond and cause pollution to the surrounding areas especially the water bodies (Kurian and Sebastian, 1993).

2.2. Prawn Pond Sludge Characteristic

Little attention had been given to the sludge sediments that are accumulated on the bottom of the prawn pond. The sludge are usually disposed by using a water jet (wet method) or let to dried and manually or mechanically removed from the bottom of the ponds. Prawn sludge are mixed constituent of soil sediments, pond soil erosion, shrimp faces, molted material, unconsumed food, dead microorganisms and prawn, and many other sources. The layer are rich in organic material especially nutrients.

They can also be referred to as sediment, bottom- pond soil, mud, or ooze (Chanratchakool et. al.., 2004). This "sludge" is enriched in nitrogen, phosphorus and carbon relative to surrounding sediment and its accumulation is associated with anaerobic decomposition and the release of ammonia, organic sulphur and hydrogen sulfide (Philips et. al.., 1993).

There is some evidence to suggest that effluent characteristics for marine shrimp ponds are similar to effluent characteristics for catfish farms, but that the final portion of effluent from marine shrimp ponds is higher in pollutant concentrations by 20% to 30% (Boyd and Tucker, 1998). For example, total annual TSS for shrimp ponds is around 5,000 lb/ac and for catfish fingerling ponds about 4,000 lb/ac. When shrimp ponds are drained for harvest, the effluent is almost identical in composition to pond water until about 80% of the pond volume has been released (Boyd, 2000). During the draining of the final 20% of the pond volume, concentrations of BOD_5, TSS, and other substances increase because of sediment resuspension caused by harvest activities, crowding of agitated shrimp, and shallow and rapidly flowing water. The average BOD_5 and TSS concentrations often are about 50 mg/L and 1,000 mg/L, respectively (Boyd, 2000). While some nutrients and pollutants are washed by the water exchange activities, much of it are deposited at the bottom of the pond and become the sludge.

According to Sonnenholzner and Boyd (2000) investigation on bottom sediments in prawn farm in Ecuador shows pH of a weak acids (ranged from 5.4 to 7.7). They also note the total nitrogen concentration of 0.16%, total phosphorus (898 mg/kg), acid extractable phosphorus (277 mg/kg), and CEC (30.8 meq/100 g), and other trace metals (high sodium concentration of 10844 mg/kg, calcium concentration of 3949 mg/kg, magnesium concentration of 3098 mg/kg, and potassium concentration of 1488 mg/kg. other metals ranged from 1.24 mg/kg (molybdenum) to 661 mg/kg (Iron) (Sonnenholzner and Boyd, 2000).

Munsiri et. al. (1996) reported that the pH of the bottom soils in shrimp pond decreases with the age of the pond (new pond with pH of 7.49 while the old pond has pH of 6.73). Other elements, on the other hand decreases with the age of the pond. They calculated 0.17% 0.65% and 554 mg/l for total nitrogen, total carbon, and total phosphorus in new ponds while the older ponds give readings of 0.28%, 1.31%, and 906 gm/l each for total nitrogen, total carbon, and total phosphorus content (Munsiri et. al.., 1996).

Other studies had also been made on the characteristic of prawn pond- bottom sludge. Martin et. al. (1998) has done a study that shows that the accumulation of sludge nitrogen content is proportional to the number of individual prawns in the respective ponds (stocking density, no of prawn/m^3) (Martin et. al.., 1998) (Table 2.1). Other study done by Masuda and Boyd (1994) shows that 99.81 % of phosphorus content in prawn ponds was accumulated in the sludge while only 0.18% was available in the pond water (Masuda and Boyd, 1994) (Table 2.2). A study made by Hopkins et. al. (1994) was done to investigate the accumulation of nutrients (nitrogen and phosphorus) in sludge and soil from different intervals of sludge removal. The nitrogen content in sludge increases if they are not removed over a long time, and the survival of prawns are negligible (Hopkins et. al.., 1994) (Table 2.3).

Table 2.1: Sediment (Prawn Pond Sludge) Characteristic during Harvest (Martin et, al., 1998)

Stocking density (no. m^{-2})	1	4	7	15	30
Accumulated Layer (cm)	0.50	1.02	2.02	2.48	4.54
Organic Matter (% dw)	6.35	6.49	7.47	8.34	9.10
Total Nitrogen (mg/ g dw)	1.50	1.85	1.89	1.80	2.04
(NH4-NH3)- N (mg/L)	1.25	2.32	3.22	4.16	6.50
(NO2-NO3)- N (mg/L)	0.68	0.17	0.67	0.25	0.74
Organic- N (mg/L)	3.99	5.07	6.82	7.73	8.66

Note: dw= dry weight

Table 2.2: Phosphorus in prawn bottom pond soil (Masuda and Boyd, 1994)

	unit	mg/ kg	%
Pond Water	Total Phosphorus	0.252	0.19
	Soluble reactive phosphorus	0.019	0.01
	Soluble non reactive phosphorus	0.026	0.02
	Particle phosphorus	0.207	0.16
Soil	total Phosphorus	132.25	99.81
	Loosely bound phosphorus	1.28	0.96
	Calcium bound phosphorus	0.26	0.20
	Iron and aluminum bound phosphorus	17.30	13.05
	Residual phosphorus	113.51	85.60
Pond	Total Phosphorus	132.60	100.00

Average pond depth= 1.0 m Soil bulk density= 0.797 g/cm^3

Soil depth= 0.2 m

Table 2.3: Characteristic of sludge just prior to pond harvest and characteristics of soil at the time of pond harvest for the three sludge management regimes. The ponds were operated without water exchange. In remain, the sludge were left to remain for the whole cycle until harvest. In remove, the sludge were removed weekly. In resuspend, the sludge were resuspended or moved daily (Hopkins et, al., 1994).

	REMAIN	REMOVE	RESUSPEND
Sludge			
Wet volume(m^3/ha)	90	na	95
Moisture (%)	87.0	na	93.2
Loss on Ignition (% dw)	26.2	na	37.1
Kjeldahl nitrogen (mg/l)	2560	na	1620
Total phosphorus (mg/l)	1480	na	1840
Soil			
Loss on Ignition (% dw)	1.9	1.4	2.5
Kjeldahl nitrogen (mg/l)	663	300	700
Total phosphorus (mg/l)	860	580	1140

Loss on ignition may not accurately reflect on organic matter concentration
na= not applicable for the treatment

2.3. Nutrient Leaching

Leaching of nutrients from aquaculture sludge was observed by Stewart (2005) for rainbow trout sludge. Leaching of total phosphorus (TP), orthophosphate (OP), total Kjeldahl nitrogen (TKN), total ammonia nitrogen (TAN), and total organic carbon (TOC) occurred rapidly during the first 24 h in both stagnant and agitated conditions. Linear increases of TP, OP, TKN and TAN concentrations occurred during the first 24 h. These linear form increases continued from day 2-7, but at slower rates than occurred during the first 24 h. Average nutrient leaching rates (mg leached/g sludge, dry weight basis) were calculated based on linear concentration increases. Nutrient concentrations decreased after 60 hours, as aerobic bacterial uptake and chemical precipitation was suspected. Therefore, average leaching rates could not be determined.

Leaching of other nutrients from sludge has also been studied. Keller et. al. (2002) had observed the leaching of micronutrients and some major elements from municipal waste upon application on a brown soil. The concentration of trace metals did not exceed the toxic levels in the runoff, while the concentration of nitrate increase significantly in the runoff for almost 2 months.

Pu et. al. (2004) experimented the effect of sludge application on grassland soil in Australia. The phosphorus content were leached from the sludge into the soil and is significantly higher than the soil that is not treated or soil that is treated with chemical fertilizer. There is no evidence of nitrate leaching into the ground from the sludge, and they are mainly deposited near the surface (less than 30 cm deep) of the soil. Even though this may be caused by little rainfall that is experienced in the area (at the time of the experiment), a heavy downpour may cause leaching of nitrate and other nutrient into the ground. This may also indicate that there is a high risk of nutrient leaching (especially nitrates and phosphorus) from top soil through runoff. Total nitrogen leaching did not happen significantly unless large amount of sludge (64 tones/ hectare and more) were applied.

Cindy et. al. (2001) studied the effect of sludge treatment (drying and mesophilic anaerobic digestion) on leaching upon application on top soil. Leaching of nitrates was significantly greater on the first rainfall (43.9- 68.0 mg/ kg) than the second one (6.4- 11.9 mg/ kg). Phosphorus leaching was significantly greater on the second rainfall (0.30 mg/ kg) than on the first rainfall (less than 0.05 mg/ kg). There is little impact on drying or applying fresh sludge on the leaching of the treated sludge as it is observed in the experiment.

2.4. Water Quality

Water quality can be determined by a few methods that examined different quality of the water. For example, total solids (TS) and total suspended solids (TSS) are used to determine the solid pollutants in the water. Other parameters are ammonia nitrogen (NH_4N), nitrite nitrogen (NO_3N), orthophosphate (PO_4P), total nitrogen (TN) and total phosphorus (TP). These parameters examined the nutrient content of the water since rich nutrient can cause severe pollution of microbial and euthrophication (algal bloom). BOD parameters are also one of the water quality parameters, determining the rate of dissolved oxygen used in biochemical activity for nutrient oxidation (Smith et. al.., 2004).

Table 2.4: Interim National Water Quality Standards For Malaysia

Parameter\Classes	I	II	III	IV	V
Ammonia Nitrogen (mg/L)	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
BOD (mg/l)	< 1	1 - 3	3 - 6	6 - 12	> 12
Dissolved Oxygen (mg/L)	> 7	5 - 7	3 - 5	1 - 3	< 1
pH	> 7.0	6.0 - 7.0	5.0 - 6.0	< 5.0	> 5.0
Total Suspended Solids (mg/L)	< 25	25 - 50	50 - 150	150 - 300	> 300
Total Dissolved Solids (mg/L)	500	1000	-	4000	-
NO_3 (mg/L)	Natural water levels	7		5	-
Water Quality Index	> 92. 7	76.5 - 92.7	51.9 - 76.5	31.0 - 51.9	< 31.0

Source: Department of Environment (http://www.jas.sains.my)

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental Design

The runoffs from prawn pond sludge were determined using a rainfall simulator and a set of 12 plots measuring 3m x 4m. Sludge are applied on the plots on an area of 2m x 3m in the middle of the plots. The amounts of sludge applied are given in Table 3.1. Rainfalls were applied on the sludge with different time durations (4 minutes, 8 minutes, and 12 minutes) to measure the effect of time duration on the discharge of nutrients and water quality through runoff.

Rainfall simulations were done using a rainfall simulation apparatus (TLALOC 3000, Joern's Inc. USA) and pump. The rainfall simulator are set on a movable pillar and moved around from plots to plots to apply rainfall on the plots. Water source used for the rainfall is pipe water and stored in tanks 2 days before the rainfall simulation is done. Pump (JS Pump RS-400) is used to deliver water from the tanks to the rainfall simulator. The rainfall falls in a round area covering the whole sludge area (in the center of the plots) with a diameter around 3.5 to 4 meter.

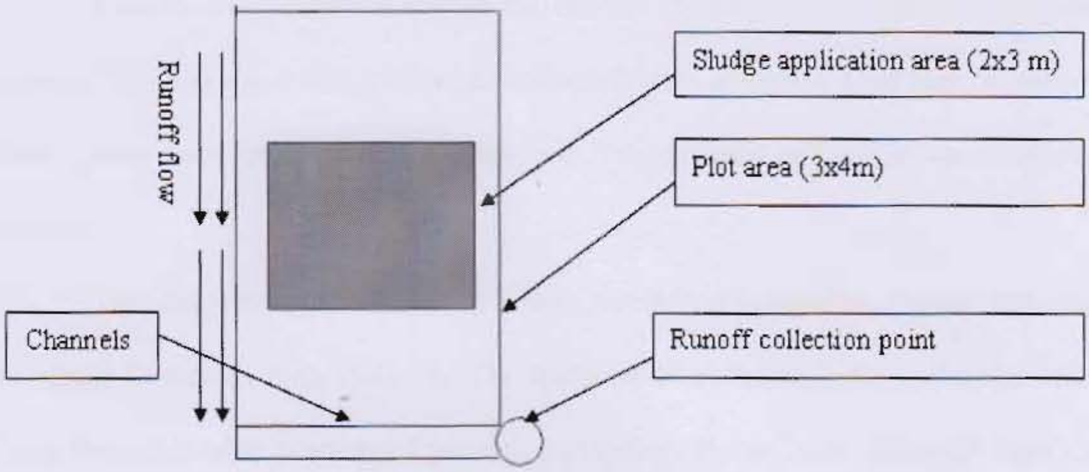

Figure 3.1: Figure of the plots

Table 3.1: Sludge weight applied on each plots and plots identifications

Experiment (minutes)	Sludge (kg wet wt.)	Plots	Rainfall Duration
		1, 2, 3	4
1	8.946	4, 5, 6	8
		7, 8, 9	12
		10, 11, 12	4, 8, 12
		1, 2, 3	4
2	20.619	4, 5, 6	8
		7, 8, 9	12
		10, 11, 12	4, 8, 12

The second sludge was collected on 9 January 2006 and the first rainfall simulations were done on 17 January 2006 on the 4 minutes plots. The other plots rainfall simulations were delayed due to bad weather and done on 19 January 2006. The second rainfall Simulations were done on 14 February 2006 on all plots.

Runoffs were collected during the rainfall simulations. The volume of water used as rain and the volume of water collected were recorded. One liter of sample were taken from each plots and analyzed for nutrients and other water quality analysis.

The sludge was collected from Telaga Air shrimp aquaculture ponds owned by Lembaga Kemajuan Ikan Malaysia. The sludge were collected 2 days after the water from the ponds were discharged prior to harvesting. Sludge were collected from the middle of the ponds where previous literature mentioned that they are the thickest layer of prawn sludge as well as the driest sludge layer.

3.2. Analytical Procedure (Clesceri et. al.., 1998) (Hach. 1996)

3.2.1. Sludge Analysis

Ammonia nitrogen is determined by wet weight within 24 hours of sample collections. The rest of the samples were air dried for a few weeks and sieved before the analysis was done.

3.2.1.1. pH

pH was determined using a pH meter (Cyberscan pH Meter 300- 310). Distill water were added to the dried sludge at ratio 1:1 and the pH were measured using the pH meter.

3.2.1.2. Conductivity

Conductivity was measured at 1:5 soil to water ratio (EC_5) according to the method from Tie (1982). The mixture was mixed and the conductivity was measured using a conductivity meter.

3.2.1.3. Organic Matter

Organic matter was determined by loss on ignition method (Ben-Dor and Banin, 1998). Dry sample after (drying in oven) will be ignited in a muffle furnace (400°c, 16 hours), cooled in dessicattor and then the weight loss in the ignition was observed.

3.2.1.4. Ammonia Nitrogen

Sample for ammonia nitrogen was first distilled by distillilation chamber (2200 Kjeltec Auto Distillation). Use indicating boric acid solution as the absorbent solution. The ammonia content were determined by titration.

3.2.1.5. Total Kjeldahl Nitrogen (TKN)

TKN is determined using acid digestion of all organic nitrogen into ammonia nitrogen using mixture of sulphuric acid, potassium sulphate and cuprum sulphate. Ammonia can be removed by borate buffer solution. The sample is then digested (320°c for 30 minutes) to turn the organic nitrogen in the sample into ammonia. The sample is then distilled; 40 ml of distillate is collected in a beaker containing 10 ml of indicating boric acid solution, and titrated using sulphuric acid. (Jones and Bradshaw, 1989)

3.2.1.6. Total Phosphorus

Total Phosphorus is determined by using ascorbic acid method. The sample was digested with sulphuric acids and ammonium sulphite ($(NH_4)_2S_20_8$) to convert all the phosphorus into reactive phosphorus (orthophosphate). Later, a set of standard is used to build a calibration curve on a UV/ Vis spectrometer (Hach kit Odessey DR-2500). The concentration of phosphate can be determined by the absorbance calibration curve and a spectrometer at 880nm. (Gales et, al.,. 1966)

3.2.2. Runoff Water Quality Analysis

The method for runoff analysis are adopted from Standard Method for The Examination of Water and Wastewater, 20th edition (Clesceri et, al.., 1998). The sample was kept at 4° C and examined within 24 hours. For longer storage, the sample was preserved with acids at pH 2 and analyzed within 28 days.

3.2.2.1. Total Solids (TS)

Total Solids were done according to the method described in Standard Method for The Examination of Water and Wastewater, 20th edition (Clesceri et, al.., 1998). Known volumes of sample (50 ml) were dried at 103-105°C. The sample was heated at 98°C to prevent splat of sample at boiling temperature. After the sample was dried, the remains were heated in drying oven at temperature from 103 to 105°C for at least one hour. Cool of the sample and weight. The procedure was repeated until the weight is constant or at least the difference between the weight and the previous readings are less then 0.5 mg.

3.2.2.2. Total Suspended Solids (TSS)

Following the method described in Standard Method for The Examination of Water and Wastewater, 20^{th} edition (Clesceri et. al.., 1998). Total suspended solids were determined by using the same method as the total solids determination. The sample was first filtered through a standard glass fiber filter (40 to 60 μm). The residue were taken and dried in oven at 103 to 105°C, cool and weight until the weight is constant or the difference between readings are less than 0.5 mg.

3.2.2.3. Five Days Biochemical Oxygen Demand (BOD_5)

BOD was determined by using the five day biochemical oxygen demand (BOD_5) method. A measured portion of the sample being analyzed are tested for dissolved oxygen using a DO membrane electrode, and then mixed with dilution water if needed. The samples were put in an air tight glass bottles and incubated for 5 days at 20° C. The dissolved oxygen after five days of incubation are measured and the BOD_5 are calculated.

3.2.2.4. Chemical Oxygen Demand (COD)

Chemical Oxygen Demands were measured using a Hach Kit's standard COD reaction Vials. 2 ml of sample were mixed in the reaction vials and then placed in a COD reactor for 3 hours. The absorbance of the reagent and sample are compared with blanks afterwards to get the COD.

3.2.2.5. Ammonia Nitrogen

Ammonia Nitrogen was determined by Nessler Method using a Hach Kit. Three drops of mineral stabilizer, 3 drops of polyvinyl alcohol dispersing agent and 1 ml of Nessler reagent are added with 25 ml of distilled samples. The samples are thoroughly mixed between each of the reagents. A minute after Nessler reagent are mixed, the sample ammonia are determined using a Hach kit UV spectrometer at 425 Nm wavelength.

3.2.2.6. Nitrate

Nitrate concentrations are determined using Cadmium Reduction Method as described by Hach, 1996. Nitra Ver 6 reagent Powder Pillow was added to 30 ml sample and mixed for 3 minutes. After that, the sample will be allowed to leave for 2 minutes. Transfer 25 ml of the sample carefully into another sample cells and add with Nitri Ver 3 reagent powder pillow. It was then mixed for 2 minutes, leaved for 15 minutes, and then examined in a Hach kit UV/vis spectrometer at 585 nm.

3.2.2.7. Nitrite

Nitrite concentration was determined using Diazotization Method by Hach kit. Nitri Ver 3 reagent powder pillow are added in a 25 ml sample and mixed. It was then left for 20 minutes before the nitrite concentration is determined using a Hach kit spectrometer.

3.2.2.8. Orthophosphate

Orthophosphate were determined using Ascorbic Acid Method. 10 ml of sample are added with Phos Ver 3 Phosphate reagent powder pillow, leaved for 2 minutes and then examined using a Hach kit at 880 nm.

3.3 Statistical Analysis

Analysis of Variance (ANOVA) Turkey- test is used to determine homogeneous subsets. The label (Table 4.5 and 4.8) a is the subsets of the 4 minutes results, b is the subsets for 8 minutes results, while c is the subsets for 12 minutes results. Significant differences (in table 4.5 and 4.8) are gain with paired sample t- test of each of the sample with the blanks. Differences between two readings (table 4.10) are tested using independence sample t- test to determine the significant difference. Correlations studies are done using Pearson correlation in bivariate correlation analysis. All test were done using SPSS Ver. 11.01 with 95% confidence interval.

3.4 Formulae for Calculation

3.4.1. Total Nutrients

Total Nutrients leached are assumed as

$$\text{Total Nutrients (mg)} = \text{Concentration (mg/l)} \times \text{Runoff Volume (l)} \qquad [1]$$

Where concentration is the concentration of the nutrients from analysis of runoff and runoff volume are the volume of runoff for the calculated nutrients.

3.4.2. Organic Matter

Organic matter are calculated as

$$\text{Organic Matter} = \frac{\{\text{Original Weight (mg)} - \text{Final Weight (mg)}\}}{\text{Original Weight}} \qquad [2]$$

Where the original weight is the weight of sample before ignition and the final weight are the weight of sample after ignition.

3.4.3. TKN

Total Kjeldahl nitrogen are calculated by

$$\text{TKN} = \frac{[(M1 \times V1) \times 14 \times V]}{[1000 \times V2 \times \text{sample weight}]} \qquad [3]$$

where M1 = Normality of H_2SO_4 used in titration

V1 = Volume of H_2SO_4 used in titration

V2 = Volume of Distillate used in titration

V3 = Volume of Distillate collected

Sample weight = sample weight in g

3.4.4. Percentage of ammonia leached

percentage of ammonia leached are calculated as

$$\text{percentage of ammonia leach} = \frac{\text{total ammonia leach}}{\{\text{ammonia content x sludge weight for plot}\}} \quad [4]$$

3.4.5. Biochemical oxygen demand (BOD)

$$\text{BOD} = \{(\text{DOi} - \text{Dof}) / \text{Volume of water used}\} \text{ x dilution factor} \quad [5]$$

3.5. Detection Limit of Hach Spectrometer

Table 3.2: Instrument detection limit of Hach kit (Odessey DR/2500) for the method of runoff water quality analysis (Hach, 1996)

	Detection limit (mg/l)	
Nutrients	Minimum	Maximum
Ammonia	0.0005	2.5
Nitrate	0.005	2.5
Nitrite	0.0005	2.5
Orthophosphate	0.0005	1.5

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Control Runoff Analysis

The results for all the analyses of control runoffs are summarized in table 4.1 and 4.2.

Table 4.1: Concentration of various water quality parameters on the runoffs of blank plots.

	Mean Concentration (mg/l)							
Durations	Ammonia	Nitrate	Nitrite	Ortho phosphate	TSS	TS	BOD	COD
4 minutes	0.23±*0.01*	0.043±*0.005*	0.006±*0.001*	0.35±*0.05*	56.0±*11.1*	143±*8*	4.24±*0.27*	12.7±*1.5*
8 minutes	0.23±*0.01*	0.023±*0.005*	0.003±*0.001*	0.62±*0.04*	201.0±*12.4*	1593±*102*	5.87±*0.02*	22.3±*0.5*
12 minutes	0.24±*0.00*	0.017±*0.005*	0.004±*0.001*	0.50±*0.04*	30.0±*10.0*	1080±*180*	4.88±*0.07*	21.3±*1.1*

Table 4.2: Volume of Water Used in rainfall simulations and volume of runoff collected for blanks rainfall simulations.

Duration	Volume of water used	Volume of runoff collected	Rainfall to runoff percentage
4 minutes simulation	53657ml	11950ml	22.27%
8 minutes simulation	107314ml	28640ml	26.69%
12 minutes simulation	160971ml	43900ml	27.27%

4.2. Sludge Analysis

The results of the second sludge analysis are shown on table 4.3.

Table 4.3: Results for analysis of sludge sample

Parameter	Mean	Martin et, al. (1998)	Masuda & Boyd (1994)	Hopkins et, al. (1994)
pH	7.27 ±0.031			
Electrical Conductivity (mS)	5.47 ±0.12			
Organic Matter (w/w)	0.059 ±0.002	8.43% dw		26.2% dw
Ammonia (mg/kg)	24.46 ±1.67	4.16 mg/l		
TKN %	0.35 ±0.02	6.82 mg/l		2560 mg/l
TP (mg/kg)	34.7 ±2.3		132.25 mg/kg	1480 mg/l
Bulk Density (g/cm^3)	0.147			

The results for sludge analysis are comparable to the previous literature. However, organic matter, TKN and TP are lower than that reported by Martin et, al. (1998) and Masuda and Boyd (1994).

4.3. Rainfall Simulation

4.3.1. First Rainfall Simulation

The concentration of nutrients in runoff from the first rainfall simulation is higher than the blanks (significant difference lower than 0.05 except for BOD). The concentration of nitrates are low and only ranged from 0.03 to 0.09 mg/l. Concentration of other nutrients (ammonia, nitrites, and orthophosphate) and total suspended solids are quite high compared to the blanks. The results of the analysis are shown in table 4.4 and 4.5.

Table 4.4: Volume of water used as rainfall simulations and volume of water discharged as runoff for the first rainfall simulations of the second sludge

Duration	Volume of water used	Volume of runoff collected	Rainfall to runoff percentage
4 minutes simulation	53657ml	18510ml	34.49%
8 minutes simulation	107314ml	28640ml	26.69%
12 minutes simulation	160971ml	42020ml	26.10%

Table 4.5: Concentration of various water quality parameters of the runoffs from the first rainfall simulations.

	Mean Concentration (mg/l)							
Durations	Ammonia	Nitrate	Nitrite	Ortho phosphate	TSS	TS	BOD	COD
Control	0.23±*0.01*	0.043±*0.005*	0.006±*0.001*	0.35±*0.05*	56±*11*	143±*8*	4.24±*0.27*	12.7±*1.5*
[illegible] minutes[a]	0.24±*0.01*	0.090±*0.010*	0.032±*0.006*	0.79±*0.05*	336±*86*	9544±*740*	4.71±*0.57*	16.7±*2.1*
Control	0.24±*0.01*	0.023±*0.005*	0.003±*0.001*	0.62±*0.04*	201±*12*	2022±*102*	5.87±*0.02*	22.3±*0.5*
[illegible] minutes[b]	0.44±*0.00*	0.033±*0.006*	0.056±*0.010*	1.23±*0.05*	356±*83*	2352±*153*	5.55±*0.67*	29.3±*2.3*
Control	0.24±*0.00*	0.017±*0.005*	0.004±*0.001*	0.50±*0.04*	30±*10*	1080±*180*	4.88±*0.07*	21.3±*1.1*
[illegible] minutes[c]	0.36±*0.01*	0.057±*0.006*	0.060±*0.006*	1.11±*0.13*	368±*75*	2694±*40*	5.77±*0.23*	22.7±*1.5*
Subsets	a≠ b≠ c	a≠ b≠ c	a≠ b= c	a≠ b= c	a= b= c	a≠ b= c	a= b= c	a≠ b≠ c
Significant difference	0.005	0.001	<0.0005	<0.0005	<0.0005	0.029	0.171	0.003

The concentration of various water quality parameters are significantly higher compared to the concentration of control plots except for biochemical oxygen demand. Concentrations of nitrates are quite low and can be defined as class 1 or natural water quality in Interim Water Quality Standard for Malaysia. Other nutrients however can be classified as class III in the standard. Total solids and suspended solids are quite high enough to be classified as class V in the water quality standard.

4.3.1.1. Nutrient Analysis

Results of the analysis of nutrients from the runoff are shown in figure 4.1. Nitrate concentration from 4 minutes that are high. This may be caused by the high nitrate concentration of the 4 minutes rainfall duration where it is done on a different day and weather condition. The nutrients concentration increases as the rain duration increases but as the duration increases even higher, the nutrients concentration is diluted to become lower.

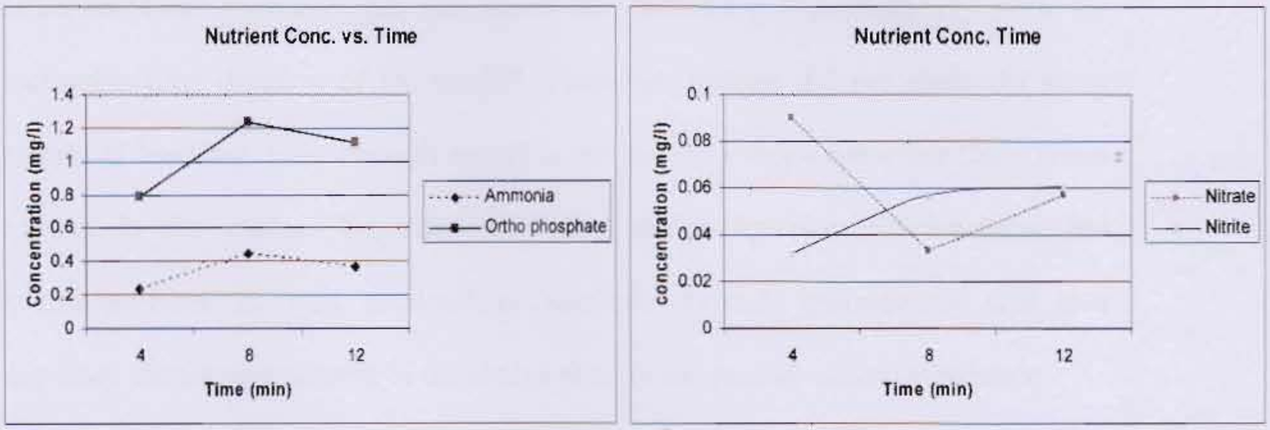

Figure 4.1: Nutrient concentration in runoff versus rainfall duration for the first run of second sludge.

Assuming that the runoff samples represent the whole population of runoff, the following results in table 4.6 are the assumed total nutrients discharged through runoff.

Table 4.6: Total nutrients leached through runoff from the first rainfall. The figures are mean of total nutrient discharge while the figures below each numbers are the standard deviation

	Amount leached (mg/l)							
Durations	Ammonia	Nitrate	Nitrite	Ortho phosphate	TS	TSS	BOD	COD
4 minutes	4.44	1.66	0.59	14.96	176671	6086	87.31	308.5
	0.20	*0.19*	*0.11*	*0.51*	*13713*	*1647*	*10.57*	*38.5*
8 minutes	12.79	0.95	1.623	35.32	67380	10214	158.95	840.1
	0.24	*0.17*	*0.28*	*1.44*	*3868*	*2387*	*19.34*	*66.1*
12 minutes	15.15	2.38	2.54	46.64	113201	15477	227.05	952.4
	0.63	*0.24*	*0.28*	*5.46*	*1680*	*3186*	*24.67*	*64.1*

The total nutrients discharge through runoff shows that the nutrients leaching tend to be increasing with increasing rainfall durations (figure 4.2). Ammonia, nitrite and orthophosphate discharge into the runoff are increasing logarithmically with the increasing time duration of the rainfall. However, nitrates did not show the same pattern of leaching. Loss through runoff is not the only factor depleting the nutrient content in the sludge. Degradation of the sludge by chemical reactions and microorganisms, as well as leaching nutrients through groundwater will also decreases the nutrient content in the sludge prior to the second rainfall simulation.

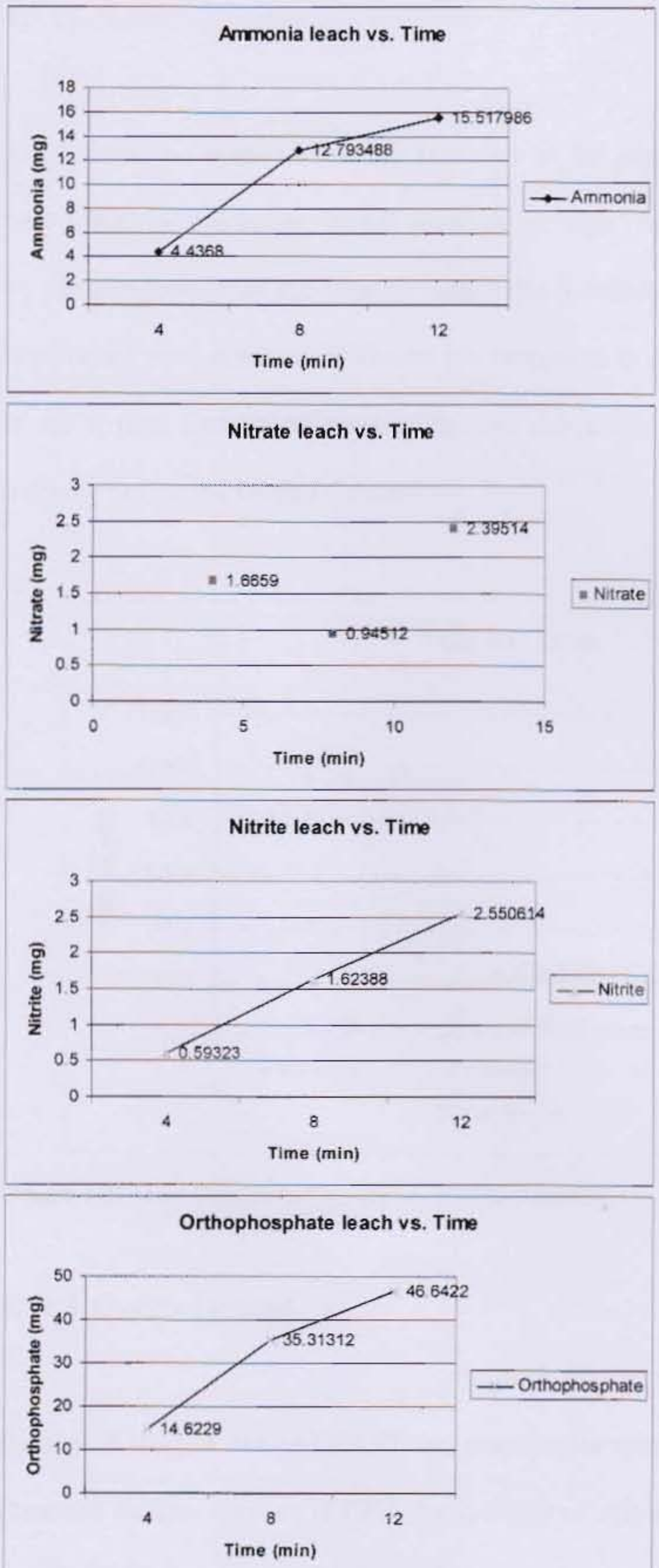

Figure 4.2: Graphs of Nutrient Leach vs. Rainfall Durations for the first rainfall durations

4.3.1.2. Solids

Total solids and suspended solids increases as the rain duration increases. However, total solids for 4 minutes rainfall duration are high (figure 4.3). This may be caused by the interference of the weather where the 4 minutes rainfall simulations for this experiment were done on a different day compared to the others. Weather at the point of the rainfall simulations were quite cold and humid caused by a rain in the early morning before the rainfall simulations.

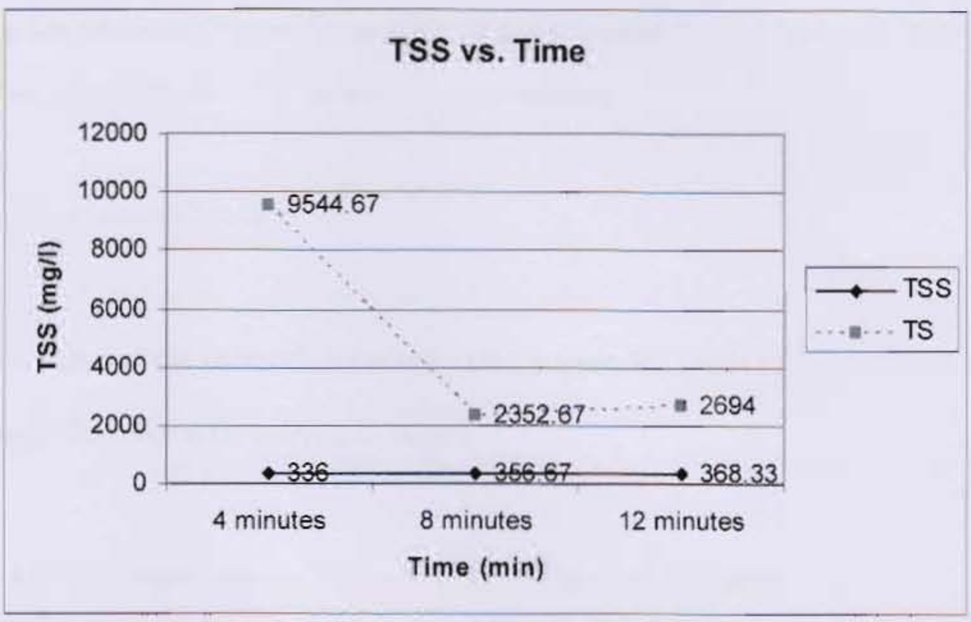

Figure 4.3: Total Suspended Solids vs. Rainfall Durations

4.3.1.3. Oxygen Demand

Biological oxygen demand (BOD) increases as the rainfall duration increases. As for chemical oxygen demand (COD), the increase of rainfall duration further diluted the runoff sample causing the COD to fall.

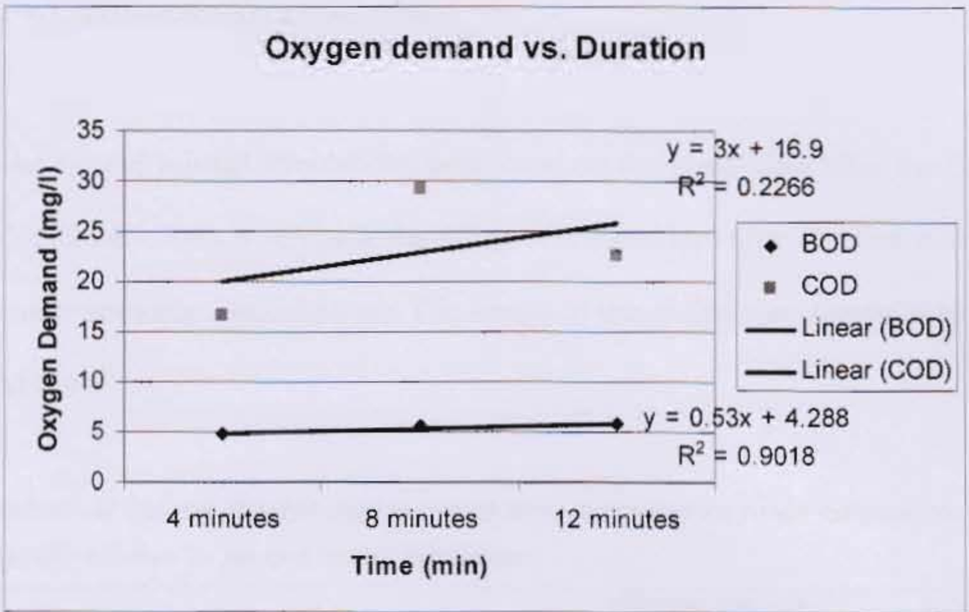

Figure 4.4: Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of first runoff vs. Rainfall Durations of the first rainfall simulations.

4.3.1.4. Correlation Studies

Table 4.7 shows the correlation between total suspended solids (TSS) and total solids (TS) with the other total nutrient in runoff

Table 4.7: Correlation between TSS and TS with the amount of nutrients

nutrients	TSS	p- value	TS	p- value
ammonia	0.205	0.596	-0.938	<0.0005
nitrate	-0.134	0.731	0.878	0.002
nitrite	0.505	0.166	-0.42	0.260
orthophosphate	0.187	0.629	-0.907	0.001
BOD	0.187	0.63	-0.753	0.019
COD	0.212	0.584	-0.826	0.006

Total suspended solids did not show any correlation with the other nutrient amount. However, total solids do show correlation with the other nutrients except nitrite. Total solids show correlation at 0.05 significant level while the other shows correlation on 0.01 significant level.

4.3.2. Second Rainfall Simulations

The second rainfall simulations were done on the same plots after the first rainfall simulations. This is to check the effect of the residues after the first rainfall on the runoff nutrients concentrations. The results of the analysis are shown in table 4.7 and table 4.8

Table 4.8: Volume of water used in rainfall simulations and the runoff collected for each rainfall duration for second rainfall simulations.

Duration	Volume of water used (ml)	Volume of runoff collected (ml)	Rainfall to runoff percentage
4 minutes simulation	53657	11950	22.27%
8 minutes simulation	107314	21950	20.45%
12 minutes simulation	160971	43900	27.27%

Table 4.9: Concentration of various water quality parameters of the runoffs from the second rainfall simulations.

	Mean Concentration (mg/l)							
...ons	Ammonia	Nitrate	Nitrite	Ortho phosphate	TSS	TS	BOD	COD
Control	0.23±*0.01*	0.043±*0.005*	0.006±*0.001*	0.35±*0.05*	56±*11*	143±*8*	4.24±*0.27*	12.7±*1.5*
...minutes[a]	0.27±0.02	0.037±0.015	0.006±0.000	0.51±0.05	76±15	4226±261	6.73±0.15	25.3±1.5
Control	0.24±*0.01*	0.023±*0.005*	0.003±*0.001*	0.62±*0.04*	201±*12*	2022±*102*	5.87±*0.02*	22.3±*0.5*
...minutes[b]	0.32±0.00	0.043±0.015	0.007±0.000	0.32±0.03	90±17	2473±482	6.61±0.28	36.7±3.8
Control	0.24±*0.00*	0.017±*0.005*	0.004±*0.001*	0.50±*0.04*	30±*10*	1080±*180*	4.88±*0.07*	21.3±*1.1*
...minutes[c]	0.30±0.00	0.030±0.000	0.005±0.000	0.59±0.02	123±15	2093±349	7.38±0.34	29.0±1.0
...ents	a≠ b= c	a= b= c	a= b= c	a= c≠ b	a≠ b= c	a= b≠ c	a= b≠ c	a= b= c
...ficant ...rence	<0.0005	0.121	0.015	0.817	0.976	0.014	<0.0005	<0.0005

4.3.2.1. Nutrient Analysis

Nutrients concentrations from runoff in the analysis this time still follow the pattern that was discovered earlier. The nutrient concentration in runoff increases with increasing rainfall duration and further rainfall diluted the concentrations of nutrients in the runoff.

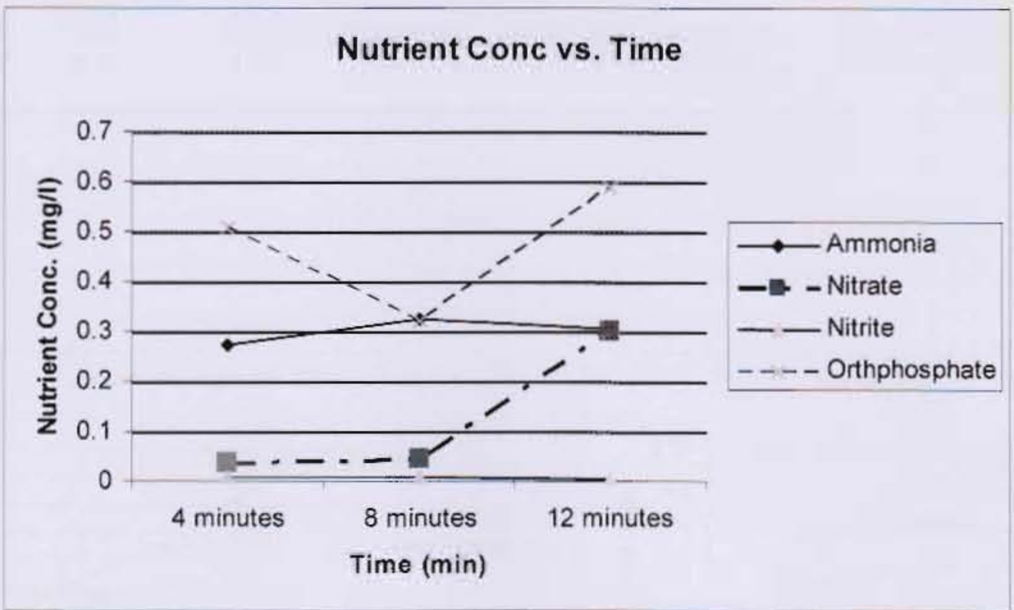

Figure 4.5: Nutrient concentration in runoff from second sludge second run versus the rainfall duration.

Total nutrients leaching through the runoff are shown in table 4.10.

Table 4.10: The assumed total nutrients discharge through runoff from the second rainfall. The figures below each numbers are the standard deviation of the means.

	Amount leached (mg/l)							
…ons	Ammonia	Nitrate	Nitrite	Ortho phosphate	TS	TSS	BOD	COD
…utes	3.23 *0.23*	0.44 *0.18*	0.08 *0.01*	6.09 *0.60*	50508.67 *3119.23*	916.16 *182.53*	80.46 *1.81*	302.73 *18.25*
…utes	7.12 *0.07*	0.94 *0.61*	0.16 *0.01*	7.02 *0.76*	54289.67 *10593.77*	1975.5 *380.18*	145.09 *6.22*	738.98 *3618.11*
…utes	13.33 *0.11*	13.17 *0.00*	0.23 *0.02*	25.9 *1.61*	91897.33 *15342*	5415.33 *670.58*	324.27 *15.21*	1485.36 *272.62*

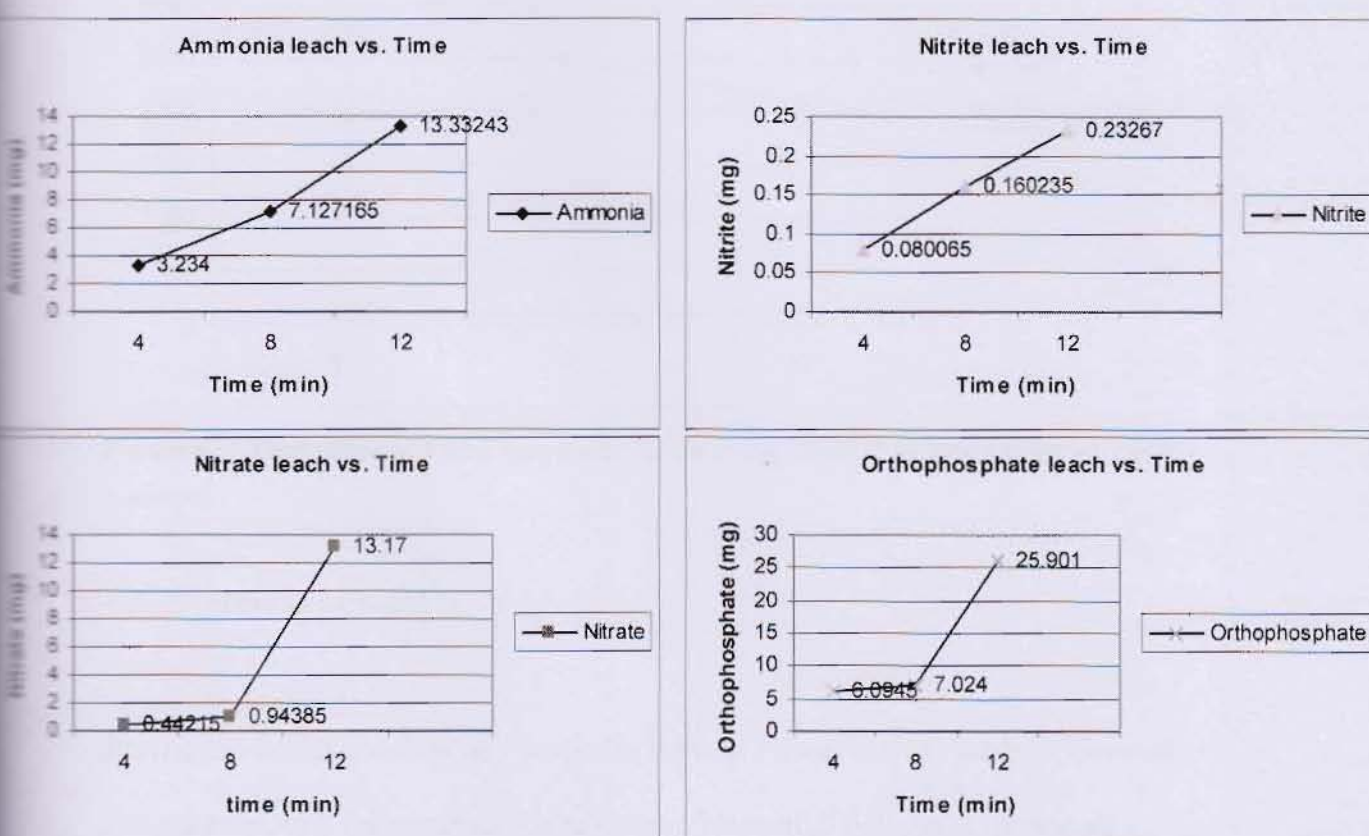

Figure 4.6: The figures shows the assumed total nutrient leaching through runoff during second rainfall analysis on the second sludge

The total leaching of the nutrients is almost the same manner as the total leaching of the previous rainfall simulations. The nutrients leaching are increasing with time duration of the rainfall as further the capacity of the nutrients leaching is becoming less with increasing rainfall volume.

4.3.2.2. Solids

Total suspended solids in the runoff still increases with increasing rainfall durations but the total solids now are becoming more diluted with more rainfalls (Figure 4.7)

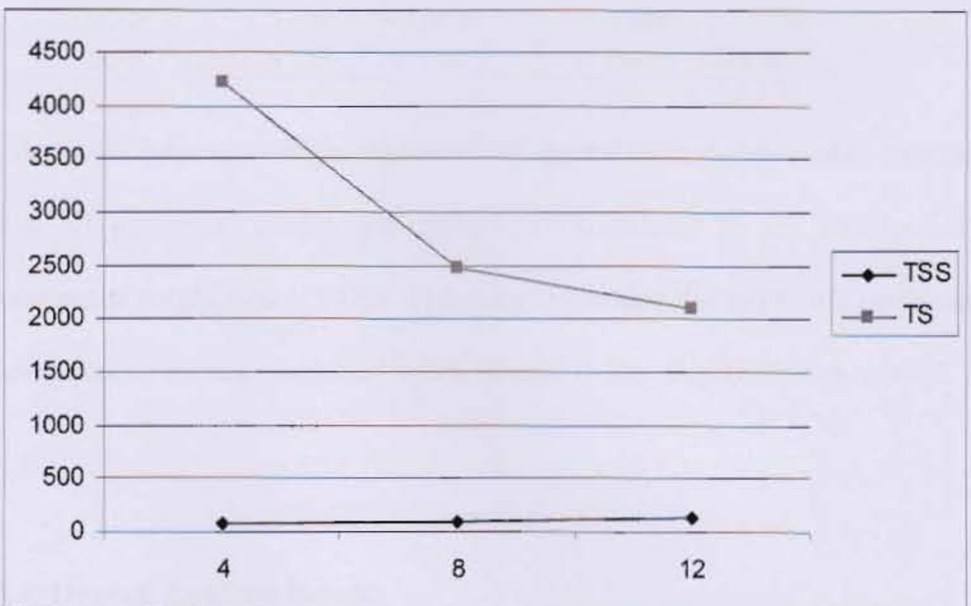

Figure 4.7: Total solids and total suspended solids in the runoff of second rainfall vs. rainfall durations

4.3.2.3. Oxygen Demand

BOD analysis did not show any particular pattern. However COD analysis shows the same pattern with the nutrients where continuous rainfall will cause increasing concentration but in the end it will dilute the concentration and cause lower readings.

4.3.2.4. Correlation studies

Table 4.11 below shows the results of correlation analysis between solids and other water quality parameters.

Table 4.11: Correlation between TSS and TS with the amount of nutrients for second rainfall

	correlations			
nutrients	TSS	p- value	TS	p- value
ammonia	0.965	<0.0005	0.857	0.003
nitrate	0.757	0.018	0.739	0.023
nitrite	0.890	0.001	0.788	0.012
orthophosphate	0.956	<0.0005	0.889	0.001
BOD	0.970	<0.0005	0.866	0.003
COD	0.126	0.746	0.063	0.872

The result from correlation studies of solids and other water quality parameter shows that all the water quality parameters are correlated to the total solids and total suspended solids except COD. This may show that the most COD nutrients (organic compounds) are not bonded to solids instead it was dissolved in the runoff.

4.4. Overall Analysis Results

The nutrients concentrations in runoff are dependant on the duration and volume of the rainfall that falls on the sludge. We can see that the concentration of the nutrients stop increasing at some stage of a continuous rainfall due to completed capacity of the nutrients discharge as well as dilution of rainwater causing the runoff nutrient concentration to decrease.

The rainfall first simulations were done separately for 4 minutes rainfall durations and the others due to raining. The runoff from 4 minutes rain durations are expected to differ slightly compared to others due to the difference in soil humidity that caused different soil ability to contain water. This will cause difference in the volume of runoff collected. Degradation of the sludge may also happen during the time duration from the first simulation to the other.

The amount of ammonia in the sludge is around 24 mg/kg. Assuming that the sludge are not degraded or lost in any other way before the start of the rainfall simulations, only 10 to 13% of the ammonia content is loss in the runoff during the first rainfall simulations. This may be caused by insoluble organic nutrients that are abundant in the sludge. According to Paul (1996), most of the nitrogen in the sediment from prawn ponds appeared to be organic because it was not soluble in either water or acid. Other possible reasons are that the way the sludge is applied on the plots caused only the nutrients on the surface of the sludge to be leached through the runoff while the other nutrient remains unaffected by the rainfall. There is also a possibility that a large amount of nutrients leached into the underground water considering the low percentage of runoff- rainfall ratio.

The first runoffs through a sample sludge applied on the ground are quite high on the content of nutrients and other water quality parameters. However, the concentrations are becoming much less during the next rainfall. This may be caused by the first nutrient leached that caused less nutrients amount in the sludge to be leached on the next rainfall. This may also be caused by degradation of the sludge that caused depletion in nutrient content in the sludge.

Relatively all the concentration of the nutrients and solids are decreasing on the second rainfall simulations of the sludge compared to the first rainfall simulations. Some of the readings (ammonia on the 4 minutes and nitrates and total solids on 8 minutes rainfall durations) are increasing on the second rainfall analysis, but independent sample test using SPSS shows no significant difference between the readings at 95% confidence limits. The leaching of nutrients from prawn pond sludge through runoff agree with previous literature (Stewart (2005) and Cindy et. al. (2001)) that the nutrients leaching are the most intensive during the early stages and gradually decreasing in rate afterwards. Figure 4.8 (page 38) shows the concentration of nutrients and solids that is obtained from the experiment of the second sludge

The two parameters of oxygen demand that is the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) of the runoff however increased during the second rainfall simulation. The reasons for the increase are unexplanable. It may be caused by the sludge reduces to less oxidation states, or production of humic acids or other materials by microorganisms.

Nitrates and nitrites concentration leached through the runoff are quite low, but the concentrations on ammonia, orthophosphate, and solids (total solids and total suspended solids) are high enough to be considered as class III or class IV water according to interim water quality standards for Malaysia (from 5 classes of water). Solids particularly are quite high in the first run of the second sludge and can be well categorized as class V water (the worst quality). Oxygen demands for the runoff samples are also considered as class III water.

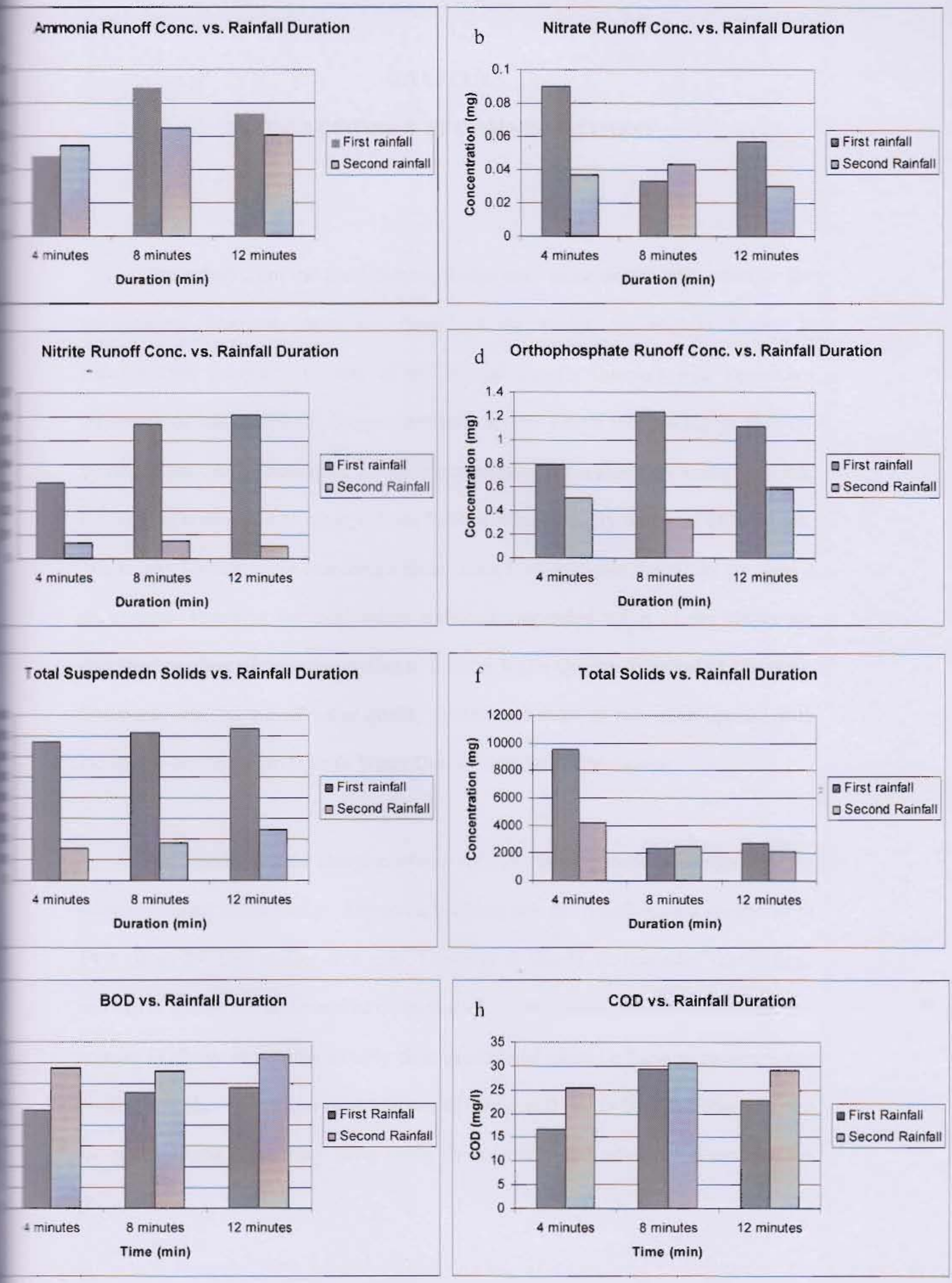

Figure 4.8: Concentration of various water quality parameters in the runoff of the first and second rainfall simulations. a. ammonia, b. nitrate, c. nitrite, d. orthophosphate, e. total suspended solids, f. total solids, g. biochemical oxygen demand, h. chemical oxygen demand

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

The runoff from the pond bottom sludge may cause detrimental effect on the environment. Nutrients from the runoff of the sludge are slightly higher in concentration compared to that of the normal runoffs (blanks) with significant difference of less than 0.05. Oxygen demands for the runoff are also higher than the normal water quality standards. Solids concentration, particularly are really high that it is can be considered as class V from Interim Water Quality Standard of Malaysia. The blanks for nitrate are considered clean (class I water) while the others are class 2 on average. However the total solids and total suspended solids of the blanks are classified as class III water according to Interim Water Quality Standard of Malaysia. Comparatively, the runoff water quality decreases a stage or two when applied with the sludge (according to Interim Water Quality Standard of Malaysia).

The runoff from the sludge contains very low nutrient content compared to the nutrient content in the sludge. Ammonia leaching into the runoff is only around 10 to 14% (from the first sludge first run). However it should be reminded that a large amount of sludge are accumulated on each cycle of the prawn culture activity and this amount of sludge may cause a really clear detrimental effect on the surrounding water bodies. It is also clear that a large amount of the rainfall (60 to 80%) are leaching into the underground. They may bring along the nutrients and other pollutants into the groundwater.

Future Research

Future research can be done to better understand the leaching characteristic of prawn pond sludge. Possible areas that still need to be studies are

1. Effect of different sludge amount on the pollutants concentrations of runoff
2. The pollutants leach into the underground
3. The degradation characteristic of prawn pond sludge in normal/ controlled environment
4. The effect of weather/ condition on the leaching of pollutants
5. Effect of different sludge thickness and surface area on the leaching through runoff and groundwater.

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Appendix 1

RESULTS DATA

Table 1: Nutrients Concentration of Runoff from the First Sludge

parameter	Duration	Replicate	Concentration	Mean	SD
ammonia	4 minutes	R1	<0.0005	0.0016	0.00289
		R2	0.005		
		R3	<0.0005		
	8 minutes	R1	0.035	0.0627	0.03219
		R2	0.055		
		R3	0.098		
	12 minutes	R1	0.055	0.1660	0.09707
		R2	0.235		
		R3	0.208		
nitrate	4 minutes	R1	0.03	0.026	0.0057
		R2	0.02		
		R3	0.03		
	8 minutes	R1	0.03	0.030	0.000
		R2	0.03		
		R3	0.03		
	12 minutes	R1	0.03	0.037	0.0115
		R2	0.05		
		R3	0.03		
nitrite	4 minutes	R1	0.04	0.046	0.0057
		R2	0.05		
		R3	0.05		
	8 minutes	R1	0.05	0.053	0.0153
		R2	0.04		
		R3	0.07		
	12 minutes	R1	0.06	0.070	0.0173
		R2	0.09		
		R3	0.06		
orthophosphate	4 minutes	R1	0.59	0.533	0.0439
		R2	0.51		
		R3	0.50		
	8 minutes	R1	0.72	0.656	0.065
		R2	0.59		
		R3	0.66		
	12 minutes	R1	0.72	0.753	0.0351
		R2	0.75		
		R3	0.79		

All figures are in mg/L units

Table 2: Results for Total Solids, Total Suspended Solids, Biochemical Oxygen Demand and Chemical Oxygen Demand for the Runoff from the First Sludge

parameter	duration	replicate	conc.	mean	SD
TSS	4 minutes	R1	541	270	235.76
		R2	157		
		R3	112		
	8 minutes	R1	66	82	0.00838
		R2	100		
		R3	80		
	12 minutes	R1	103	176.67	86.55
		R2	155		
		R3	272		
TS	4 minutes	R1	1796	1527.33	307.47
		R2	1192		
		R3	1594		
	8 minutes	R1	1510	1593.33	102.65
		R2	1562		
		R3	1708		
	12 minutes	R1	1712	1727.33	18.58
		R2	1722		
		R3	1748		
BOD	4 minutes	R1	3.26	3.83	0.6139
		R2	4.48		
		R3	3.75		
	8 minutes	R1	4.09	4.146	0.4974
		R2	4.67		
		R3	3.68		
	12 minutes	R1	3.6	3.77	0.3297
		R2	4.15		
		R3	3.56		
COD	4 minutes	R1	8	11.3	5.77
		R2	18		
		R3	8		
	8 minutes	R1	9	5.6	3.05
		R2	3		
		R3	5		
	12 minutes	R1	0	1.3	1.53
		R2	1		
		R3	3		

All figures are in mg/L units

Table 3: Nutrients from Runoff for Second Sludge First Run

parameter	Duration	Replicate	Concentration	Mean	SD
ammonia	4 minutes	R1	0.231	0.2397	0.01097
		R2	0.252		
		R3	0.236		
	8 minutes	R1	0.437	0.4467	0.00838
		R2	0.452		
		R3	0.451		
	12 minutes	R1	0.355	0.3693	0.01504
		R2	0.368		
		R3	0.385		
nitrate	4 minutes	R1	0.08	0.090	0.0100
		R2	0.09		
		R3	0.10		
	8 minutes	R1	0.04	0.333	0.0057
		R2	0.03		
		R3	0.03		
	12 minutes	R1	0.06	0.057	0.0057
		R2	0.06		
		R3	0.05		
nitrite	4 minutes	R1	0.035	0.0320	0.00610
		R2	0.036		
		R3	0.025		
	8 minutes	R1	0.067	0.0567	0.00961
		R2	0.055		
		R3	0.048		
	12 minutes	R1	0.055	0.0607	0.00666
		R2	0.059		
		R3	0.068		
orthophosphate	4 minutes	R1	0.79	0.790	0.0500
		R2	0.74		
		R3	0.84		
	8 minutes	R1	1.18	1.233	0.0503
		R2	1.28		
		R3	1.24		
	12 minutes	R1	1.24	1.110	0.1300
		R2	0.98		
		R3	1.11		

All figures are in mg/L units

Table 4: Results for Total Solids, Total Suspended Solids, Biochemical Oxygen Demand and Chemical Oxygen Demand for the Runoff from the Second Sludge Second Run

parameter	duration	replicate	conc.	mean	SD
TSS	4 minutes	R1	324	336	86.62
		R2	256		
		R3	428		
	8 minutes	R1	374	356.67	83.36
		R2	430		
		R3	266		
	12 minutes	R1	302	368.33	75.83
		R2	352		
		R3	451		
TS	4 minutes	R1	10400	9544.67	740.85
		R2	9104		
		R3	9130		
	8 minutes	R1	2490	2352.67	153.06
		R2	2348		
		R3	2220		
	12 minutes	R1	2734	2694	40
		R2	2654		
		R3	2694		
BOD	4 minutes	R1	4.06	4.717	0.5713
		R2	5.1		
		R3	4.99		
	8 minutes	R1	4.77	5.55	0.6755
		R2	5.94		
		R3	5.94		
	12 minutes	R1	5.89	5.777	0.232
		R2	5.51		
		R3	5.93		
COD	4 minutes	R1	16	16.7	2.08
		R2	15		
		R3	19		
	8 minutes	R1	32	29.3	2.31
		R2	28		
		R3	28		
	12 minutes	R1	24	22.7	1.53
		R2	23		
		R3	21		

All figures are in mg/L units

Table 5: Nutrients for Runoff from Second Sludge Second Run

parameter	Duration	Replicate	Concentration	Mean	SD
ammonia	4 minutes	R1	0.254	0.2707	0.01943
		R2	0.266		
		R3	0.292		
	8 minutes	R1	0.325	0.3247	0.00351
		R2	0.328		
		R3	0.321		
	12 minutes	R1	0.304	0.3037	0.00251
		R2	0.306		
		R3	0.301		
nitrate	4 minutes	R1	0.050	0.037	0.0513
		R2	0.02		
		R3	0.04		
	8 minutes	R1	0.03	0.043	0.0513
		R2	0.06		
		R3	0.04		
	12 minutes	R1	0.03	0.300	0.0000
		R2	0.030		
		R3	0.030		
nitrite	4 minutes	R1	0.006	0.0067	0.00057
		R2	0.007		
		R3	0.007		
	8 minutes	R1	0.007	0.0073	0.00057
		R2	0.008		
		R3	0.007		
	12 minutes	R1	0.006	0.0053	0.00057
		R2	0.005		
		R3	0.005		
orthophosphate	4 minutes	R1	0.46	0.51	0.0500
		R2	0.51		
		R3	0.56		
	8 minutes	R1	0.28	0.32	0.0346
		R2	0.34		
		R3	0.34		
	12 minutes	R1	0.60	0.59	0.0265
		R2	0.61		
		R3	0.56		

All figures are in mg/L units

Table 6: Results for Total Solids, Total Suspended Solids, Biochemical Oxygen Demand and Chemical Oxygen Demand for the Runoff from the Second Sludge Second Run

parameter	duration	replicate	conc.	mean	SD
TSS	4 minutes	R1	80	76.67	15.275
		R2	90		
		R3	60		
	8 minutes	R1	70	90	17.321
		R2	100		
		R3	100		
	12 minutes	R1	110	123.33	15.275
		R2	120		
		R3	140		
TS	4 minutes	R1	4140	4226.67	261.023
		R2	4020		
		R3	4520		
	8 minutes	R1	1940	2473.33	482.631
		R2	2880		
		R3	2600		
	12 minutes	R1	2000	2093.33	349.476
		R2	1800		
		R3	2480		
BOD	4 minutes	R1	6.57	6.733	0.1518
		R2	6.76		
		R3	6.87		
	8 minutes	R1	6.39	6.61	0.2835
		R2	6.51		
		R3	6.93		
	12 minutes	R1	7.54	7.387	0.3464
		R2	7.63		
		R3	6.99		
COD	4 minutes	R1	24	25.3	1.53
		R2	25		
		R3	27		
	8 minutes	R1	34	36.7	3.79
		R2	35		
		R3	41		
	12 minutes	R1	29	29	1
		R2	30		
		R3	28		

All figures are in mg/L units

Table 7: Results of the Analysis on the Second Sludge

parameter	replicate	readings	mean	SD	units
pH	R1	7.24	7.27	0.0305	
	R2	7.28			
	R3	7.30			
Electrical conductivity	R1	5.39	5.47	0.121	mS
	R2	5.61			
	R3	5.41			
Organic matter	R1	0.568	0.598	0.029	w/w DW
	R2	0.603			
	R3	0.625			
ammonia	R1	23.5	24.46	1.67	mg/kg
	R2	26.4			
	R3	23.5			
Total Kjeldahl Nitrogen	R1	0.33	0.353	0.021	w/w
	R2	0.37			
	R3	0.36			
TP	R1	35.5	34.7	2.36	mg/l
	R2	32.0			
	R3	36.5			

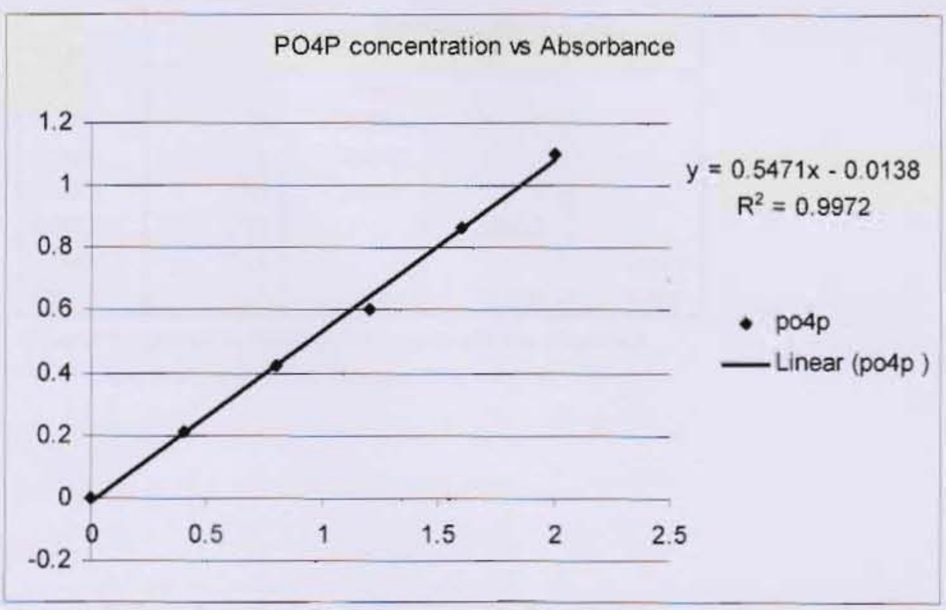

Figure above shows the calibration curve for the total phosphorus analysis

Appendix 2

ANOVA table

Summary for multiple comparison tests

*Sample labeled 1, 2, 3 are the sample of runoff for 4 minutes, 8 minutes and 12 minutes respectively. Sample 4, 8, and 12 are the BLANK sample for 4, 8, and 12 minutes respectively.

ANOVA table and homogeneous subsets for the first rainfall analysis of second sludge (page 54- 59)

AMMONIA

ANOVA

AMMONIA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.124	5	.025	214.302	.000
Within Groups	.001	12	.000		
Total	.125	17			

AMMONIA

Tukey HSD[a]

		Subset for alpha = .05		
SAMPLE	N	1	2	3
4.000	3	.23200		
8.000	3	.23933		
1.000	3	.23967		
12.000	3	.24367		
3.000	3		.36933	
2.000	3			.44667
Sig.		.765	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

NITRATE

ANOVA

NITRATE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.011	5	.002	48.125	.000
Within Groups	.001	12	.000		
Total	.011	17			

NITRATE

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05			
		1	2	3	4
12.000	3	.01667			
8.000	3	.02333			
2.000	3	.03333	.03333		
4.000	3		.04333	.04333	
3.000	3			.05667	
1.000	3				.09000
Sig.		.082	.480	.214	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

NITRITE

ANOVA

NITRITE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.011	5	.002	72.595	.000
Within Groups	.000	12	.000		
Total	.011	17			

NITRITE

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05		
		1	2	3
8.000	3	.00300		
12.000	3	.00433		
4.000	3	.00600		
1.000	3		.03200	
2.000	3			.05667
3.000	3			.06067
Sig.		.981	1.000	.939

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

ORTHOPHOSPHATE

ANOVA

PO4P

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.802	5	.360	75.432	.000
Within Groups	.057	12	.005		
Total	1.859	17			

PO4P

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05			
		1	2	3	4
4.000	3	.35000			
12.000	3	.50333	.50333		
8.000	3		.62000	.62000	
1.000	3			.79000	
3.000	3				1.11000
2.000	3				1.23333
Sig.		.142	.363	.089	.311

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

TOTAL SOLIDS

ANOVA

TS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.68E+08	5	33686592.22	278.859	.000
Within Groups	1449616	12	120801.333		
Total	1.70E+08	17			

TS

Tukey HSD[a]

		Subset for alpha = .05			
SAMPLE	N	1	2	3	4
4.000	3	143.33333			
12.000	3	1080.000	1080.000		
8.000	3		2022.000	2022.000	
2.000	3			2352.667	
3.000	3			2694.000	
1.000	3				9544.667
Sig.		.055	.053	.241	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

TOTAL SUSPENDED SOLIDS

ANOVA

TSS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	352088.7	5	70417.733	20.526	.000
Within Groups	41167.333	12	3430.611		
Total	393256.0	17			

TSS

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05 1	2	3	4
12.000	3	30.00000			
4.000	3	56.00000	56.00000		
8.000	3		201.00000	201.00000	
1.000	3			336.00000	336.00000
2.000	3			356.66667	356.66667
3.000	3				368.33333
Sig.		.993	.086	.059	.981

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

BIOCHEMICAL OXYGEN DEMAND

ANOVA

BOD

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.462	5	1.292	8.442	.001
Within Groups	1.837	12	.153		
Total	8.299	17			

BOD

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05 1	2	3
4.000	3	4.24667		
1.000	3	4.71667	4.71667	
12.000	3	4.88000	4.88000	4.88000
2.000	3		5.55000	5.55000
3.000	3		5.77667	5.77667
8.000	3			5.87667
Sig.		.404	.054	.074

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

CHEMICAL OXYGEN DEMAND

ANOVA

COD

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	486.500	5	97.300	36.488	.000
Within Groups	32.000	12	2.667		
Total	518.500	17			

COD

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05		
		1	2	3
4.000	3	12.66667		
1.000	3	16.66667		
12.000	3		21.33333	
8.000	3		22.33333	
3.000	3		22.66667	
2.000	3			29.33333
Sig.		.091	.909	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

ANOVA table and homogeneous subsets for the SECOND rainfall analysis of second sludge (page 60- 65)

AMMONIA

ANOVA

AMMONIA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.022	5	.004	38.502	.000
Within Groups	.001	12	.000		
Total	.023	17			

AMMONIA

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05		
		1	2	3
4.000	3	.23200		
8.000	3	.23933		
12.000	3	.24367	.24367	
1.000	3		.27067	
3.000	3			.30367
2.000	3			.32467
Sig.		.754	.074	.220

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

NITRATE

ANOVA

NITRATE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.002	5	.000	3.765	.028
Within Groups	.001	12	.000		
Total	.003	17			

NITRATE

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05	
		1	2
12.000	3	.01667	
8.000	3	.02333	.02333
3.000	3	.03000	.03000
1.000	3	.03667	.03667
2.000	3		.04333
4.000	3		.04333
Sig.		.192	.192

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

NITRITE

ANOVA

NITRITE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	5	.000	10.462	.000
Within Groups	.000	12	.000		
Total	.000	17			

NITRITE

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05		
		1	2	3
8.000	3	.00300		
12.000	3	.00433	.00433	
3.000	3		.00533	.00533
4.000	3		.00600	.00600
1.000	3			.00667
2.000	3			.00733
Sig.		.435	.229	.110

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

ORTHOPHOSPHATE

ANOVA

PO4P

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.227	5	.045	24.450	.000
Within Groups	.022	12	.002		
Total	.249	17			

PO4P

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05	
		1	2
2.000	3	.32000	
4.000	3	.35000	
12.000	3		.50333
1.000	3		.51000
3.000	3		.59000
8.000	3		.62000
Sig.		.951	.054

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

TOTAL SOLIDS

ANOVA

TS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28453938	5	5690787.556	58.941	.000
Within Groups	1158603	12	96550.222		
Total	29612540	17			

TS

Tukey HSD[a]

		Subset for alpha = .05			
SAMPLE	N	1	2	3	4
4.000	3	143.33333			
12.000	3		1080.000		
8.000	3			2022.000	
3.000	3			2093.333	
2.000	3			2473.333	
1.000	3				4226.667
Sig.		1.000	1.000	.512	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

TOTAL SUSPENDED SOLIDS

ANOVA

TSS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	54413.167	5	10882.633	56.944	.000
Within Groups	2293.333	12	191.111		
Total	56706.500	17			

TSS

Tukey HSD[a]

		Subset for alpha = .05			
SAMPLE	N	1	2	3	4
12.000	3	30.00000			
4.000	3	56.00000	56.00000		
1.000	3		76.66667		
2.000	3		90.00000	90.00000	
3.000	3			123.33333	
8.000	3				201.00000
Sig.		.264	.089	.098	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

BIOCHEMICAL OXYGEN DEMAND

ANOVA

BOD

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	21.494	5	4.299	84.419	.000
Within Groups	.611	12	.051		
Total	22.105	17			

BOD

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05				
		1	2	3	4	5
4.000	3	4.24667				
12.000	3		4.88000			
8.000	3			5.87667		
2.000	3				6.61000	
1.000	3				6.73333	
3.000	3					7.38667
Sig.		1.000	1.000	1.000	.982	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

CHEMICAL OXYGEN DEMAND

ANOVA

COD

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	934.278	5	186.856	19.442	.000
Within Groups	115.333	12	9.611		
Total	1049.611	17			

COD

Tukey HSD[a]

SAMPLE	N	Subset for alpha = .05		
		1	2	3
4.000	3	12.66667		
12.000	3		21.33333	
8.000	3		22.33333	
1.000	3		25.33333	25.33333
3.000	3			33.00000
2.000	3			33.66667
Sig.		1.000	.625	.056

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

APPENDIX 3

Independent Sample test

The tables display the Independent Sample test table from SPSS for the significant difference between The first and the second runoff concentration of the second sludge

Table 1 to 8 displays the results for the 4 minutes rainfall duration (page 66- 68)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MONI.	Equal variance assumed	1.163	.342	-2.407	4	.074	-.0310	.01288	-.06676	.00476
	Equal variance not assumed			-2.407	3.158	.091	-.0310	.01288	-.07085	.00885

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TRATE	Equal variance assumed	.727	.442	5.060	4	.007	.0533	.01054	.02407	.08260
	Equal variance not assumed			5.060	3.448	.011	.0533	.01054	.02212	.08454

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
ITRITE Equal variance assumed	12.237	.025	7.181	4	.002	.0253	.00353	.01554	.03513
Equal variance not assumed			7.181	2.036	.018	.0253	.00353	.01041	.04026

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
O4P Equal variance assumed	.000	1.000	6.859	4	.002	.2800	.04082	.16665	.39335
Equal variance not assumed			6.859	4.000	.002	.2800	.04082	.16665	.39335

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
SS Equal variance assumed	3.963	.117	5.106	4	.007	259.3333	50.78495	18.33171	00.33496
Equal variance not assumed			5.106	2.124	.032	259.3333	50.78495	52.62627	66.04040

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TS	Equal variances assumed	5.857	.073	11.726	4	.000	5318.0000	453.50438	4058.870	6577.130
	Equal variances not assumed			11.726	2.489	.003	5318.0000	453.50438	3691.743	6944.257

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
BOD	Equal variances assumed	7.340	.054	-5.909	4	.004	-2.0167	.34130	-2.96428	-1.06905
	Equal variances not assumed			-5.909	2.281	.020	-2.0167	.34130	-3.32481	-.70852

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
COD	Equal variances assumed	.500	.519	-5.814	4	.004	-8.6667	1.49071	-12.80555	-4.52779
	Equal variances not assumed			-5.814	3.670	.006	-8.6667	1.49071	-12.95667	-4.37666

able 9 to 16 shows the results on the Independent Sample test for the 8 minutes rainfall durations (page 69- 71)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MMONI/	Equal variances assumed	4.208	.110	23.241	4	.000	.1220	.00525	.10743	.13657
	Equal variances not assumed			23.241	2.680	.000	.1220	.00525	.10411	.13989

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TRATE	Equal variances assumed	2.571	.184	-1.061	4	.349	-.0100	.00943	-.03618	.01618
	Equal variances not assumed			-1.061	2.560	.379	-.0100	.00943	-.04314	.02314

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TRITE	Equal variances assumed	5.881	.072	8.876	4	.001	.0493	.00556	.03390	.06476
	Equal variances not assumed			8.876	2.014	.012	.0493	.00556	.02558	.07308

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PO4P	Equal variances assumed	.308	.609	25.891	4	.000	.9133	.03528	.81539	1.01128
	Equal variances not assumed			25.891	3.548	.000	.9133	.03528	.81026	1.01641

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TSS	Equal variances assumed	4.432	.103	5.425	4	.006	266.6667	49.15734	30.18400	03.14933
	Equal variances not assumed			5.425	2.172	.027	266.6667	49.15734	70.45439	62.87894

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TS	Equal variances assumed	4.270	.108	-.417	4	.698	-120.6667	289.35253	-924.038	82.70476
	Equal variances not assumed			-.417	2.311	.712	-120.6667	289.35253	-1217.98	76.64780

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
3OD	Equal variances assumed	4.490	.101	-2.506	4	.066	-1.0600	.42297	-2.23434	.11434
	Equal variances not assumed			-2.506	2.684	.097	-1.0600	.42297	-2.50047	.38047

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
:OD	Equal variances assumed	1.538	.283	-2.864	4	.046	-7.3333	2.56038	14.44209	-.22457
	Equal variances not assumed			-2.864	3.307	.057	-7.3333	2.56038	15.06953	.40286

Table 17 to 24 shows the on the Independent Sample test for the 12 minutes rainfall durations (page 72- 74)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MMONI/	Equal variances assumed	3.505	.135	7.457	4	.002	.0657	.00881	.04122	.09012
	Equal variances not assumed			7.457	2.112	.015	.0657	.00881	.02963	.10170

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TRATE	Equal variances assumed	16.000	.016	8.000	4	.001	.0267	.00333	.01741	.03592
	Equal variances not assumed			8.000	2.000	.015	.0267	.00333	.01232	.04101

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TRITE	Equal variances assumed	6.957	.058	14.340	4	.000	.0553	.00386	.04462	.06605
	Equal variances not assumed			14.340	2.030	.005	.0553	.00386	.03896	.07170

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
'O4P	Equal variances assumed	2.326	.202	6.789	4	.002	.5200	.07659	.30734	.73266
	Equal variances not assumed			6.789	2.165	.017	.5200	.07659	.21343	.82657

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
'SS	Equal variances assumed	4.674	.097	5.486	4	.005	245.0000	44.66045	21.00272	68.99728
	Equal variances not assumed			5.486	2.162	.027	245.0000	44.66045	66.00409	23.99591

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
'S	Equal variances assumed	6.969	.058	2.958	4	.042	600.6667	203.08728	36.80597	1164.527
	Equal variances not assumed			2.958	2.052	.095	600.6667	203.08728	-252.116	1453.449

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
OD	Equal variances assumed	1.050	.363	-6.690	4	.003	-1.6100	.24067	-2.27821	-.94179
	Equal variances not assumed			-6.690	3.492	.004	-1.6100	.24067	-2.31838	-.90162

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
OD	Equal variances assumed	.727	.442	-6.008	4	.004	-6.3333	1.05409	-9.25996	-3.40670
	Equal variances not assumed			-6.008	3.448	.006	-6.3333	1.05409	-9.45422	-3.21245

APPENDIX 4

PAIRED T- TEST TABLE

The table below shows the correlation between the water quality parameter with the associated blanks. The name of each parameter represent the sample concentration while the variable (VAR0000X) paired to each parameter are the blanks for the first rainfall simulations.

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	NITRATE & VAR00001	9	.716	.030
Pair 2	NITRITE & VAR00002	9	-.499	.171
Pair 3	PO4P & VAR00003	9	.859	.003
Pair 4	BOD & VAR00004	9	.509	.162
Pair 5	TSS & VAR00005	9	-.044	.910
Pair 6	TS & VAR00006	9	-.852	.004
Pair 7	COD & VAR00007	9	.861	.003
Pair 8	AMMONIA & VAR00008	9	.449	.226

The table below shows the paired sample t test table of the various water quality parameter of the runoff paired with the control runoff for the first rainfall simulations.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	NITRATE - VAR00001	.03222	.018559	.006186	.01796	.04649	5.209	8	.001
Pair 2	NITRITE - VAR00002	.04533	.015827	.005276	.03317	.05750	8.593	8	.000
Pair 3	PO4P - VAR00003	.55333	.122678	.040893	.45903	.64763	13.531	8	.000
Pair 4	BOD - VAR00004	.34667	.691321	.230440	-.18473	.87806	1.504	8	.171
Pair 5	TSS - VAR00005	258.00000	110.596112	36.865371	172.98830	343.01170	6.998	8	.000
Pair 6	TS - VAR00006	3782.000	4269.397850	1423.133	500.25030	7063.750	2.658	8	.029
Pair 7	COD - VAR00007	4.11111	2.934469	.978156	1.85548	6.36674	4.203	8	.003
Pair 8	AMMONIA - VAR00008	.11356	.087214	.029071	.04652	.18059	3.906	8	.005

The table below shows the correlation between the water quality parameter with the associated blanks. The name of each parameter represent the sample concentration while the variable (VAR0000X) paired to each parameter are the blanks for the second rainfall simulations.

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	NITRATE & VAR00001	9	.261	.497
Pair 2	NITRITE & VAR00002	9	-.060	.877
Pair 3	PO4P & VAR00003	9	-.604	.085
Pair 4	BOD & VAR00004	9	-.181	.640
Pair 5	TSS & VAR00005	9	-.270	.482
Pair 6	TS & VAR00006	9	-.770	.015
Pair 7	COD & VAR00007	9	.798	.010
Pair 8	AMMONIA & VAR00008	9	.463	.210

e table below shows the paired sample t test table of the various water quality parameter of the off paired with the control runoff for the second rainfall simulations.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
r 1	NITRATE - VAR00001	.00889	.015366	.005122	-.00292	.02070	1.735	8	.121
r 2	NITRITE - VAR00002	.00200	.001936	.000645	.00051	.00349	3.098	8	.015
r 3	PO4P - VAR00003	-.01778	.222866	.074289	-.18909	.15353	-.239	8	.817
r 4	BOD - VAR00004	1.90889	.909539	.303180	1.20976	2.60802	6.296	8	.000
r 5	TSS - VAR00005	1.00000	90.403263	30.134421	-68.49010	70.49010	.033	8	.974
r 6	TS - VAR00006	1849.333	1764.925777	588.3086	492.69129	3205.975	3.143	8	.014
r 7	COD - VAR00007	11.88889	3.295620	1.098540	9.35565	14.42213	10.822	8	.000
r 8	AMMONIA - VAR00008	.06133	.022782	.007594	.04382	.07884	8.077	8	.000

Appendix 5
Pictures

Picture of the pond sludge after water discharge

The sludge

Rainfall simulator (TLALOC 3000, Joern's Inc. USA)

Odessey *Hach*® DR/2500 Portable Spectrophotometer for water quality analysis