

**THE EFFECT OF DOSING UNSTABILIZED LANDFILL
LEACHATE TO A NUTRIENT
REMOVAL ACTIVATED SLUDGE SYSTEM**

by

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DECLARATION

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Signed

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SYNOPSIS

Due to the ever increasing urban population and the increased environmental awareness, the amount of available land for landfills has decreased. This has resulted in the need to maximise the life of a landfill. Leachate, which can be in an unstabilized or stabilized form, poses the greatest threat to the environment by possible pollution to the ground water. To avoid this pollution the leachate generated in the landfill needs to be collected and treated. Various treatment processes have been used to treat leachate, however, little is known on the treatment by an activated sludge wastewater treatment plant. Accordingly, this study focuses on the effect of unstabilized leachate on a nutrient removal activated sludge plant and in particular, the feasibility of adopting an integrated approach to municipal waste management by operating conventional sewage treatment plants (liquid waste management) and sanitary landfill sites (solid waste management) in conjunction with each other. In terms of this approach, the excess liquid leachate stream produced in the landfill is treated in the sewage treatment plant and the solids sludge stream generated in the sewage treatment plant is disposed of to the landfill (Novella *et al.*, 1995). The sites of both the sewage treatment plant and the sanitary landfill site are thus very important as they would need to be close to each other so that transport costs are kept to a minimum. The experimental data for this investigation have been obtained from two laboratory scale UCT nitrification/denitrification biological excess phosphorus removal (NDBEPR) systems operated for 495 days at 20°C and 10 days sludge age; one experimental (EXP) system receiving a dose of unstabilized leachate as well as domestic sewage, and the other control (CTL) system receiving domestic sewage as influent.

The objective of the experimental program was to determine if addition of landfill leachate to the raw influent of an activated sludge nutrient removal plant would have either an enhancing or detrimental effect on biological COD uptake, P and N removal, nitrification, and sludge settleability. To this end, landfill leachate taken from an experimental (pilot-scale) system (operated in a previous study) was added to two laboratory scale UCT nitrification/denitrification biological excess phosphorus removal (NDBEPR) systems operated for 495 days at 20°C and 10 days sludge age; one experimental (EXP) system receiving a dose of unstabilized leachate as

well as sewage, and the other control (CTL) system receiving only influent sewage.

To establish the reliability of the experimental data, COD and N balances were performed on each system. In these balances, the mass entering the system is reconciled with the mass leaving the system and the reliability of the data is directly proportional to the mass balance deviation from 100 %. The average COD balances in the EXP and CTL systems were 92 % and the average N balance 90 % and 88 % respectively. Although considerably lower than 100 %, these are acceptable and similar to COD and N balances observed in other investigations on nutrient removal systems (Clayton *et al.*, 1989; Pilson *et al.*, 1995; Mellin *et al.* 1996).

A leachate dose of 42 ml with COD concentration of approximately 46 000 mgCOD/l was added to the 20 l/d influent sewage feed of 660 mgCOD/l. This increased the influent COD and TKN by 147 mgCOD/l and 5.4 mgN/l respectively. The leachate dose did not increase the total P content significantly. The reason why the leachate dose increased the influent COD by 147 mgCOD/l and not $(0.042 \cdot 46000/20) = 97$ mgCOD/l cannot be explained and thus the measured value of 147 mgCOD/l was used in all calculations. The percentage COD and N removals in the EXP system were 95.0 % and 96.6 % respectively, and in the CTL system 94.1 % and 96.7 % respectively. The proportion of the leachate TKN that was ammoniacal was 82 %.

The overall average 0.45 μ m membrane filtered effluent COD concentrations from the EXP and CTL systems were 40.8 and 38.8 mgCOD/l respectively. The difference of 2.0 mgCOD/l represents the additional unbiodegradable soluble COD concentration from the leachate which as a fraction of the leachate COD is 1.3 %. The leachate unbiodegradable particulate COD fraction (f_{up}) was calculated using the Wentzel *et al.* (1990) model, and was zero. Hence 98.7 % of the leachate COD was biodegraded in the system. The unbiodegradable soluble COD fraction (f_{us}) and unbiodegradable particulate COD fraction (f_{up}) was calculated to be 0.052 and 0.045 respectively for the sewage/leachate mixture, and 0.056 and 0.062 respectively for the sewage only (see later for calculation procedure).

The overall average 0.45 μ m membrane filtered effluent TKN concentrations from the EXP and CTL systems were 2.45 and 2.21 mgN/l respectively. The difference of 0.24 mgN/l represents the additional unbiodegradable soluble TKN concentration from the leachate which as a fraction of the leachate TKN is 4.5 %. The leachate unbiodegradable particulate TKN fraction was

calculated using the Wentzel *et al.* (1990) model, and found to be zero. Hence 95.5 % of the leachate TKN was biodegraded in the system. The unbiodegradable soluble TKN fractions (f_{no}) were calculated to be 0.034 for the sewage/leachate mixture and 0.033 for the sewage only.

The TSS and VSS sludge production and TSS and VSS concentrations in the reactor were 25.1 % and 19.7 % higher in the EXP system than in the CTL system. The higher TSS and VSS in the EXP system is due to the leachate COD load and additional BEPR it stimulates. The oxygen utilization rate was found to be 21.3 % higher in the EXP system than in the CTL system. This was also due to the additional organic COD and N load from the leachate.

To calculate the unbiodegradable particulate COD fractions (f_{up}) stated earlier, an appropriate f_{up} value was selected so that the system VSS mass calculated with the BEPR model of Wentzel *et al.* (1990) using the measured readily biodegradable concentration and influent characteristics of the sewage (f_{us} , S_{ii}) and the systems parameters as input was equal to that measured. This procedure fractionates the VSS mass into its hypothetical constitutive components viz. active ordinary heterotrophic organisms (OHOs), polyphosphate accumulating organisms (PAOs), endogenous residue of OHOs and PAOs and unbiodegradable particulate COD (X_i). This fractionation also is required to determine the P removal and specific denitrification rates. After reconciling the calculated VSS mass in the CTL system with that measured, the calculated P removal for the standard PAO P content ($f_{x_{bg,p}}$) of 0.38 mgP/mgPAOAVSS was lower than that measured (14.52 versus 15.80 mgP/ℓ). One of two Wentzel *et al.* (1990) model parameters could be increased to increase the calculated P removal; either (1) the conversion rate (K) of RBCOD to VFA, which increases the proportion of the RBCOD obtained by the PAOs and hence increases their mass in the system, or (2) the P content of the PAOs $f_{x_{bg,p}}$. Approach 2 does not affect the calculated VSS mass and fractionation. Approach 1 increases the calculated VSS mass and results in a lower f_{up} and OHO concentration, which in turn affects the measured specific denitrification rates. Because the f_{up} value was already low compared to other NDBEPR systems treating the same wastewater, it was decided to accept approach 2. This approach was also the most appropriate for design because in design situations the active PAO mass will be calculated using the Wentzel *et al.* (1990) model from the influent RBCOD concentration with the “standard” conversion rate of $K=0.06$ ℓ/(mgOHOAVSS.d). An $f_{x_{bg,p}}$ value of 0.428 mgP/mgPAOAVSS set the calculated P removal equal to that measured in the CTL system (15.80 mgP/ℓ). This was then applied to the EXP system results and using the Wentzel *et al.*

(1990) model in reverse, the RBCOD taken up in the anaerobic reactor was selected so that the calculated P removal was equal to that measured (20.06 mgP/ℓ). From this, the fraction of leachate COD taken up in the anaerobic reactor was calculated. With the BEPR correctly calculated, the f_{up} value was found by adjusting the f_{up} value until the calculated VSS mass was equal to that measured in the EXP system. The f_{up} of the EXP system (sewage/leachate mixture) was 0.045. Because the f_{up} of the sewage/leachate mixture was lower ($0.045 \times 807 = 36.3$ mgCOD/ℓ) than the CTL system ($0.062 \times 660 = 40.9$ mgCOD/ℓ) it was concluded that the unbiodegradable particulate COD fraction of the leachate itself was zero.

The difference between the average P removals in the EXP and CTL systems was (20.00-15.80) 4.20 mgP/ℓ. The additional P removal to COD added ratio was therefore $(4.20/147) = 0.029$ mgP/mgCOD. Theoretically with the model of Wentzel *et al.* (1990), if all the influent is VFA type RBCOD, then the P removal/COD ratio expected is 0.19 mgP/mgCOD. Comparing this with the 0.029 value measured, gives a result of $(0.029/0.190) = 15.4\%$ of the leachate COD being taken up in the anaerobic reactor. Following the procedure described above, 18.4 % of the biodegradable COD of the sewage/leachate mixture was taken up in the anaerobic reactor. In the CTL system this was 18.8 % and hence the leachate COD taken up was $0.184 \times (1 - 0.045 - 0.052) \times 807 - 0.188 \times (1 - 0.062 - 0.056) \times 660 = 24.6$ mgCOD/ℓ i.e. $(24.6/147) = 16.8\%$ of the leachate COD. This compares well with the 15.4 % stated earlier.

To investigate further the proportion of leachate COD taken up for BEPR, anaerobic batch tests were carried out on the EXP system. Six batch tests were carried out, two using the standard leachate/sewage mixture, one using an acetate/sewage mixture, and three with leachate only. In all the anaerobic batch tests except the one on the sewage/acetate mixture, the COD taken up to P released ratio was around the expected Wentzel *et al.* (1985) value of 0.5 mgP/mgCOD; the sewage/acetate mixture yielded 0.89 mgP/mgCOD. All the batch tests showed a two phase P release behaviour, with a fast first phase and a slower second. The initial rate for the sewage/acetate mixture was 2.62 times faster than that for the sewage /leachate mixture and 1.87 times faster for the leachate only. This indicated that the soluble COD in the leachate did not stimulate an acetate type P release response. In the leachate only batch tests, an average of 32.4 % (47.6 out of 147 mgCOD/ℓ) was taken up. Why this was so much higher than the average 18.4 % determined for the EXP system, cannot be explained. The batch tests confirmed that the acid leachate appeared to contain an unexpectedly low concentration of organic compounds that

stimulate BEPR like acetate. Clearly, the high P removal expected from the acid leachate with an anticipated 30 % VFA content (from Novella *et al.*, 1995) was not realized.

The total and biodegradable soluble COD in the sewage only and sewage/leachate mixture was determined from the difference in the flocculation/filtration COD concentration of influent and effluent. The biodegradable soluble COD of the sewage only was used as the input RBCOD concentration for the CTL system BEPR calculations and the biodegradable soluble COD of the sewage/leachate mixture was determined to be 27.7 % (i.e. 72.3 % is colloidal and can be flocculated out). We also know that 18.4 % of the sewage/leachate mixture was taken up for BEPR. Hence $27.7 - 18.4 = 9.3$ % of the sewage/leachate mixture soluble biodegradable COD was not taken up in the anaerobic reactor for BEPR. A possible reason for this could be that the leachate contains slowly biodegradable soluble COD which is more easily degraded than the sewage particulate slowly biodegradable COD.

The average ratio of P removal to influent COD was 0.025 (20.06/807) and 0.024 (15.80/660) mgP/mgCOD for the EXP and CTL systems respectively. For the EXP system this was slightly higher than the usual 0.022 mgP/mgCOD expected for the sewage only because a part of the influent COD (leachate) is more amenable for BEPR than influent slowly biodegradable COD.

The average denitrification rate on slowly biodegradable COD (K'_2) in the EXP system was 0.0845 mgNO₃-N/(mgOHOAVSS.d); that in the CTL system was 0.0711 mgNO₃-N/(mgOHOAVSS.d) i.e. 19 % higher in the EXP system. No initial rapid rate of denitrification (K'_1) associated with utilization of RBCOD was observed which implies that no RBCOD “leaked” from the anaerobic reactor despite the low proportion of leachate COD taken up in the anaerobic reactor (18.4 %).

In the EXP and CTL systems, 31.3 and 29.7 mgN/ℓ nitrate were denitrified in the anoxic reactors respectively. The nitrate denitrified are similar because both systems were operated at the same a-recycle ratio (2:1) and in both systems the denitrification was recycle limited (zero nitrate in the anoxic reactor). Based on the batch test K'_2 denitrification rates, the denitrification potential for the EXP and CTL systems were 23.55 and 15.53 mgNO₃-N/ℓ respectively. These potentials are lower than the nitrate denitrified in the continuous systems. The batch test K'_2 denitrification rates therefore underestimate the nitrate denitrified. The leachate nitrate denitrified amounted

to 2.87 mgN/ℓ which left 0.23 mgN/ℓ not denitrified. In the EXP system, due to the low a-recycle ratio, the leachate COD did not contribute to the denitrification of the nitrate formed from the sewage TKN. Indeed, the nitrate formed from the leachate TKN was not all denitrified in the EXP system. However, if the *difference* in the EXP and CTL system denitrification potential calculated from the batch tests is accepted (viz 23.55-15.53= 8.02 mgN/ℓ), then the potential (i.e. when operated at the appropriate a-recycle ratios) effluent nitrate concentration due to leachate addition would be 4.92 mgN/ℓ less than with no leachate addition i.e. the leachate can remove an extra 4.92 mgN/ℓ from the sewage over and above that of its own nitrogen.

The average maximum specific growth rate of the nitrifiers at 20°C (μ_{nm20}) in the EXP system was 0.3005 /d and in the CTL systems was 0.3002 /d i.e. no difference between the two systems so that the leachate did not influence the μ_{nm20} rate. There was also no difference between the temperature sensitivity coefficient θ calculated from this investigation and that of Mellin *et al.* (1997), and that of Pilson *et al.* (1995) ($\theta=1.10$). However, there was a difference between the μ_{nm20} of this investigation (0.3002 /d) and that of Pilson *et al.* (1995) (0.67 /d). This difference can be ascribed either to changes in the sewage content that was collected for the investigations or to adaptation of nitrifiers to system conditions.

The NO_x concentrations leaving the anoxic reactor in the EXP and CTL systems in this investigation were 0.56 and 0.85 mg $\text{NO}_x\text{-N}/\ell$ respectively, which according to the hypothesis of Casey *et al.* (1994) means that a bulking sludge should not occur. The mean DSVI in the EXP and CTL systems were 140 and 153 ml/g respectively i.e. 10 % higher in the EXP system. Although these DSVIs are not ideal (not between 80 to 100 ml/g), they are however below (or near to) the upper limit for bulking (150 ml/g). This provides supporting evidence that the Casey *et al.* (1989) hypothesis does have merit.

The metals that were of interest to this study were those Potentially Toxic Metals or Elements (PTMEs) specified in the Sewage Sludge Utilization and Disposal Information Document (WISA, 1993). Due to the nature of the refuse contents of the lysimeters (filled with selected refuse, Chapman and Ekama, 1993), the only PTME to have any significant concentration was Zinc (Zn) which resulted from the corrosion of the galvanized lysimeters themselves. It is likely that other PTMEs that would be present in landfill leachate would follow a similar course through the activated sludge plant as Zn. The leachate in the influent of the EXP system

increased the mass of Zn added to the system per day from 3.18 mgZn/d (CTL system) to 10.91 mgZn/d. In both systems, the bulk of the Zn left the system via the waste sludge (85.2 % in the EXP system and 82.7 % in the CTL system) with only 4.9 % and 10.1 % leaving the systems via the effluent in the EXP and CTL systems respectively (9.9 % and 7.2 % was unaccounted for respectively). Due to the high Zn concentration in the waste sludge, care should be taken in disposing of waste activated sludges from plants to which leachate has been dosed as they will contain increased concentrations of PTMEs from the leachate. With most of the Zn leaving the system via the waste sludge, leachate dosing is unlikely to result in PTME contamination of the receiving water body.

From the results of this investigation it can be seen that it is feasible to adopt an integrated approach to municipal waste management by operating conventional sewage treatment plants in conjunction with sanitary landfill sites. The unstabilized leachate generated in the landfill site has a positive impact on phosphorus and nitrogen removal (as long as the a-recycle ratios are optimized) and little impact on effluent quality, sludge settleability and effluent metal concentrations. The only negative impacts are the increase in cost that would result from the increased oxygen demand and the potential toxicity of the waste sludge due to most of the metals being taken up into the sludge.

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LIST OF SYMBOLS

μ_{nm}	Maximum Specific growth rate of nitrifiers (/d) Additional subscripts 12, 20, 30 and T refer respectfully to the rate at 12°C, 20°C, 30°C and T°C.
AVSS	Active volatile suspended solids
BEPR	Biological excess phosphorus removal
b_{hT}	Specific Endogenous mass loss rate for heterotrophic organisms at T°C (/d)
b_{nT}	Specific Endogenous respiration rate for nitrifying bacteria at T°C (/d)
CH ₄	Methane gas
CMC	Cape Metropolitan Council
CO ₂	Carbon dioxide
COD	Chemical oxygen demand
CTL	Control system in this investigation
D_{pt}	Denitrification potential of the primary anoxic reactor
DSVI	Diluted sludge volume index
EXP	Experimental system in this investigation
$f_{av,OHO}$	Active fraction of the sludge mass with respect to the OHOs
f_{bs}	Fraction RBCOD of the influent with respect to the biodegradable COD concentration
f_{cv}	COD to VSS ratio of the volatile sludge mass
f_{up}	Unbiodegradable particulate COD fraction in the influent
f_{us}	Unbiodegradable soluble COD fraction in the influent
$f_{xbg,p}$	Fraction of PAO biological active mass that is phosphorus
JHB	Johannesburg
K	General parameter for denitrification rate (mgNO ₃ /mgAVSS/d). Subscripts 1 and 2 refer respectively to the 1st and 2nd rates in the anoxic reactor
MLE	Modified Ludzack Ettinger system configuration
MUCT	Modified UCT system configuration
N	Nitrogen
N ₂	Nitrogen gas
NaHCO ₃	Sodium hydrogen carbonate

NH_4^+	Saline ammonia
NH_4Cl	Ammonia chloride
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_x	Nitrite + Nitrate
OHO	Ordinary heterotrophic organism
OUR	Oxygen utilization rate (mgO/ℓ/h)
P	Phosphorus
PAO	Poly-phosphate accumulating organism
PTME	Potentially toxic metal or element
RBCOD	Readily biodegradable COD
R_s	Sludge age (days)
SBCOD	Slowly biodegradable COD
SCFA	Short chain fatty acids
SE	Standard Error of the mean
S_{ii}	Total COD concentration in the influent (mgCOD/ℓ)
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket reactor
UCT	University of Cape Town
VFA	Volatile fatty acids
VSS	Volatile suspended solids
Y_h	Heterotrophic organism yield coefficient = 0.45 mgVSS/mgCOD
Y_n	Nitrifier organism yield coefficient = 0.10 mgVSS/mgN
WRC	Water Research Commission

 CHAPTER 1

 INTRODUCTION

1.1 WASTE ACTIVATED SLUDGE AND LEACHATE CO-DISPOSAL

In the past, sanitary landfill sites are used primarily for disposing of solid refuse with little or no effort to promote stabilization of the solid wastes. However, management and operation of landfill sites has now become necessary due to (1) increased urban population resulting in a shortage of land for landfills and hence the need to maximise the life of a landfill, and (2) increased environmental awareness and the need to preserve the natural environment. The most serious environmental threat posed by a landfill site is the pollution of the groundwater caused by leachate. Leachate is generated as a result of the percolation of water or other liquid through any waste and by squeezing of the waste due to its weight (Bagchi, 1990). Leachate can thus be defined as the liquid that is formed when water or any other liquid comes into contact with solid waste. It is an aqueous solution which is highly contaminated and carries in it dissolved solids and the intermediate and final products of decomposition (Ball, 1984). To avoid groundwater pollution, leachate formed in the sanitary landfills needs to be collected for further treatment. In order to collect the leachate some sort of lining material (i.e. clay or geomembrane) is required at the base of the landfill to prevent it from seeping into the natural soil. The amount of leachate that is generated within a landfill site can be estimated using the Waste Site Water Balance (WSWB) method and is based on the following:

$$\text{Leachate generation} = \text{Water Input} - \text{Water Losses} \pm \text{Change in Storage}$$

This can then be expressed in equation form as the following (see also Figure 1.1):

$$L = (P + W_m + B) - (R + E_t + G) \pm \Delta S \quad (1.1)$$

where:	L	=	Leachate generation
	P	=	Precipitation
	W_m	=	Initial moisture content of the waste
	B	=	Chemical and biological water production
	R	=	Runoff
	E_t	=	Evapotranspiration
	G	=	Vapour loss in gas
	ΔS	=	Change in storage

Figure 1.1 illustrates a section through a sanitary landfill site with the flow of water and the prevention of leachate pollution to the natural groundwater and soil.

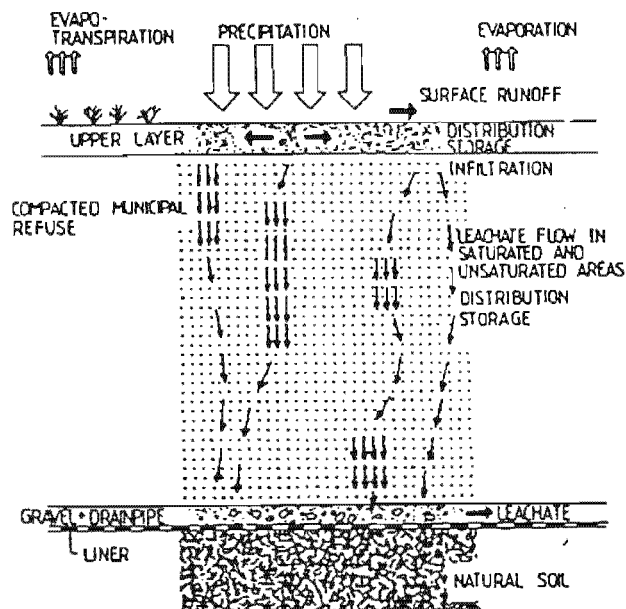


Figure 1.1: The water budget of a sanitary landfill.

Two types of leachates can be formed at a sanitary landfill, viz. acid leachate from a landfill in its acidogenic phase of decomposition and stabilized leachate from a landfill in its methanogenic phase of decomposition. Novella (1995) found that acid leachate can be treated at the landfill by discharging it onto methanogenic refuse to produce stabilized leachate via anaerobic digestion. Stabilized leachate contains only about 10 % of the organic content of unstabilized leachate i.e. 5000 - 6000 mgCOD/l versus 50 000 to 60 000 mgCOD/l, but the TKN and Total P contents remain high. Therefore stabilized leachate, although anaerobically treated, still contains high organic and nitrogen concentrations (COD \approx 5 300 mgCOD/l; TKN \approx 450 mgN/l; Hansford and Ekama, 1993) and requires further treatment.

Accordingly, a study was undertaken to provide additional information on the treatment of landfill leachates. In particular, the feasibility of adopting an integrated approach to municipal waste management by operating conventional sewage treatment plants (liquid waste treatment) and sanitary landfill sites (solid waste management) in conjunction with each other. In terms of this approach, the excess liquid leachate stream produced in the landfill is treated in the sewage treatment plant and the solids sludge stream generated in the sewage treatment plant is disposed to the landfill (see Figure 1.2). The siting of both the sewage treatment plant and the sanitary landfill are thus very important as they should be close to one another so that transporting

costs are kept to a minimum. Figure 1.2 includes an illustration of the organic loading on both a wastewater treatment works and a landfill site. Biogas, which is rich in methane (CH_4), is generated both in the anaerobic digestion process at the wastewater treatment works (at a rate of some 20 l biogas per capita per day) and in the refuse methanogenic stabilisation phase at the landfill (at a rate of some 400 l biogas per capita per day). Comparing the organic component of the wastewater sludge and municipal refuse for say a population of 3 million people, it is estimated that 54 tons of dry solids sludge (18 g per person) and 3 000 tons of refuse (1 kg per person) would be produced per day. The sludge would have a potential to produce some 60 Ml (equivalent to 15 MW power) and the refuse some 1 200 Ml (equivalent to 300 MW power) of biogas per day. Assuming that 3 million people would use 1 000 MW/d of electricity, at 50 % efficiency, the waste streams could produce about 15 % of the daily electricity requirement (Novella, 1995). It can thus be seen that the contribution from the sludge is small compared to that from the refuse, therefore landfilling of sludge would essentially be a disposal option and not as a means to boost biogas production.

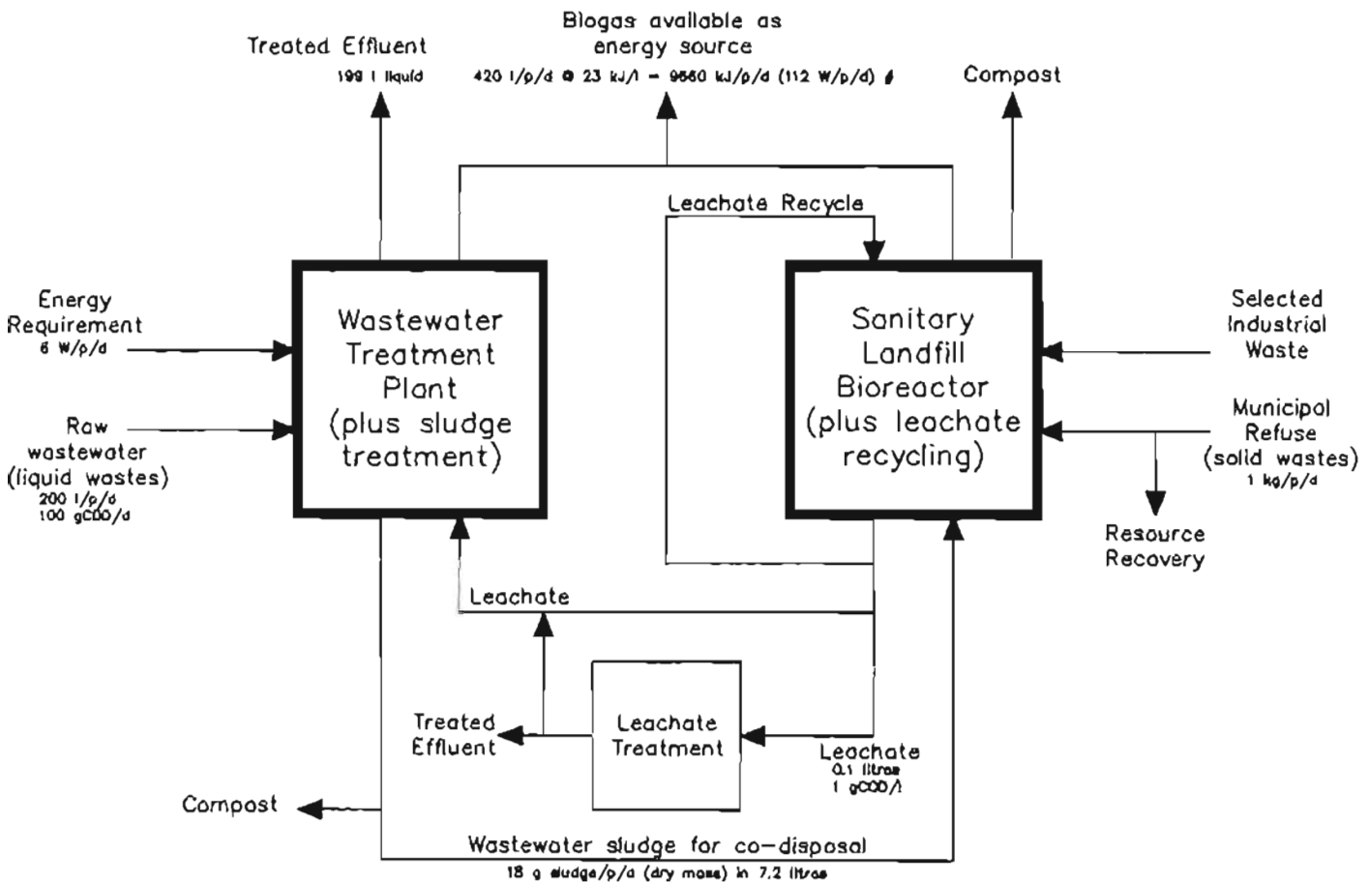


Figure 1.2: Diagram showing co-disposal of waste activated sludge and leachate with per capita loading and available energy in the biogas (at 50 % efficiency is equivalent to about 15 % of electricity consumption) (Novella, 1995).

1.2 CLAIMED ADVANTAGES AND DISADVANTAGES OF WASTEWATER SLUDGE CO-DISPOSAL WITH REFUSE IN SANITARY LANDFILLS

Novella (1995) stated a number of advantages and disadvantages for waste activated sludge and leachate co-disposal. They are summarized below.

1.2.1 Advantages

The operation of a landfill as a bioreactor can be enhanced by the co-disposal of wastewater sludge. There are various advantages in doing this including:

- The additional moisture acquired from the sludge can significantly improve the compaction and subsequent rate of settlement of the previously dry refuse. This can extend the life of the landfill by improving void reduction;
- The addition of anaerobically digested wastewater sludge can possibly encourage suitable conditions within the refuse to stimulate methanogenic bacteria and accelerate the onset of methane formation, thereby causing an earlier transfer in the carbon loss route via the leachate to the more environmentally acceptable carbon loss via the biogas;
- The co-disposal of wastewater sludge on a landfill provides a viable alternate sludge disposal option which can, perhaps, eliminate or reduce expensive sludge dewatering and disposal costs.

1.2.2 Disadvantages

The main problems claimed with wastewater sludge co-disposal practices in sanitary landfills are:

- Application - the sludge must be handled and applied in a safe and effective manner without disrupting the normal operation of the landfill
- Leachate quantity - the generation and release from the landfill of increased leachate volumes and the effects of this on the quality of ground and surface waters. It is generally accepted that the closer the operation of a landfill becomes to a bioreactor (focussing on refuse treatment as opposed to refuse storage) the more leachate will be generated, requiring leachate management and treatment to be included in the operation strategy of the landfill;
- Odours - the increased potential for generating odours, especially in the case of undigested primary sludge;
- Fly and mosquito breeding - the increased potential for fly and mosquito breeding and associated health risks of exposed wet sludge operations.

1.3 OBJECTIVES OF THIS INVESTIGATION

The principal aim of this study is to see the effect of leachate which is still in its unstabilized acidic phase of degradation (i.e. high COD with concentration of approximately 50 000 to 60 000 mgCOD/l), on a nutrient (N and P) removal activated sludge wastewater treatment plant. In particular, the study focuses on the effect of leachate addition on the biological excess phosphorus removal (BEPR) from domestic wastewater.

1.4 LAYOUT OF REPORT

In the past various biological methods have been used to treat landfill leachate and the literature review undertaken in this investigation, which can be found in Chapter 2, describes these processes with their advantages and disadvantages. The treatment processes are categorised into two groups according to the environment in which the treatment process takes place; viz, anaerobic and aerobic treatment. A more detailed review is given of the study of Hansford *et al.* (1993) in which stabilized leachate was treated in a conventional nitrogen removal activated sludge sewage system.

Chapter 3 begins with a description of the experimental setup and operation of the laboratory scale activated sludge systems used in this investigation. The study focuses on the BEPR performance of the Experimental (EXP) system (system with leachate dosing) compared to the Control (CTL) system (system without leachate dosing) and comparisons are made with P removals obtained in previous studies. The source and characteristics of the sewage and leachate are given as well as details on the running of the laboratory scale systems. The various laboratory tests that were carried out on the systems are described as well as the results achieved, with particular interest in the COD, N and P mass balances. These results show the reliability of the data collected during the investigation. To complement the day to day results of the two continuously operated systems, anaerobic, anoxic and aerobic batch tests were conducted on sludge harvested from the two systems. The results of these batch tests, from which the P release, denitrification and nitrification kinetics of the two systems were calculated, are shown in Chapter 3. Towards the end of Chapter 3, the results of the filament identifications and their effect on the settleability of the sludge are described as well as the fate of the metals present in the leachate. The report closes by drawing conclusions from the measured data and the results obtained from the experimental procedures; these are set out in Chapter 4.

CHAPTER 2

LITERATURE REVIEW

2.1 LEACHATE TREATMENT THROUGH BIOLOGICAL PROCESSES

Biological treatment of landfill leachate can be categorized into two groups according to the environment in which the treatment process takes place. Treatment can take place under anaerobic and aerobic (oxygen present) conditions.

The following treatment methods are described in more detail below:

- Anaerobic biological treatment
 - anaerobic lagoons
 - upflow anaerobic sludge blanket (UASB) reactor

- Aerobic biological treatment
 - aerated lagoons
 - rotating biological contactor (RBC)
 - trickling filter

2.1.1 Anaerobic Biological Treatment

The main advantage of the anaerobic biological treatment process is the low energy requirement since no oxygen needs to be supplied. It is generally found to be most effective when the leachate is still in its unstabilized acid form (i.e. very high COD) as it is capable of removing a high degree of the organic acids. A disadvantage of this kind of treatment is that the treatment process can only be operated for a relatively short time while the refuse is generating acid leachate (4-7 years) as this is when the organic degradable leachate concentrations are high. Usually acid refuse leachates can be effectively treated anaerobically on methanogenic refuse via recycling of leachate from acid refuse onto methanogenic refuse at the landfill site (Novella *et al.*, 1995). Indeed, Novella *et al.* (1995) also showed that recycling methanogenic refuse leachate (i.e. stabilized) onto acid refuse generating unstabilized (acid) leachate was advantageous because it stimulated the onset of methanogenesis in the acid refuse possibly due to addition of high

alkalinity with the stabilized leachate and perhaps due to seeding with methanogens. It is therefore likely in well managed landfills that only stabilized leachate is generated. In laboratory scale plants, Christensen *et al.* (1992) concluded that anaerobic treatment is an effective process, however the remaining COD effluent concentrations of approximately 1000-4000 mgCOD/l still need to be treated by means of aerobic processes to meet the standard effluent requirements.

2.1.1.1 Anaerobic Lagoons

Laboratory scale experiments carried out on simulated anaerobic lagoons have provided an encouraging insight into an alternative approach to landfill leachate management (Christensen *et al.*, 1992). This was particularly the case when an anaerobic lagoon was placed as a balancing tank prior to a secondary aerobic treatment process. The full scale application of the process may however be limited by the long retention times required to reach significant COD removals, particularly at lower temperatures. This in turn may cause problems with on-site odours from hydrogen sulphide production and it is therefore unlikely that these lagoons could be situated near housing developments. Christensen *et al.* (1992) stated that the potential advantages of such a system, when adopted alongside alternative leachate treatment processes, would include:

- i) Minimising the potential blockage/clogging of spray equipment with ferric hydroxide precipitate and/or bacteria growth during leachate recirculation. Odour problems associated with high volatile acid concentrations may also be reduced.
- ii) Reduction in heavy metals toxicity to vegetation where spray irrigation to land was adopted. Oxygen deficiency at root level caused by high organic load would be alleviated.
- iii) If the sewage works charged a rate for treating certain types of wastewater as is the case in some countries, the effluent from the lagoons would be subjected to lower disposal/treatment costs than that waste still in its primary form.
- iv) Where on-site aerobic treatment follows anaerobic lagooning, the lower organic and heavy metal content of the leachate would result in a lower sludge volume. Electricity costs in supplying air may consequently be reduced.

2.1.1.2 Upflow Anaerobic Sludge Blanket (UASB) Reactor

The UASB reactor has achieved widespread acceptance in Europe as a high-rate partial treatment process for high organic strength and low suspended solids content wastewaters. Leachate is thus one of those wastewaters as it has high organic strength and low suspended solids. In addition,

detention times are necessary so that even not-easily biodegradable organics can be degraded. The main advantages of an aerated lagoon treatment process is that the maintenance and operational costs are relatively low, and low effluent organic and ammonia concentrations are achieved. For low temperatures ($< 5^{\circ}\text{C}$) the effluent organic and ammonia concentrations tend to rise sharply, however such low water temperatures such as these are seldom found in South Africa. Aerated lagooning is performed using particular devices which enhance the aerobic processes of degradation of organic substances and which act over the entire depth of the tank. This is obtained by continuously agitating the leachate by means of an aeration system in such a way that anaerobic conditions are prevented from forming anywhere in the lagoon. This also facilitates the oxygen entering the lagoon from the atmosphere (Christensen *et al.*, 1992).

2.1.2.2 Rotating Biological Contactor (RBC)

In a Rotating Biological Contactor (RBC), the bacteria are attached to a rotating drum which is half in and half out of the liquid. The air supply takes place naturally in that the bacteria are exposed to air for a time period after which they are submerged in the liquid to take up organics. The relative cost of running such a system is very low as it consumes a low amount of energy with little man power needed. Christensen *et al.* (1992) concluded, from his experimental investigations on this type of treatment process, that the RBC system is best suited to treatment of stabilized leachate (from methanogenic refuse).

2.1.2.3 Trickling Filter

This treatment method also consumes a low amount of energy in that the air supply also takes place naturally. Air is funnelled through the base of the fixed media trickling filter upwards through the stone (or other fixed medium) bed. As for the RBC method of leachate treatment, trickling filters are also better suited to the treatment of stabilized leachate as it can be completely nitrified. The treatment of high strength leachates with trickling filters could lead to clogging or scaling due mainly to oxidation and precipitation of iron and manganese and precipitation of calcium carbonate. For this reason the process can be better employed as part of a combined plant or to treat stabilized leachates (Christensen *et al.*, 1992).

the UASB lends itself to design where liquid, gas and solid phases can be separated within a single reactor. In the past however, UASB reactors have had a negative stigma attached to them as it was thought that the process was too slow (long retention times), often unreliable and sensitive to loading shock and toxic constituents. These considerations have since proved unfounded and anaerobic reactors have performed with high efficiency. A pilot-scale UASB plant, operated by the Water Research Commission (Christensen *et al.*, 1992) using a medium to high strength (>10 000 mgCOD/l) leachate, found that hydrogen sulphide, formed by the reduction of the sulphate present in the leachate, provided an unusually efficient precipitant of most of the toxic metals. These accumulated as inert solids within the sludge blanket and were removed periodically from the reactor. Toxic metals were thus almost completely precipitated by the anaerobic process. Hydrogen sulphide gas was only rarely detected as a by-product of this treatment process and the average COD removals for this leachate only treatment process was 82 %.

2.1.2 Aerobic Biological Treatment

Biological aerobic treatment processes are very effective methods of reducing significantly biodegradable organics. For this reason they are often employed as a post-anaerobic treatment process where it is not always possible to reduce the COD to effluent standards. Aerobic treatment processes are also a lot faster in organic degradation than anaerobic processes as oxygen is present as the electron acceptor but sludge production is around an order of magnitude higher. Also the oxygen input requires energy so aerobic systems have a net energy demand while anaerobic systems are generally net energy producers. However, aerobic processes allow nitrogen (and possibly phosphorus) removal while anaerobic processes generally do not remove N and P. The organics are converted mainly to CO₂ and water and except for bacterial sludge produced, no other sludges or concentrates are produced. Heavy metal accumulation in the sludge has been observed quite often (Christensen *et al.*, 1992), which may cause problems in regard to the final disposal of the sludge.

2.1.2.1 Aerated Lagoons

Aerated lagoons are frequently used for leachate treatment due to the relatively low leachate production rates. An aerated lagoon works in such a way that the detention time of the leachate in the lagoon is long enough so that the bacterial mass leaving the lagoon with the effluent, is replaced by new bacterial mass for a specific time period (i.e. no sedimentation tank). Long

2.2 LEACHATE TREATMENT IN CONVENTIONAL ACTIVATED SLUDGE SEWAGE SYSTEMS

In a combined activated sludge sewage/leachate treatment system the sludge used for treating the sewage can also be used to treat leachates. In this regard, a fraction of the influent to a treatment plant can be leachate with the remainder being conventional sewage. A previous study involving the treatment of stabilized leachate in a laboratory N removal treatment plant has been undertaken by Hansford *et al.* (1993) and is discussed in detail below.

2.2.1 Leachate Addition to a Nitrogen Removal Activated Sludge System

In the study of Hansford *et al.* (1993), the treatment of stabilized landfill leachate in an N removal activated sludge system and its effect on the system performance were investigated. Two parallel identical N removal systems were operated, one experimental and one control. Both systems received the same municipal wastewater as influent at the same COD concentration and influent flow rate. Additionally, stabilized landfill leachate was dosed to the experimental system. By comparing the response of the control and experimental systems, the effect of the leachate could be determined.

2.2.1.1 Experimental Setup and Testing

To determine the effect of stabilized leachate on the nitrogen removal activated sludge system, two anoxic (4ℓ) - aerobic (8ℓ) reactor Modified Ludzack Ettinger (MLE) systems at 15 days sludge age were operated for 80 days at 20°C. Both, one experimental and control, received 15 ℓ/d real raw sewage diluted to a concentration of 600 mgCOD/ℓ, but the experimental system received additionally 300 ml/d stabilized leachate at 5 300 mgCOD/ℓ, representing 18 % of the sewage organic load. This is a leachate organic load about three times higher than would be expected on a *per capita* basis (i.e. stabilized leachate COD from three times more people than sewage COD).

For 47 days, daily testing of influent, reactor and effluent COD, TKN, NH_4^+ , NO_3^- , and NO_2^- concentrations were conducted on both the experimental and control systems. Also daily the VSS, TSS, sludge settleability in terms of DSVI and oxygen utilization rate were measured on the aerobic reactors of both systems.

2.2.1.2 Results

Analysis of the results indicated that:

- The N and COD balances were generally good (better than 90 %).
- 11.5 % of the leachate COD contributed to unbiodegradable soluble COD of the effluent, which increased the effluent COD concentration from the treatment system by 13 mgCOD/ℓ (25 %).
- 5.7 % of the leachate COD was unbiodegradable particulate, increasing the VSS concentration of the solids in the reactor by 75 mgVSS/ℓ (3 %).
- 83 % of the leachate COD was biodegradable and contributed to the biodegradable organics of the sewage.
- No noticeable difference between the effluent TKN concentration of the experimental and control systems could be detected, indicating that the leachate contains negligible soluble unbiodegradable organic N. Also nitrification was complete and all free and saline ammonia of the leachate was nitrified.
- The additional leachate biodegradable COD caused an increase in the reactor VSS concentration of about 400 mgVSS/ℓ i.e. 20 % more than in the control. The biodegradable COD and TKN caused the oxygen utilization rate to increase by 5 mgO/ℓ/h i.e. also about 20 % more than in the control system. These increases seem reasonable considering the leachate increased the organic and nitrogen load by 18 %.
- The effluent nitrate concentration from the experimental system was lower than that from the control system. This implied, and detailed comparison on the denitrification performance of the two systems confirmed this, that the leachate not only was capable of denitrifying all the nitrate that was generated from its own TKN content, but also contributed to denitrification of nitrate generated from the sewage's TKN content.
- Once the leachate/sewage mixture was characterized (viz. f_{us} , f_{up} , f_i , f_{nu} , f_{na} , f_{bs} all known) the WRC (1984) steady state activated sludge model could predict the performance of the experimental system.
- Sludge settleability in both systems improved from over 150 ml/g at the start of the investigation to below 60 ml/g at the end). The filaments in the sludge were the usual Anoxic-Aerobic (AA or low F/M) types (i.e. *M.parvicella*, type 0092, type 0041, and type 0675) but were only present at common level. This indicated that the leachate did not stimulate poor sludge settleability in N removal systems.

2.2.1.3 Conclusions

Addition of the stabilized leachate to an N removal activated sludge system indicates that (1) it is about 90 % biodegradable, and (2) due to its high short chain fatty acid (SCFA) concentration and readily biodegradable content it not only is able to denitrify all the nitrate that is generated from its own TKN, but also contributed significantly to the N removal of the TKN in the sewage. The high SCFA content of unstabilized leachate was thought to maybe also stimulate additional biological excess phosphorus removal (BEPR) if it were to be added to a nutrient (N & P) removal system. This therefore led to the current investigation being undertaken.

2.3 CLOSURE

The investigation of Novella *et al.* (1995) found that the unstabilized landfill leachate used in their study contained high concentrations of Volatile Fatty Acids (VFAs), the main cause for phosphorus removal (This is described in detail in Chapter 3). It is therefore assumed that since the source of the unstabilized leachate remains the same, unstabilized leachate dosed to a NDBEPR activated sludge system may promote a large increase in Biological Excess Phosphorus Removal (BEPR), and to a lesser extent, an increase in nitrogen removal. With regards to nitrogen removal, it is thought that leachate dosing may even cause more nitrogen to be removed from the domestic sewage than that which would be removed if no leachate dosing took place. With insufficient proof for these theories, it was decided that a comprehensive laboratory scale investigation, consisting of two laboratory NDBEPR activated sludge systems, should be carried out and a detailed report given.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

3.1 EXPERIMENTAL SET-UP AND OPERATION

To achieve the objectives of the investigation, two identical laboratory scale systems were set up in the UCT biological nutrient removal system configuration, one experimental (EXP) and one control (CTL). Both systems were fed the same mass and volume of raw sewage obtained from Mitchell's Plain Sewage Works throughout the investigation and were operated at a sludge age of 10 days and a constant temperature of 20°C. A schematic diagram of the two laboratory systems is given in Figure 3.1 and the design and operating parameters in Table 3.1.

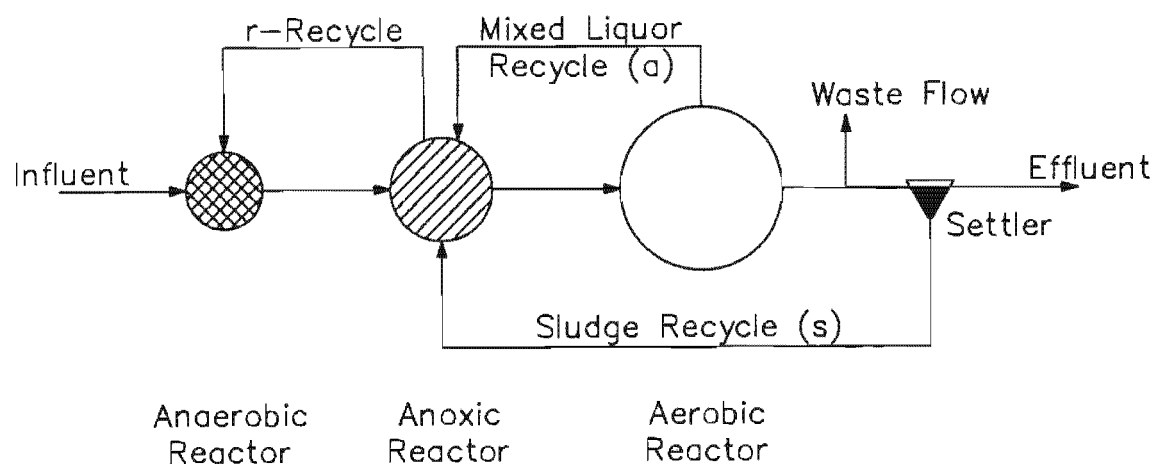


Figure 3.1: Schematic layout of the UCT system configuration.

During the investigation, which lasted 495 days, a number of changes were made to the influent sewage; these are given in Table 3.2. A graphical representation of these changes is given in Figure 3.2. Both systems received 20 l of sewage daily at an average concentration of 660 mgCOD/l. Apart from receiving the 20 l/d raw sewage influent, the EXP system started receiving 21 ml unstabilized leachate per day on day number 32. The unstabilized acid leachate had an approximate COD concentration of 46 000 mgCOD/l. The leachate dosing thus constituted 1/14th of the total influent COD mass. The leachate dose was doubled to 42 ml/d on day number 56, constituting 1/7th of the total influent COD mass; this was done to ensure that the effect of the leachate could be readily monitored.

Table 3.1: Design and operating parameters of the laboratory scale UCT systems.

Parameter	Value	Units
System:		
Sludge age	10	days
Temperature	20	°C
pH of anaerobic reactor	7.2 - 8.2	
pH of aerobic reactor	7.2 - 8.2	
DO in aerobic reactor	2.0 - 5.0	mg/ℓ
Influent:		
Flow	20	ℓ/d
COD concentration	660	mgCOD/ℓ
Additional leachate COD concentration	~147	mgCOD/ℓ
TKN/COD ratio	0.06 - 0.11	mgN/mgCOD/ℓ
Total P concentration	13.6 - 28.9	mgP/ℓ
Reactor Volumes (ℓ) and Mass Fractions:		
Anaerobic	3 [#]	15 %
Anoxic	7	35 %
Aerobic	10	50 %
Un-aerated mass fraction	10	50 %
Recycles:		
Anoxic to anaerobic (r-recycle)	1:1	
Aerobic to anoxic (a-recycle)	2:1	
Underflow (s-recycle)	1:1	

[#] actual volume is 6ℓ, but with r=1:1 the VSS concentration in the anaerobic reactor is half that in the remainder of the system; therefore equivalent volume at system VSS concentration is 3ℓ.

The raw sewage was collected in batches approximately every 14 days from the Mitchell's Plain Sewage Works and after maceration stored in stainless steel tanks at 4°C. This sewage served as feed for both systems for a period of about 2 weeks and constituted a steady state period. Days on which new sewage batches commenced are shown in Figure 3.2. To feed the laboratory systems, a sample of sewage was drawn from the storage tanks after thorough mixing and then diluted with tap water from its raw COD of approximately 1 100 mgCOD/ℓ to 660 mgCOD/ℓ. The diluted influent was buffered with the addition of sodium hydrogen carbonate (NaHCO₃) to prevent reduction in pH of the mixed liquor by nitrification. The 20 ℓ diluted influent was placed in the systems' gently stirred influent feed drums which were refrigerated at approximately 8°C and served as influent for a 24 hour period. This also provided a check that daily all the influent COD was discharged to the systems; any solids that accumulated in the bottom of the feed drums were collected and poured into the anaerobic reactor.

Table 3.2: Changes made to the EXP and CTL systems.

Item	From Day No.	To Day No.	Reason
Leachate dosing:	32	56	Dosed 21 ml leachate (966 mgCOD/d) for the first time to the EXP system (7 % of sewage COD load).
	57	495	Doubled leachate dose to 42 ml (1 932 mgCOD/d) so that effect of leachate on EXP system could be more easily observed.
Phosphorus dosing:	79	109	Phosphorus was dosed (100 mgP/d) to EXP and CTL systems so that maximum P removal could be readily measured.
	110	445	Increased P dose to 200 mgP/d as effluent Phosphorus concentrations were approaching zero.
	446	495	Increased P dose to 300 mgP/d as effluent Phosphorus concentrations were again approaching zero.
Fire:	178	226	Both systems destroyed by fire in laboratory on day 178 which resulted in a loss of 49 days.
	179		EXP system restarted; daily monitoring commenced again on day 227.
	183		CTL system restarted; daily monitoring commenced again on day 227.

Six refuse test lysimeters, 4.5 m high with a diameter of 0.6 m, are located on the University of Cape Town's campus. These were originally constructed in 1991 for previous studies (Chapman & Ekama, 1993; Novella *et al.*, 1995) and were still in relatively good condition to provide leachate for this study. At the start of this study, leachate samples were taken from each of the six lysimeters and their COD concentrations were measured (see Table 3.3). Of the six lysimeters, two were found to produce an acidic unstabilized leachate with an average COD concentration of 46 000 mgCOD/l (lysimeters 1 and 2). The other four lysimeters produced stabilized leachate with an approximate COD concentration of 3 500 mgCOD/l. The leachate from the two lysimeters with the acidic unstabilized leachate were used in this study.

Table 3.3: COD concentrations of leachate within lysimeters.

Lysimeter No.	1	2	3	4	5	6
COD conc. (mgCOD/l) [#]	36 557	41 453	1 726	2 774	3 966	5 581

[#] In later samples, the leachate COD concentration after blending leachate from (1) and (2) was \pm 46 000 mgCOD/l.

After blending the leachate taken from lysimeters 1 and 2, the characteristics of the blend is shown below in Table 3.4.

Table 3.4 Measured leachate characteristics.

Parameter	Value	Units	No. Of Tests
COD (unfiltered) [☆]	41 810 [#]	mgCOD/ℓ	23
COD (filtered) [†]	39 813 [#]	mgCOD/ℓ	24
fraction VFA [†]	0.30		
TKN (unfiltered)	1 411 [#]	mgN/ℓ	12
TKN (filtered) [†]	1 311 [#]	mgN/ℓ	13
FSA (unfiltered)	1 299 [#]	mgN/ℓ	9
FSA (filtered) [†]	1 096 [#]	mgN/ℓ	12
Total Phosphorous (unfiltered)	101 [#]	mgP/ℓ	10
Total Phosphorous (filtered) [†]	90 [#]	mgP/ℓ	10

[#] Results obtained by Kimaru *et al.* (1996)

[†] Filtered through Schleicher & Schüll 0.45 µm glass fibre membrane

[☆] Due to various samples of leachate being taken during the investigation the raw COD of the leachate varied. This however was taken into account by varying the dosage amount so that the same COD was added to the EXP system throughout the investigation.

In addition to operating and evaluating the performance of the two UCT systems by daily sampling, various batch tests were conducted on sludge drawn from the two systems. The days on which these were done, usually in pairs with one from each system, are shown in Figure 3.2. The two UCT systems had been operated for approximately one month (3 sludge ages) prior to the start of the investigation. This served as a period in which the systems had time to adjust and reach a steady state. Day 1 of the investigation was the day that testing of the EXP system began.

[†] Novella *et al.* (1995) measured the VFA concentration in the unstabilized leachate of lysimeters 1 and 2 and approximately 30 % of the leachate COD was VFA as COD. VFA's were not measured in the acid leachate from these two lysimeters during this investigation - Novella's earlier measurements were accepted. The VFA could not be measured because the Water Research Laboratory (UCT), Department of Chemistry (UCT), Scientific Services of CMC, SABS, Fishing Industries Research Institute, Stellenbosch Farmers Winery and A L Abbott Laboratories were not equipped or set up to measure VFA's in aqueous wastewater samples. This point is important to note because it will be shown later that apparently less COD was taken up in the anaerobic zone for BEPR than the estimated VFA content of the leachate. If VFA "leaked" out of the anaerobic reactor into the anoxic reactor then an initial rapid rate of denitrification should have been observed in the anoxic batch test. Such an initial rate was *not* observed. It is therefore likely that the VFA estimate based on Novella's measurements is too high for this investigation.

However, at this time no leachate was dosed to the influent of this system. Leachate was dosed for the first time on day 32 while testing of the CTL system commenced on day 46. All data obtained from the EXP system prior to day 39 were not included in the evaluation of the results from this investigation.

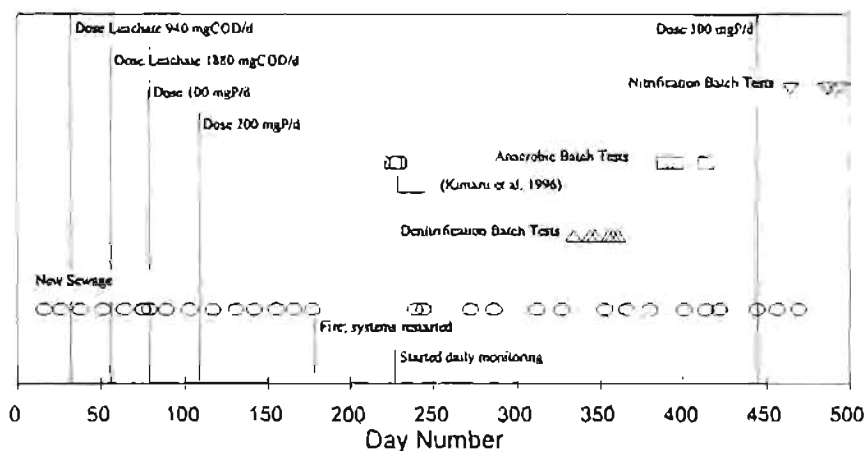


Figure 3.2: Graphical summary of changes made to both systems as well as the different steady state periods.

For the month preceding day 1 and up to day 32 of the investigation, both systems were operated identically (i.e. both at 20°C and 10 days sludge age) to ensure similarity of overall system response. Leachate was first dosed on day 32 and amounted to 966 mgCOD/d which constituted about 7 % of the sewage COD load on the system (Table 3.2). The leachate dose was doubled on day 57 (i.e. 1 932 mgCOD/d) constituting 14.6 % of the sewage COD load so that the effect of the leachate on the EXP system could be more readily monitored. Theoretically, dosing 42 ml of leachate with COD = 46 000 mgCOD/l should yield a COD increase in the EXP system of 96.4 mgCOD/l after dilution into the influent sewage, and the COD concentration of the influent to the EXP system should therefore have been 756.4 mgCOD/l. The leachate dose however increased the COD concentration of the EXP system's influent by 147 mgCOD/l on average to 810 mgCOD/l. The reason why an additional 51 mgCOD/l was measured in the influent is unknown. As the COD concentration of 147 mgCOD/l was measured, this value is used throughout the investigation. Due to the increase of COD by the leachate in the influent of the EXP system, the phosphorus (P) and nitrogen (N) removal in that system should be more than in the CTL system. To quantify this difference, it was therefore imperative that the amount of P and N removed by the systems did not become a system limiting factor. The nitrogen content of the sewage was sufficient, but if the volatile fatty acids (VFA) in the leachate were to stimulate biological excess phosphorus removal (BEPR) then the influent P content would be too low.

Therefore, when the effluent P concentrations in the EXP system were found to approach zero on day 78, P was dosed to the influent of both the systems. It was decided that 100 mgP/d (5 mgP/ℓ) be dosed to both the EXP and CTL systems as it was thought that this would be sufficient. On day 109 the effluent P concentrations again approached zero and the P dose was doubled to 200 mgP/d (10 mgP/ℓ). The dose was increased again on day 445 to 300 mgP/d (15 mgP/ℓ) at which it remained until the end of the investigation (day 495).

The refrigerator in which the raw sewage was kept in stainless steel tanks at 4°C was not operational from day 44 to day 166. This resulted in the raw sewage having to be refrigerated at about 8°C for six days until a backup refrigerator became operational. From day 50 to day 166 the raw sewage was kept in stainless steel tanks at 4°C in a backup refrigerator.

On day 178 of the investigation a fire broke out in one of the pumps of the systems which destroyed both systems (see Table 3.2). This required the reconstruction of one of the reactors in the CTL system and two new peristaltic pumps. Apart from this hardware needing replacement and repair, the sludge had to be re-grown within the systems themselves. Sludge was supplied by two other existing laboratory systems, one being a N and the other being a N & P removal system. The EXP system was operational within one day on day 179, however, the CTL system only became operational 5 days after the fire, on day 183. At this time there was still only one peristaltic pump available so both systems were run on this one pump which meant that the mixed liquor (a) recycle ratio could only be set at 1:1. From the time of restarting the systems, they received raw undiluted influent with a COD concentration of about 1 100 mgCOD/ℓ for four days to stimulate greater growth. Leachate dosing to the EXP system was commenced again on day 184, but additional P was only dosed again to both systems from day 188. During this time, no monitoring was carried out on the systems other than the TSS, VSS and the DSVI. The second pump was connected to the CTL system on day 198 and at this time both systems were set at the desired mixed liquor (a) recycle ratio of 2:1. Complete daily testing of both systems re-commenced on day 202; however, all data before day 227 was ignored as it could be seen that the systems had not reached steady state. The fire thus resulted in a loss of 49 days from day 178 to day 226 inclusive.

3.2 DATA ACQUISITION AND SYSTEM PERFORMANCE MONITORING

To monitor the effects of changes in both systems, samples were drawn virtually daily from each of the reactors of both systems for analysis, throughout the 495 day duration of the investigation. Table 3.5 illustrates the parameters measured on the samples collected from the two systems. These day to day results are listed in Appendix A. In the case of a poor quality sewage (unusually high TKN/COD ratio > 0.12 mgN/mgCOD) being fed to the systems and various other problems encountered with the operating of the systems, such as overnight pipe blockages, some sewage batches or daily data were rejected from the analysis. These rejected data are indicated by the shaded areas in the day to day record of the results of the systems (see Appendix A).

Table 3.5: Sampling position and parameter measurement.

Test	COD	TKN	FSA	NO ₃	NO ₂	Tot P	OUR	DSVI	V/TSS	pH
Influent	* †	*	*			*				
Anaerobic				†	†	†				✓
Anoxic				†	†	†				
Aerobic	*	*		†	†	†	✓	✓	✓	✓
Effluent	* †	* †		†	†	* †				

✓ Measurement taken (filtering not applicable).

* Unfiltered sample.

† Filtered through Schleicher & Schiill 0.45 µm glass fibre membrane

The day to day results of the measured parameters (excluding the rejected data) are shown in Figures A1 to A58 in Appendix A. A summary of these parameters with their corresponding Figure numbers is shown in Table 3.6.

Table 3.6: Summary of measured parameters with corresponding Figure numbers.

Test		Test	
COD	Figure A1 to Figure A8.	Nitrite	Figure A31 to Figure A38.
TKN	Figure A9 to Figure A16.	Total P	Figure A39 to Figure A50.
Ammonia	Figure A17 to Figure A18.	mgO/gVSS.d	Figure A51 to Figure A52
Solids	Figure A19 to Figure A22.	DSVI	Figure A53 to Figure A54.
Nitrate	Figure A23 to Figure A30.	pH	Figure A55 to Figure A58.

3.3 COD REMOVAL PERFORMANCE

3.3.1 COD Balance

To establish the accuracy of the experimental data, COD balances were performed on each system. In these balances, the COD mass entering the systems via the influent flow was reconciled with the COD mass leaving the systems via: (1) nitrate denitrified; (2) oxygen utilized; (3) sludge wasted and (4) the effluent flow. The reliability of the data is directly proportional to the mass balance deviation from the target value of 100 %. i.e. the closer the mass balances were to 100 % the more reliable the data. To achieve this, the 495 day investigation was divided into a number of steady state periods. The steady state periods were differentiated according to variation in influent TKN concentration, any changes in the system configurations and change in the leachate or P dosing amounts. The TKN varied quite considerably between the different sewage batches used as influent and thus nearly all steady state periods started and ended with a sewage batch. Overall there were 31 steady state periods during the 495 day investigation. The start and end day numbers of the steady state periods are shown later in Table 3.8.

The data over each steady state period were averaged. The averages of the daily measured parameters are given in Table 3.7 and Appendix C - the COD mass balance calculations were based on these averages. The method of evaluation of the COD mass balance is given by Musvoto *et al.* (1992) and can be found in Appendix B. However, as there was very little nitrite present in the systems, the concentrations of nitrate and nitrite were added together (NO_x) in calculating the mass balances. The main constituents of the COD mass balances are shown in Figures 3.3 and 3.4 for the EXP and CTL systems respectively and the totals are shown in Table 3.8.

The mean COD balances obtained in the EXP and CTL systems was 92 %. Although lower than 100 %, this is acceptable and similar to COD balances observed in other investigations e.g. 84 % - Pilson *et al.* (1995); 92 % - Clayton *et al.* (1989), 92 % - Mellin *et al.* (1997), 84 % - Kaschula *et al.* (1993). The only recent investigation in which a COD balance greater than 100 % was obtained was by Musvoto *et al.* (1992) - 106 %. Of the 100 % influent COD to the CTL system, on average 6.9 % passed out of the system via the effluent, 37.4 % via the waste sludge, 12.8 % via nitrate denitrified and 34.3 % via oxygen utilized with 8.6 % unaccounted for. Of the 100 % influent COD to the EXP system, on average 6.1 % passed out of the system via the effluent, 36.7 % via the waste sludge, 11.0 % via nitrate denitrified and 37.1 % via oxygen utilized with

Table 3.7: Steady state averages of the daily measured parameters.

EXPERIMENTAL SYSTEM

Steady State No.	Influent				Anaerobic Reactor				Anoxic Reactor				Aerobic Reactor						Filtered Effluent				Unfiltered Effluent						
	COD	TKN	FSA	TP	NO3	NO2	TP	pH	NO3	NO2	TP	COD	TKN	NO3	NO2	TP	DSVI	OUR	VSS	TSS	pH	COD	TKN	NO3	NO2	TP	COD	TKN	TP
1	732.71	57.31	38.09	21.31	0.00	0.07	24.87	7.52	0.03	0.08	14.38	3078.85	203.38	9.25	0.60	10.01	211.03	2000.31	2390.31	7.77	55.67	4.35	10.27	0.79	17.20	43.45	5.17	20.06	
2	697.51	64.08	65.18	14.85	0.06	0.04	20.67	7.56	0.31	0.06	10.26	3184.83	199.58	11.24	0.37	6.81	205.01	2033.11	2446.89	7.45	53.99	4.00	12.59	0.26	4.78	41.57	3.28	5.04	
3	702.36	71.77	54.18	14.32	0.09	0.03	19.36	7.53	0.14	0.05	8.66	3261.21	217.00	8.63	0.22	3.04	193.38	2137.33	2591.83	7.54	47.69	3.91	10.32	0.27	3.27	35.58	3.74	4.21	
4	798.54	62.50	42.78	15.45	0.07	0.05	23.38	7.48	0.20	0.08	10.33	3006.89	188.89	6.20	0.22	2.55	183.83	40.93	2163.06	2644.00	7.61	41.00	2.92	7.47	0.22	2.60	43.95	3.13	2.81
5	874.84	84.64	47.80	13.98	0.21	0.03	27.26	7.42	0.04	0.03	10.41	3470.91	217.00	6.87	0.16	1.30	182.34	39.38	2382.44	2917.78	7.64	37.21	2.92	7.71	0.15	1.26	40.60	3.29	1.63
6	901.06	84.64	57.43	15.80	0.16	0.04	27.12	7.49	0.08	0.13	9.45	3432.83	211.65	9.94	0.13	0.74	175.52	46.96	2453.80	3010.00	7.57	36.87	2.58	11.99	0.11	0.73	39.64	3.13	1.11
7	849.68	64.58	41.02	13.56	0.08	0.03	26.81	7.38	0.04	0.03	11.88	3703.74	235.20	6.27	0.08	0.63	190.07	38.64	2582.50	3148.00	7.50	35.16	2.66	8.16	0.05	0.76	35.67	3.17	1.27
8	842.25	63.03	40.72	19.56	0.19	0.03	32.99	7.46	0.03	0.03	14.36	3851.53	219.33	6.19	0.14	3.28	144.06	40.59	2539.11	3135.11	7.62	35.74	2.66	7.37	0.09	3.43	41.89	3.21	3.54
9	825.10	75.35	46.06	15.37	0.14	0.06	28.63	7.48	0.17	0.20	11.19	3696.45	227.64	7.66	0.20	1.90	137.49	40.54	2594.00	3222.43	7.74	29.83	3.14	9.64	0.17	2.20	33.00	3.58	2.37
10	812.56	73.70	53.22	24.36	0.23	0.04	37.85	7.67	0.05	0.13	18.07	3730.26	230.40	9.22	0.34	5.72	120.82	38.68	2653.14	3278.57	7.81	34.17	2.74	10.93	0.33	6.01	41.14	3.55	6.43
11	800.84	80.03	59.12	24.21	0.27	0.05	37.57	7.94	0.18	0.91	17.76	3606.22	206.09	12.25	0.24	7.42	122.12	39.11	2613.14	3229.00	7.81	34.83	2.10	15.00	0.21	7.80	48.84	3.96	8.44
12	735.93	75.64	55.59	22.29	0.48	0.06	34.50	7.79	0.67	0.97	18.96	3203.98	194.88	14.40	0.33	7.33	124.77	38.67	2425.40	3013.20	7.76	33.08	2.34	17.57	0.14	7.50	45.63	3.52	8.21
13	767.14	76.19	55.53	23.23	0.21	0.05	37.89	7.61	0.10	0.34	18.27	3215.12	189.64	10.83	0.36	7.27	119.99	38.29	2305.83	2931.00	7.76	39.96	2.56	13.30	0.25	6.52	44.98	3.16	6.87
14	821.93	89.61	62.78	25.17	0.39	0.05	38.79	7.60	0.78	1.34	19.29	3171.91	181.30	13.45	0.37	7.28	122.06	41.51	2313.09	2894.91	7.73	31.68	2.67	15.78	0.21	7.15	37.58	2.89	7.47
15	780.00	56.34	39.53	24.05	0.50	0.04	39.30	7.38	0.03	0.12	19.83	2991.66	174.84	6.09	0.28	5.30	133.81	33.55	2238.86	2827.78	7.76	33.07	2.01	7.42	0.18	5.57	38.96	3.08	5.97
16	778.25	64.01	47.36	24.98	0.09	0.06	45.98	7.38	0.07	0.04	24.78	2747.97	162.24	6.24	1.10	4.77	128.36	41.42	1978.92	2687.89	7.72	37.02	1.51	10.41	1.05	3.67	42.75	1.89	4.06
17	785.81	68.38	46.62	26.20	0.09	0.20	50.46	7.35	0.07	0.05	26.27	2501.06	153.48	9.38	0.41	5.96	130.52	39.41	1743.20	2404.80	7.73	38.70	1.54	11.49	0.34	4.85	52.58	2.24	5.27
18	789.29	60.96	43.10	24.48	0.18	0.09	49.60	7.35	0.23	0.06	25.40	2490.22	139.70	7.80	0.50	5.48	114.68	41.25	1679.71	2354.57	7.57	27.07	0.86	8.73	0.47	4.82	43.98	1.77	5.11
19	941.08	78.95	57.42	24.57	0.14	0.06	45.91	7.35	0.14	0.07	23.82	2447.26	148.40	8.94	1.01	6.40	139.14	48.17	1688.31	2325.38	7.58	45.80	2.49	9.80	1.13	5.47	71.30	3.60	5.71
20	819.42	77.95	59.59	23.63	0.16	0.09	45.64	7.35	0.34	0.19	22.48	2524.08	151.26	11.54	2.75	4.35	134.88	48.87	1663.98	2354.17	7.51	47.47	1.45	12.46	3.13	4.51	61.16	3.12	4.88
21	886.03	69.68	51.28	23.79	0.44	0.10	44.28	7.44	0.22	0.09	21.91	2640.70	151.34	11.50	0.61	3.78	170.28	47.42	1758.40	2406.60	7.60	40.33	1.57	13.10	0.51	3.40	56.49	2.99	3.85
22	868.67	77.46	52.92	23.99	0.43	0.07	55.19	7.67	0.30	0.04	25.66	3285.70	223.05	11.33	0.32	2.84	127.78	48.41	2335.09	3202.91	7.90	34.20	2.39	12.81	0.32	2.17	43.89	3.57	2.40
23	803.73	56.85	36.39	22.02	0.07	0.03	48.18	7.60	0.31	0.03	22.78	3061.89	212.80	7.74	0.21	3.82	186.15	43.25	2197.87	3002.83	7.85	40.07	2.88	8.48	0.16	3.20	65.81	3.90	3.78
24	817.62	65.47	45.84	21.16	0.49	0.06	52.11	7.50	0.18	0.08	24.20	2803.44	172.33	8.05	0.23	4.00	71.62	44.10	2048.55	2819.45	7.76	44.62	2.15	10.04	0.29	3.22	67.88	3.27	4.06
25	931.94	84.85	64.48	21.84	0.18	0.10	47.20	7.50	0.26	0.26	22.67	2908.28	148.24	11.68	1.14	3.34	185.98	43.55	1877.60	2430.00	7.56	35.17	2.84	8.18	0.11	5.05	39.75	3.50	5.56
26	813.10	58.36	38.47	19.55	0.11	0.04	23.72	7.46	0.05	0.05	14.21	2952.88	179.13	6.86	0.14	8.52	182.70	24.10	2008.20	2388.40	7.68	32.79	2.86	7.93	0.13	9.18	42.62	3.54	10.17
27	736.32	106.28	82.64	22.87	0.29	0.22	44.68	7.59	0.00	0.92	25.19	1940.56	118.90	17.09	8.40	9.58	175.63	44.93	1391.14	1842.57	7.43	51.02	3.72	18.38	8.83	9.18	67.32	4.74	9.44
28	815.37	70.49	49.52	24.67	0.36	0.08	48.05	7.56	0.28	0.12	24.90	2512.42	143.11	9.67	0.48	4.74	161.71	38.98	1818.22	2430.56	7.62	46.42	1.68	11.32	0.55	4.33	67.49	2.67	4.92
29	837.84	66.66	51.64	28.63	0.41	0.05	52.99	7.56	0.64	0.08	26.85	2700.76	155.23	10.38	1.07	7.47	99.82	41.75	2088.75	2768.50	7.59	45.18	2.49	11.64	1.23	7.71	53.21	2.86	8.07
30	851.72	72.76	53.67	27.08	0.16	0.03	54.09	7.56	0.26	0.16	29.33	2908.77	166.74	6.99	8.17	7.49	119.77	42.36	2060.18	2752.18	7.67	47.87	1.90	7.68	6.12	6.83	50.34	3.25	7.23
31	852.43	59.47	43.21	28.92	0.27	0.02	50.04	7.56	0.40	0.06	29.63	2433.13	135.55	10.14	0.54	11.58	122.89	35.06	1628.18	2171.09	7.68	46.60	1.61	10.57	0.38	10.62	54.71	2.56	11.06
Mean	811.40	72.05	51.35	21.93	0.23	0.08	39.95	7.51	0.21	0.35	19.61	2979.35	181.16	9.60	0.95	5.16	139.74	37.80	2098.14	2703.84	7.68	40.82	2.45	11.18	0.97	5.10	49.62	3.20	5.60
STD	60.78	11.12	9.56	4.33	0.14	0.04	10.46	0.14	0.19	0.89	6.23	463.59	33.20	2.53	1.78	2.63	34.87	12.96	340.52	364.98	0.13	7.15	0.78	2.86	1.84	3.23	11.08	0.71	3.55

CONTROL SYSTEM

Steady State No.	Influent				Anaerobic Reactor				Anoxic Reactor				Aerobic Reactor						Filtered Effluent				Unfiltered Effluent							
	COD	TKN	FSA	TP	NO3	NO2	TP	pH	NO3	NO2	TP	COD	TKN	NO3	NO2	TP	DSVI	OUR	VSS	TSS	pH	COD	TKN	NO3	NO2	TP	COD	TKN	TP	
1																														
2																														
3																														
4	625.23	56.80	42.28	15.18	0.17	0.07	18.51	7.45	0.13	0.09	9.04	2679.44	150.85	3.43	1.08	2.77	188.90	29.12	1											

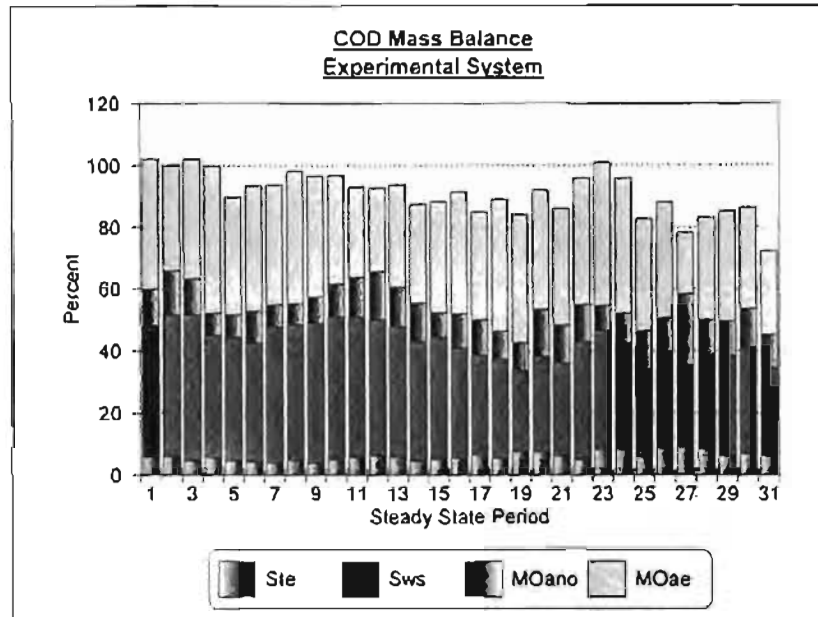


Figure 3.3: COD mass balances of EXP system for 31 steady state periods. Percentages are also shown for: Unfiltered effluent COD (Ste); COD of waste sludge (Sws); Oxygen demand for anoxic growth of heterotrophs (MOano); and Oxygen demand for aerobic growth of heterotrophs (MOae).

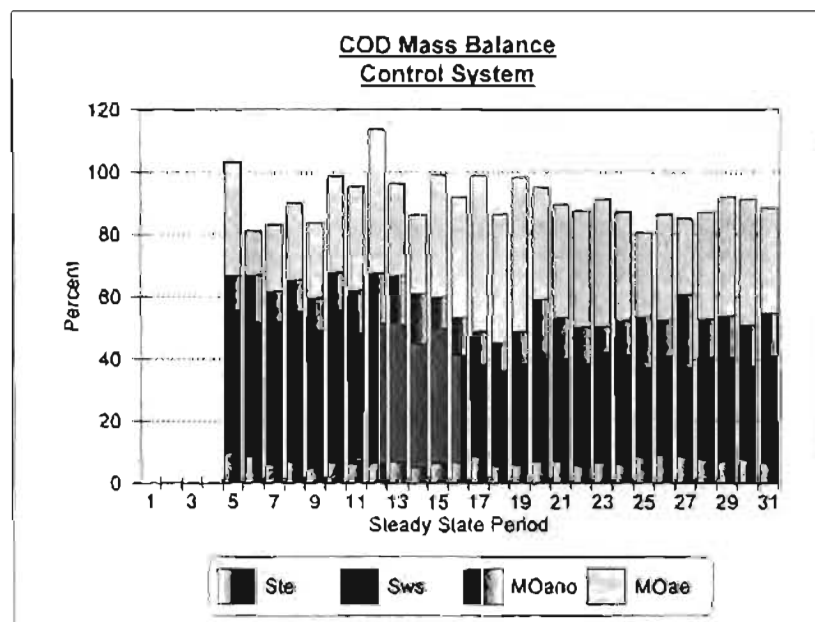


Figure 3.4: COD mass balances of CTL system for 31 steady state periods. Percentages are also shown for: Unfiltered effluent COD (Ste); COD of waste sludge (Sws); Oxygen demand for anoxic growth of heterotrophs (MOano); and Oxygen demand for aerobic growth of heterotrophs (MOae).

9.1 % unaccounted for.

3.3.2 Effect of Leachate on the COD Removal Performance

The average COD concentration of the diluted raw sewage used as influent to both the EXP and CTL systems was 660 mgCOD/ℓ. The leachate dose however, increased the COD concentration of the EXP systems' influent by about 147 mgCOD/ℓ on average, to 810 mgCOD/ℓ.

It was found that the leachate consisted mainly of biodegradable COD as the overall effluent COD concentrations of the two systems differed by only 2 mgCOD/ℓ. Assuming this to be unbiodegradable gives the leachate an unbiodegradable soluble COD fraction of about 0.013 (2/147). The unbiodegradable particulate COD of the leachate was found to be insignificant (see section 3.5.2.1) which resulted in 98.7 % of the leachate COD being degraded in the EXP system.

3.4 NITROGEN REMOVAL PERFORMANCE

3.4.1 Nitrogen Balance

Nitrogen balances were also performed on the EXP and CTL systems for the same steady state periods mentioned above. For these mass balances the total Nitrogen mass entering each system, measured by the influent TKN, was reconciled with that leaving each system via: (1) nitrogen for sludge production; (2) nitrate and nitrite (NO_x) denitrified; (3) TKN in the effluent; and (4) NO_x in the effluent. The data over each steady state period were averaged and the nitrogen mass balance calculations were based on these averages. The day to day data is shown in Appendix A, and the method of evaluation of the nitrogen mass balance can be found in Musvoto *et al.* (1992) (see Appendix B). Even though there was very little nitrite present in the systems, the concentrations of nitrate and nitrite were added together (NO_x) when calculating the mass balances. The nitrogen mass balance was calculated by separate determination of the net reduction of nitrate and nitrite in the anoxic and anaerobic (usually zero) reactors. This was done by subtracting the mass of nitrate and nitrite leaving the reactor from that entering the reactor. The results of the nitrogen mass balances for the EXP and CTL systems are also shown in Table 3.8. The main constituents of the nitrogen mass balances are shown in Figures 3.5 and 3.6 for the EXP and CTL systems respectively.

The mean nitrogen balances obtained in the EXP and CTL systems were 90 % and 88 %

Table 3.8: COD and Nitrogen mass balances for the 31 steady state periods.

Steady State Period	Start Day	End Day	Duration in Days	COD % EXP System	COD % CTL System	N % EXP System	N % CTL System
1	4	16	13	101	-	121	-
2	18	26	9	100	-	84	-
3	27	38	12	102	-	91	-
4	39	51	12	101	-	79	73
5	56	64	11	90	106	78	94
6	65	75	11	94	82	80	94
7	76	79	14	94	84	86	92
8	80	89	9	98	90	84	91
9	90	103	14	98	84	80	86
10	110	117	7	99	99	92	88
11	118	131	14	94	96	94	86
12	132	141	10	93	115	108	93
13	143	155	13	93	97	91	94
14	156	166	11	88	87	81	92
15	169	177	9	88	100	87	96
16	227	239	13	92	93	93	85
17	240	244	5	85	99	92	79
18	264	272	7	90	87	82	75
19	273	286	13	84	99	76	79
20	291	317	24	93	96	99	96
21	318	327	10	87	90	99	91
22	341	353	11	97	89	97	83
23	354	366	12	101	92	100	87
24	367	380	11	98	89	88	85
25	388	400	9	87	82	87	87
26	407	414	7	89	87	85	81
27	415	422	8	79	85	93	85
28	423	445	18	83	87	85	86
29	446	456	8	86	92	94	88
30	458	470	11	88	93	96	87
31	483	495	11	71	88	97	108
Average				91.75	92.14	90.36	87.99

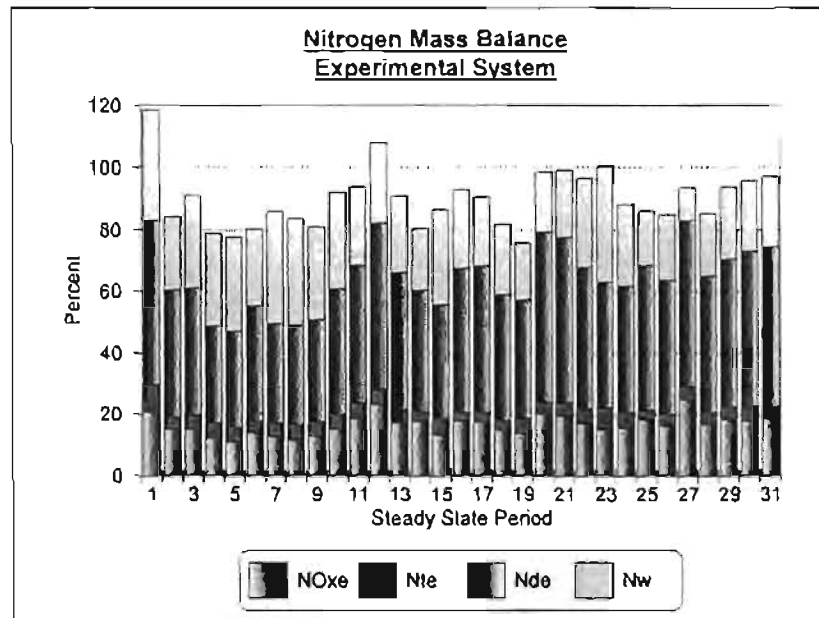


Figure 3.5: Nitrogen mass balances of EXP system for 31 steady state periods. Percentages are also shown for: Nitrate and Nitrite in the effluent (NOxe); TKN in the effluent (Nte); Nitrogen denitrified (Nde); and Nitrogen in the waste sludge (Nw).

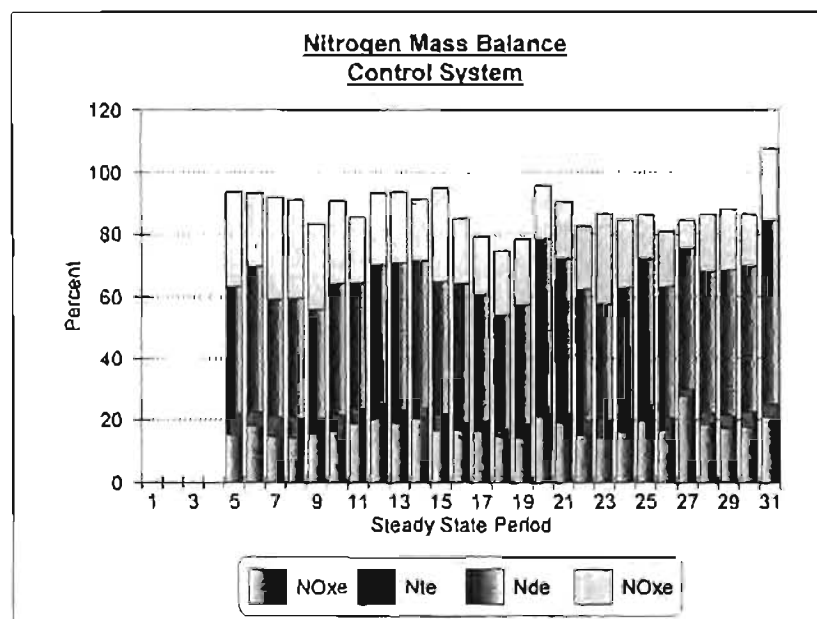


Figure 3.6: Nitrogen mass balances of EXP system for 31 steady state periods. Percentages are also shown for: Nitrate and Nitrite in the effluent (NOxe); TKN in the effluent (Nte); Nitrogen denitrified (Nde); and Nitrogen in the waste sludge (Nw).

respectively. Although lower than 100 %, this is acceptable and similar to nitrogen balances observed in other investigations e.g. 97 % - Pilson *et al.* (1995); 91 % - Clayton *et al.* (1989), 82 % - Mellin *et al.* (1997), 89 % - Kaschula *et al.* (1993). The only recent investigation in which a nitrogen balance greater than 100 % was obtained was by Musvoto *et al.* (1992) - 102 %. Of the 100 % influent TKN to the CTL system, on average 18.2 % and 4.2 % passed out of the system via the effluent as nitrate and TKN respectively, 21.7 % via the waste sludge and 44.6 % via denitrification with 11.3 % unaccounted for. Of the 100 % influent TKN to the EXP system, on average 16.9 % and 4.4 % passed out of the system via the effluent as nitrate and TKN respectively, 25.2 % via the waste sludge and 43.5 % via denitrification with 10.0 % unaccounted for. (see Figures 3.5 and 3.6).

3.4.2 Effect of Leachate on the Nitrogen Removal Performance

The TKN of the leachate was found to be soluble and amounted to 5.35 mgN/l of influent. The unbiodegradable TKN fraction of the leachate was found to be insignificant. All the TKN in the leachate was removed in the EXP system because the effluent concentrations in the EXP and CTL systems were found to be the same. The nitrogen removal in the EXP system amounted to 57.5 mgN/l and in the CTL system 52.6 mgN/l. It should be noted however, that there was no nitrate present in the anoxic reactors (of both systems) and therefore more nitrate could have been removed by increasing the mixed liquor recycles (see Table 3.7). The denitrification potential of the EXP system is calculated from the anoxic batch tests and compared with that of the CTL system in Section 3.6.4.

The additional COD added to the influent of the EXP system via the leachate amounted to 147 mgCOD/l. This led to an increase in nitrogen required for sludge production, the amount being given by the following equation (WRC 1984):

$$N_{sl} = f_n \left(\frac{(1-f_{us}-f_{up}) Y_h}{(1+b_h R_s)} (1+f.b_h.R_s) + \frac{f_{up}}{f_{cv}} \right) S_{ii} \quad (3.1)$$

where: N_{sl} = Nitrogen required for sludge production due to leachate COD addition
 f_n = Nitrogen content of the volatile solids
 f_{us} = Fraction unbiodegradable soluble COD of leachate = 0.013.²
 f_{up} = Fraction unbiodegradable particulate COD of leachate = 0.000.²

² See section 3.3.2 where characterization of leachate is discussed.

$$\begin{aligned}
 b_h &= 0.24 /d \\
 f &= 0.02 \\
 R_s &= 10 \text{ d} \\
 f_{cv} &= 1.48 \text{ mgCOD/mgVSS}
 \end{aligned}$$

The additional nitrogen required for sludge production due to the addition of the 147 mgCOD/ℓ of the leachate was calculated to be 2.01 mgN/ℓ. A comparison of the denitrification potential of both systems is made in Section 3.6.4.

3.5 BIOLOGICAL EXCESS PHOSPHORUS REMOVAL (BEPR) PERFORMANCE

3.5.1 Total P Reactor Concentrations

The most important objective of this investigation was to assess the impact of the leachate on the BEPR. This can be done by comparing the BEPR in the EXP system with that in the CTL system. The daily results of the influent and effluent total P (TP) concentrations, as well as those in the anaerobic, anoxic and aerobic reactors are given in Figures A39 - A50 in Appendix A for the EXP and CTL systems. Accepting the same 31 steady state periods as earlier for the COD and N removal performance evaluations, the average influent, reactor and effluent TP concentrations for both systems during these steady state periods are given in Table 3.9. The stages at which the P dosing was increased can clearly be seen in Table 3.9; viz, at the start of steady state periods 8, 10 and 29. At these times the effluent P concentrations in the EXP system were approaching zero (which was compensated for by adding additional P to the influent so that the effluent P concentration remained greater than 2 mgP/ℓ - see Table 3.9).

By conducting a TP balance over each reactor in the EXP and CTL systems, the net P uptake or release in each reactor was calculated (see Table 3.10; a positive value indicates P release and a negative value indicates P uptake). Adding these net uptake and releases for a steady state period gives the system P removal equal to influent - effluent P concentration. The last column in Table 3.10 shows the system P uptake i.e. the system BEPR for the EXP and CTL systems respectively. A graphical representation of the two systems' P uptake is shown in Figures 3.7 and 3.8. The average P removal in the EXP system (from steady state 1 to 15) was 13.65 mgP/ℓ influent and that in the CTL system was 9.92 mgP/ℓ influent. However, the average P removal for steady state periods 19 to 31 (excluding steady state periods 26 and 27 due to low RBCOD and nitrate recycling) in the EXP system was 20.00 mgP/ℓ influent and that in the CTL system

Table 3.9: Influent, reactor and effluent Total P concentrations for the 31 steady state periods in the EXP and CTL systems.

Steady State Period	Unfiltered Influent (mgP/ℓ inf)		Filtered Anaerobic (mgP/ℓ inf)		Filtered Anoxic (mgP/ℓ inf)		Filtered Aerobic (mgP/ℓ inf)		Filtered Effluent (mgP/ℓ inf)		
	Sys.	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL
1		21.31	-	24.87	-	14.38	-	10.01	-	17.20	-
2		14.85	-	20.67	-	10.26	-	6.81	-	4.78	-
3		14.32	-	19.36	-	8.68	-	3.04	-	3.27	-
4		15.45	15.16	23.38	16.51	10.33	9.04	2.55	2.77	2.60	2.09
5		13.96	13.44	27.26	19.93	10.41	10.00	1.30	3.48	1.26	3.48
6		15.80	15.68	27.12	20.80	9.45	11.29	0.74	6.17	0.73	6.07
7		13.56	13.90	28.81	18.69	11.88	10.36	0.93	5.14	0.76	5.05
8		19.56	19.55	32.99	23.72	14.36	14.21	3.26	8.52	3.43	9.18
9		15.37	15.32	28.63	18.88	11.19	11.44	1.90	6.90	2.20	7.93
10		24.36	24.25	37.85	27.81	18.07	17.55	5.72	12.13	6.01	13.04
11		24.21	23.73	37.57	25.26	17.76	17.24	7.42	13.76	7.80	15.14
12		22.29	22.02	34.50	23.28	16.96	16.04	7.33	12.76	7.50	14.20
13		23.23	22.80	37.89	25.17	18.27	17.30	7.27	12.92	6.52	13.71
14		25.17	24.88	38.70	25.68	19.29	17.60	7.28	13.51	7.15	14.71
15		24.05	23.94	39.30	25.31	19.83	17.75	5.30	12.39	5.57	13.46
16		24.99	24.51	45.96	35.65	24.79	20.03	4.77	9.00	3.67	8.58
17		26.20	28.75	50.46	38.05	26.27	21.62	5.96	10.06	4.85	10.35
18		24.46	23.68	49.60	40.80	25.40	22.58	5.46	9.91	4.82	9.55
19		24.57	24.01	45.91	33.68	23.82	20.77	6.40	10.96	5.47	10.78
20		23.63	23.40	45.64	40.64	22.46	20.08	4.35	7.34	4.51	7.52
21		23.79	23.24	44.28	37.45	21.91	20.41	3.78	7.16	3.40	7.57
22		23.99	23.94	55.19	43.00	25.66	20.68	2.84	5.90	2.17	5.71
23		22.02	22.58	49.18	39.25	22.76	20.99	3.82	7.68	3.20	7.12
24		21.16	21.38	52.11	37.59	24.20	20.86	4.00	7.78	3.22	8.11
25		21.84	22.11	47.20	35.43	22.67	19.54	3.37	8.84	3.40	8.13
26		23.51	23.65	44.08	36.55	20.96	19.57	3.51	7.89	3.88	8.03
27		22.87	22.31	44.68	32.61	25.19	21.51	9.58	14.11	9.18	14.24
28		24.67	24.13	48.05	35.42	24.90	20.35	4.74	9.66	4.33	9.12
29		28.63	28.55	52.99	44.56	26.85	24.62	7.47	11.40	7.71	10.42
30		27.08	27.37	54.09	43.49	29.33	24.27	7.49	10.20	6.83	9.18
31		28.92	28.60	50.04	38.26	29.63	27.50	11.58	16.28	10.62	16.35
Avg. ¹		19.17	19.56	30.59	22.59	14.07	14.15	4.72	9.20	5.12	9.84
Avg. ²		24.52	24.51	48.72	38.28	24.80	21.59	5.57	9.64	5.08	9.42
Avg. ³		24.57	24.48	49.52	38.98	24.93	21.82	5.44	9.38	4.99	9.09

¹ Average calculated for steady states 1 to 15.

² Average calculated for steady states 16 to 31.

³ Average calculated for steady states 19 to 31 excluding Steady State periods 26 and 27.

Table 3.10: P release or uptake for each reactor and net P removal for the 31 steady state periods in the EXP and CTL systems.

Steady State Period	Anaerobic (mgP/l inf)		Anoxic (mgP/l inf)		Aerobic (mgP/l inf)		Settler (mgP/l inf)		Removal (mgP/l inf)		
	Sys.	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL	EXP	CTL
1		14.00	-	-13.12	-	-17.46	-	13.57	-	4.15	-
2		16.22	-	-8.67	-	-13.78	-	-4.07	-	-10.30	-
3		15.84	-	-5.62	-	-22.56	-	0.47	-	-11.13	-
4		20.76	14.70	-3.05	2.65	-31.11	-23.68	0.10	-1.36	-12.99	-10.09
5		30.15	16.41	-6.70	-0.59	-36.44	-26.07	-0.07	0.00	-13.07	-10.17
6		29.00	14.63	-9.96	-4.27	-34.84	-20.49	-0.20	-0.19	-15.07	-10.31
7		32.18	13.13	-1.19	-1.43	-43.79	-20.88	-0.33	-0.17	-13.14	-9.36
8		32.00	13.67	-4.81	-3.62	-44.38	-22.73	0.33	1.32	-16.14	-11.36
9		31.14	10.99	-8.43	-2.73	-37.30	-17.37	0.61	1.74	-13.33	-8.02
10		33.27	13.82	-3.12	-5.88	-49.40	-21.68	0.57	1.82	-18.55	-11.58
11		33.17	9.54	-9.49	-7.52	-41.36	-13.92	0.75	2.76	-16.92	-9.13
12		29.75	8.50	-7.06	-6.55	-38.52	-13.12	0.34	2.87	-15.49	-8.29
13		33.94	10.24	-4.19	-3.73	-45.42	-17.53	-1.40	1.57	-17.06	-9.45
14		32.95	8.87	-2.99	-5.34	-48.05	-16.40	-0.25	2.42	-16.75	-10.45
15		34.71	8.92	3.98	-0.41	-58.11	-21.48	0.52	2.15	-18.90	-10.82
16		42.15	26.76	18.46	2.03	-80.07	-44.13	-2.20	-0.83	-21.65	-16.16
17		48.44	25.73	13.26	-0.01	-81.26	-46.24	-2.21	0.59	-21.77	-19.92
18		49.33	35.36	11.79	1.82	-79.78	-50.66	-1.29	-0.72	-19.95	-14.21
19		43.42	22.57	8.82	3.26	-69.69	-39.25	-1.86	-0.37	-19.31	-13.78
20		45.20	37.81	7.36	-3.31	-72.42	-50.97	0.31	0.35	-19.54	-16.11
21		42.85	31.24	9.60	4.94	-72.52	-53.00	-0.76	0.82	-20.83	-15.99
22		60.73	41.39	9.91	-0.48	-91.26	-59.10	-1.35	-0.39	-21.96	-18.58
23		53.59	34.92	4.17	3.76	-75.78	-53.25	-1.23	-1.13	-19.25	-15.69
24		58.87	32.93	4.70	4.84	-80.78	-52.30	-1.57	0.66	-18.79	-13.87
25		49.88	29.21	8.44	0.51	-77.21	-42.79	0.06	-1.42	-18.82	-14.49
26		43.69	29.87	5.28	0.63	-69.79	-46.72	0.74	0.28	-20.09	-15.93
27		41.29	21.40	7.87	-0.47	-62.46	-29.60	-0.80	0.26	-14.09	-8.42
28		46.53	26.35	14.07	2.02	-80.66	-42.77	-0.81	-1.07	-20.88	-15.47
29		50.49	35.96	5.34	0.31	-77.51	-52.87	0.48	-1.96	-21.19	-18.56
30		51.77	35.34	16.28	4.38	-87.37	-56.26	-1.33	-2.05	-20.65	-18.59
31		41.54	20.42	13.83	11.69	-72.18	-44.87	-1.92	0.14	-18.73	-12.62
Avg. ¹		27.94	11.95	-5.63	-3.29	-37.50	-19.61	0.73	1.24	-13.65	-9.92
Avg. ²		48.11	30.45	9.95	2.25	-76.92	-47.80	-0.98	-0.43	-19.84	-15.52
Avg. ³		49.53	31.65	9.32	2.90	-77.94	-49.77	-0.91	-0.58	-20.00	-15.80

¹ Average calculated for steady states 1 to 15.

² Average calculated for steady states 16 to 31.

³ Average calculated for steady states 19 to 31 excluding Steady State periods 26 and 27.

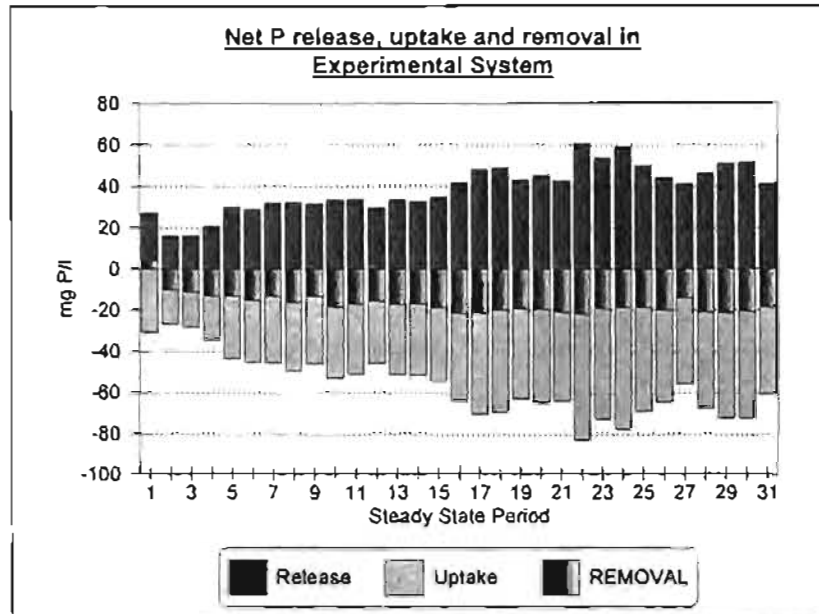


Figure 3.7: Net P release, uptake and removal over all reactors in the EXP system.

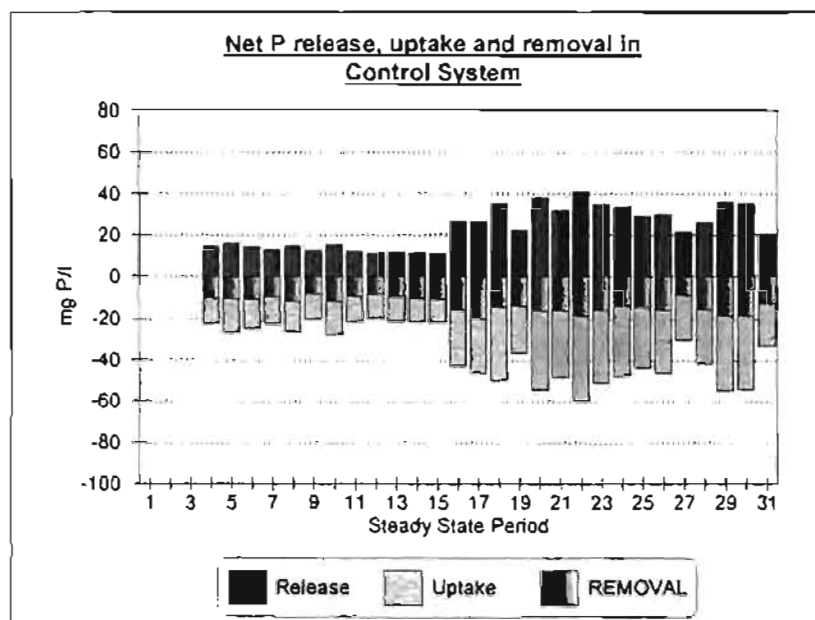


Figure 3.8: Net P release, uptake and removal over all reactors in the CTL system.

was 15.80 mgP/l influent. Also, during these steady state periods there was P release in the anoxic reactors of the two systems; 9.32 and 2.90 mgP/l influent in the EXP and CTL anoxic reactors respectively. This was a consequence of too little nitrate being recycled to the anoxic reactors and again indicates that the anoxic reactors of the two systems were under-loaded.

From the averages for steady state periods 19 to 31 (excluding periods 26 & 27), the P removal was thus 4.20 mgP/l higher in the EXP system than in the CTL system. The average BEPR performance over these periods will be evaluated in depth, in particular for the calculation of the fraction leachate utilized for BEPR, as the influent RBCOD fraction of the wastewater was measured daily only during these periods. As the influent to the EXP system had the same P concentration as the influent to the CTL system, it can be concluded that the leachate contained negligible P when diluted into the sewage (see Table 3.4 for leachate characteristics). The additional P removal was therefore P removed from the sewage by the leachate addition.

3.5.2 Comparison of Measured and Predicted P Removal

In order to calculate the predicted BEPR from the steady state BEPR model of Wentzel *et al.* (1990), the proportion of the biodegradable COD that the polyphosphate accumulating organisms (PAOs) obtain in the anaerobic reactor needs to be determined. To do this, the volatile fatty acids (VFA) concentration in the influent needs to be known and also the proportion of the influent RBCOD that is converted to VFA in the anaerobic reactor by the ordinary facultative heterotrophs (OHOs). The PAOs obtain that part of the influent COD which is VFA and the part of the RBCOD converted to VFA in the anaerobic reactor; the OHOs (facultative and aerobic) obtain the balance of the biodegradable COD i.e. that part of the RBCOD not converted to VFA in the anaerobic reactor and all of the slowly biodegradable COD (SBCOD) (The Wentzel *et al.*, 1990 BEPR model does not include SBCOD hydrolysis to RBCOD in the anaerobic reactor). Therefore, to calculate the BEPR requires the two active heterotrophic organism groups (i.e. the PAOs and the OHOs) to be determined.

The problem of determining the PAO and OHO active masses in the BEPR system is compounded by the fact that the unbiodegradable particulate COD fraction (f_{up}) also is unknown and determines the proportion of the total influent COD which is biodegradable. As a result the determination of f_{up} and the PAO and OHO active masses is done simultaneously using the measured BEPR and MLVSS concentrations as benchmarks.

3.5.2.1 Determination of f_{up}

The model that was used to calculate f_{up} was that of Wentzel *et al.* (1990) and uses the measured VSS concentration. The model is structured such that the heterotrophic organism mass is divided into two groups; the “ordinary” heterotrophs (OHOs) and the polyP heterotrophs (PAOs), the difference being their stoichiometric kinetic constants, the main one being their P content. The procedure for calculating the PAO active mass and unbiodegradable particulate COD fraction is shown diagrammatically in Figure 3.9. With the unbiodegradable soluble COD fraction f_{us} known from the filtered effluent COD concentration ($f_{us} = \text{filtered effluent COD} / \text{total influent COD}$), it involves an iterative process where an estimate of the unbiodegradable particulate fraction (f_{up}) is made from which the total biodegradable COD available is calculated by difference. The split of this biodegradable COD between the PAOs and the OHOs is calculated interactively from the measured influent RBCOD concentration and the known system design parameters that govern RBCOD conversion i.e. anaerobic mass fraction and sludge age as

Total COD - <i>known</i>				
Total biodegradable COD - <i>unknown?</i>			Total unbiodegradable COD - <i>unknown?</i>	
Measured from influent - <i>known</i>		<i>Unknown?</i>		Measured from effluent - <i>known</i>
RBCOD		SBCOD		USCOD
				f_{up}
<i>Unknown?</i>		<i>Unknown?</i>		f_{us}
COD obtained by PAOs		COD obtained by OHOs		
Active polyP VSS mass	Endogenous polyP VSS mass	Active ordinary heterotroph VSS mass	Endogenous ordinary heterotroph VSS mass	Inert VSS mass
1	2	3	4	5 (Components contributing to Total VSS mass)
Total VSS mass (must equal measured value)				
ΔP_G		ΔP_H		ΔP_I
Total P removal (must equal measured value)				

Figure 3.9: Diagrammatic representation of the utilisation of the Total influent COD in the model of Wentzel *et al.* (1990).

demonstrated by Wentzel *et al.* (1990). With the proportions of the biodegradable COD obtained by the PAOs and OHOs known, the mass of active and indigenous VSS generated by these two groups is calculated. Also from the initial estimate of f_{up} the inert VSS mass is calculated. Consequently by adding the 5 calculated constituent components of the VSS mass (shown in Figure 3.9), the total VSS mass of the system is known. The correct estimate of the f_{up} is that value which gives the calculated VSS equal to the measured VSS. Similarly, the fraction of P content of the PAO mass ($f_{xbg,p}$) is estimated so that the P content of the 5 constituent fractions of the VSS can be calculated. Knowing the P content of each of the 5 constituent fractions of the VSS, the total P removal is calculated. The correct value of $f_{xbg,p}$ is that value at which the calculated P removal is the same as the measured P removal. The results of the spreadsheet calculations for the steady state periods of the EXP and CTL systems is shown in Appendix C. Due to the nature of the P removal calculation and that the measurement of the soluble COD by flocculation/filtration was only started at steady state 19, the P removal calculations could only be carried out for steady state periods 19 to 31. The steady state periods 1 to 18 were therefore ignored in this calculation and are not included in the averages.

From the Table in Appendix C (on page C2), the average f_{up} value over Steady State periods 19 - 31 for the CTL system was 0.062 which is very much lower than the 0.15 value of Clayton *et al.* (1989) and the 0.153 and 0.111 of Pilson *et al.* (1995). Table 3.11 shows a comparison of

Table 3.11: Calculated mean, standard deviation, maximum and minimum f_{up} , $f_{av,OHO}$ and $f_{xbg,p}$ for the M/UCT systems of 5 investigations.

System	Unbio. Part COD frac (f_{up})				OHO active frac ($f_{av,OHO}$)				PAO P content ($f_{xbg,p}$)			
	Mean	S Dev	Max	Min	Mean	S Dev	Max	Min	Mean	S Dev	Max	Min
Clayton	0.150	-	-	-	0.210	-	-	-	0.388	-	-	-
Musvoto	0.287	0.056	0.371	0.163	0.133	0.023	0.192	0.101	0.144	0.067	0.291	0.084
Musvoto	0.317	0.074	0.456	0.230	0.122	0.024	0.154	0.079	0.113	0.021	0.143	0.087
Pilson	0.111	0.017	0.26	0.01	0.327	0.011	0.45	0.22	0.136	0.031	0.196	0.085
Pilson	0.153	0.014	0.26	0.02	0.302	0.008	0.38	0.26	0.098	0.031	0.166	0.041
Mellin I ¹	0.14	0.06	0.25	0.03	0.288	0.060	0.42	0.20	0.28	0.05	0.38	0.19
Mellin II	0.18	0.05	0.24	0.09	0.260	0.049	0.34	0.21	0.20	0.05	0.27	0.15
Mellin III	0.12	0.03	0.17	0.08	0.303	0.033	0.35	0.25	0.26	0.06	0.35	0.15
EXP	0.045	0.062	0.132	-0.042	0.477	0.103	0.678	0.340	0.428 ²	0.070	0.541	0.296
CTL	0.062	0.026	0.107	0.023	0.428	0.038	0.505	0.370	0.428	0.070	0.541	0.296

¹ The 582 days of Mellin was divided into 3 parts, i.e. I: day 1-237; II: 238-468; III: 469-582.

² The $f_{xbg,p}$ of CTL was applied to EXP to calculate the percent leachate taken up for BEPR.

the calculated mean, standard deviation, maximum and minimum f_{up} , $f_{av,OHO}$ and $f_{xbg,p}$ between the systems in this investigation and those used in previous investigations. The discussion in Section 3.5.5 below will return to assess possible reasons for the differences encountered.

3.5.3 Comparison of Measured P Removal to that of Wentzel *et al.* (1990) Model

Comparing the P removals measured in the CTL system of this study (excluding Steady State periods 26 and 27) with that predicted by the Wentzel *et al.* (1990) model ($f_{xbg,p} = 0.38$ mgP/mgPAOAVSS), it can be seen that the two values are very similar (see Figure 3.10; and 3.11 for interest only). The CTL systems measured P removal was in fact slightly higher than that predicted by the model. In terms of the Wentzel model, higher P removals can be predicted for a fixed (measured) influent RBCOD concentration if (1) the P content of the polyP organism mass ($f_{xbg,p}$) is greater than the model value of 0.38 mgP/mgPAOAVSS, or (2) if the conversion rate of RBCOD in the anaerobic reactor is increased i.e. the K rate is greater than the model value of 0.06 /d. In the first case the split of biodegradable COD between the PAOs and OHOs is the same and therefore results in the same constituent VSS fractions and f_{up} estimate; only the P content of the polyP organisms ($f_{xbg,p}$) is increased to account for the higher P removal. In the second case, the split of the biodegradable COD changes resulting in a reduced mass of OHOs and an increased mass of PAOs to account for the increased P removal. The P content of the P organisms ($f_{xbg,p}$) remains at 0.38 mgP/mgPAOAVSS but to achieve the same measured VSS mass, the f_{up} fraction decreases. Since only a very large increase in the conversion rate K (K=0.16) would give the observed P removal, and the fact that the f_{up} value obtained was already low in relation to other investigations which used the same sewage source (Table 3.11), it was decided that the P content of the polyP organisms $f_{xbg,p}$ in the model be increased from the model value of 0.38 mgP/mgPAOAVSS. The average $f_{xbg,p}$ value obtained for the CTL system in the study (Steady State periods 19 - 31, excl. SS periods 26 & 27) was 0.428 mgP/mgPAOAVSS which is 12 % greater than the model value.

The fraction of P content of the PAO mass ($f_{xbg,p}$) obtained for the CTL system was then substituted for the EXP system. This was done because the concentration of RBCOD/VFA obtained by the PAOs in the anaerobic reactor of the EXP system was not known because of the leachate addition. By accepting that the $f_{xbg,p}$ for the CTL and EXP systems were equal, this RBCOD/VFA concentration was calculated to find the proportion of the leachate COD that stimulated BEPR. Matching the measured VSS concentration and P removal in the EXP system

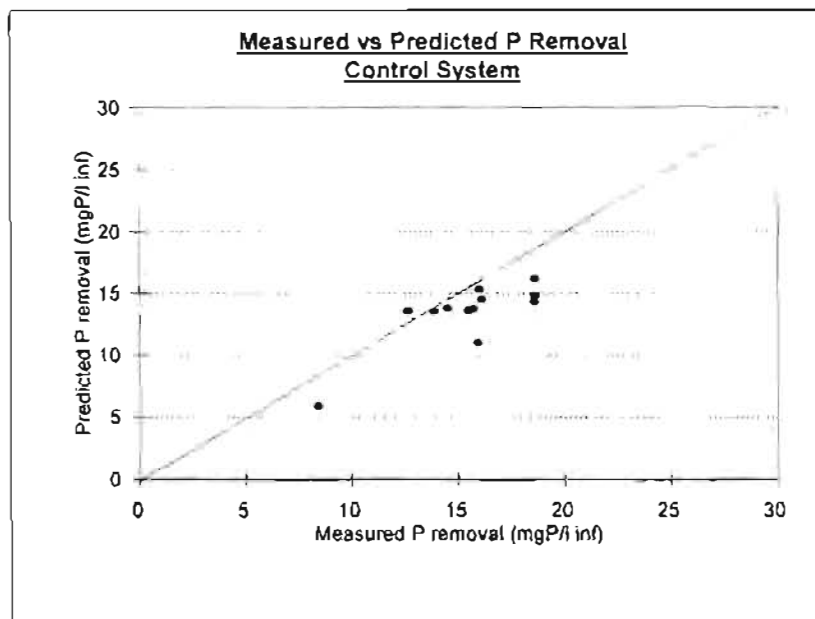


Figure 3.10: The measured P removal vs the predicted P removal calculated from the Wentzel et al. (1990) model ($K=0.06$ /d and $f_{x_{bg,p}}=0.38$ mgP/mgAPPHVSS) for the CTL system.

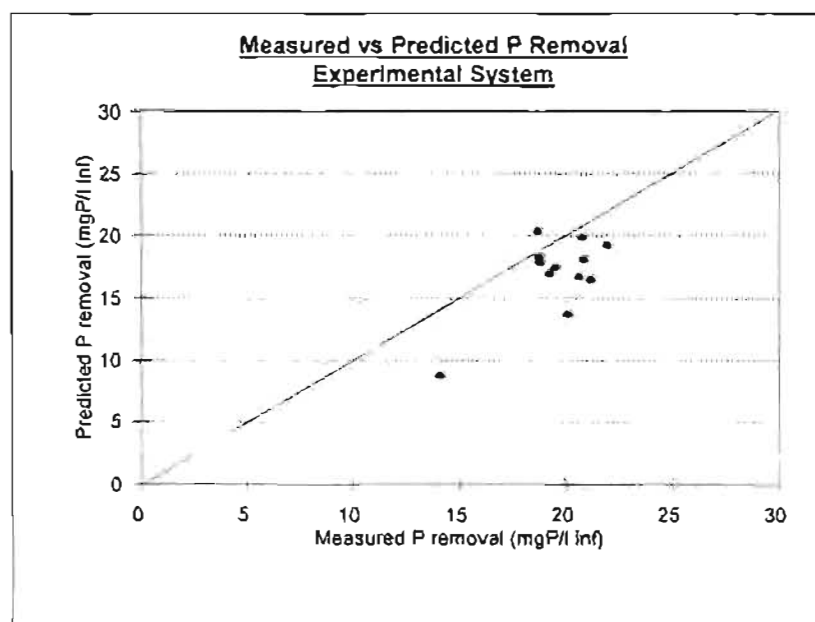


Figure 3.11: The measured P removal vs the predicted P removal calculated from the Wentzel et al. (1990) model ($K=0.06$ /d and $f_{x_{bg,p}}=0.38$ mgP/mgAPPHVSS) for the EXP system (For interest only).

by altering the f_{up} and f_{bs} using the CTL systems $f_{x_{bg,p}}$ values, allowed the RBCOD fraction of the sewage and leachate mixture that stimulated BEPR to be calculated. This RBCOD fraction of the sewage/leachate mixture was calculated to be 0.184. This means that 18.4 % of the biodegradable COD in the leachate/sewage mixture was taken up in the anaerobic reactor to stimulate BEPR (see the Table on page C2 in Appendix C).

The soluble COD of the sewage/leachate mixture (EXP system) was measured by the flocculation/filtration method which measures all of the soluble COD that was present in the influent. The same test was carried out on the effluent of the EXP system with the difference between the two concentrations (soluble COD in influent and effluent) being the biodegradable soluble COD. This value divided by the influent biodegradable COD yielded an influent biodegradable soluble COD to biodegradable COD fraction of 0.277 (i.e. 27.7 %). This value is greater than the 18.4 % calculated earlier which thus indicates that not all of the soluble COD in the leachate is RBCOD but some is SBCOD. This therefore indicates that the flocculation/filtration testing method for determining the RBCOD in the leachate/sewage mixture is inadequate and should not be used for leachate/sewage mixtures.

3.5.4 Calculation of RBCOD in Leachate

To calculate the percentage of the leachate that was taken up by PAOs in the anaerobic reactor, the following calculation was carried out using the calculated RBCOD fraction taken up by PAOs 0.184. This value was obtained above by setting the P content of the PAOs in the EXP system equal to that of the CTL and calculating the PAO AVSS (X_{AG}) concentration that would give the observed EXP system P removal; knowing X_{AG} , the concentration of RBCOD obtained by them also is known which was 18.4 % of the influent biodegradable COD to the EXP system; (For comparison, the flocculation/filtration methods yielded a biodegradable soluble COD to influent biodegradable COD fraction of 27.7 %). The calculation is as follows for the average of all the steady state periods taken together:

Fraction RBCOD to PAOs (EXP system)	=	0.184
Fraction RBCOD to PAOs (CTL system)	=	0.188
Influent COD concentration to CTL system	=	660 mgCOD/ℓ
COD added with leachate	=	147 mgCOD/ℓ
Therefore, influent COD concentration to EXP system	=	807 mgCOD/ℓ

Unbiodegradable soluble COD fraction of sewage/leachate	=	0.045
Unbiodegradable soluble COD fraction of sewage only	=	0.062
Unbiodegradable particulate COD fraction of sewage/leachate	=	0.052
Unbiodegradable particulate COD fraction of sewage only	=	0.056

Hence the leachate COD concentration taken up was:

$$\{0.184*(1-0.045-0.052)*807\} - \{0.188*(1-0.062-0.056)*660\} = 24.6 \text{ mgCOD/}\ell$$

which is (24.6/147) 16.8 % of the leachate COD.

The additional P removal to leachate COD added (147 mgCOD/ℓ influent) ratio was found to be 0.029 (4.3/147). Theoretically, with the model of Wentzel *et al.* (1990), if all the influent is VFA type RBCOD, then the P removal/COD ratio expected is 0.19 mgP/mgCOD. A leachate ratio of 0.029 therefore indicates that a proportion of $0.029/0.19 = 0.153 = 15.3\%$ of the leachate COD was taken up in the anaerobic zone. This compares very well to the 16.8 % calculated earlier in this section. From Table 3.4 it can be seen that about 30 % of the unstabilized leachate COD was measured previously (about two years earlier) to be in the VFA form. Therefore it would appear that 16.8 % of the leachate COD stimulates BEPR, which is 56 % of the expected VFA content in the leachate. The remaining 44 % of the expected leachate VFA COD did not seem to stimulate BEPR. The reason why less than half of the expected leachate VFA stimulated BEPR is not known. Although the literature states that acetate and propionic acids can be taken up by PAOs, it is possible that only the acetic acid part of the VFAs in the leachate was taken up by PAOs in the anaerobic reactor. The COD not taken up by PAOs in the anaerobic zone would “leak” through to the anoxic zone. Curiously, anoxic batch tests on anoxic reactor sludge did *not* indicate an initial fast rate of denitrification stimulated by the “leaked through” leachate COD (see Section 3.6 below).

Kimaru *et al.* (1996) carried out experiments on the leachate to determine the amount of the leachate COD that was soluble biodegradable. The leachate was diluted to the same concentration as that of the total COD that was being fed to the EXP system (1 part leachate : 80 parts water which made the concentration of the diluted leachate approximately 550 mgCOD/ℓ - see Table 3.12). The flocculent, aluminium sulphate, was then added to this diluted leachate (dilution ratio of 1 part aluminium sulphate : 100 parts diluted leachate) and mixed by hand at a very high rate. After this rapid mixing, the sample was allowed to stand for 30 minutes so that flocculation could take place. The supernatant was then passed through 0.45 μm filter paper so

that all particles were removed from the liquid. The results of the flocculation/filtration tests are shown in Table 3.12. It can be seen in Table 3.12 that approximately 84.3 percent of the leachate is soluble biodegradable. This is very different to the

Table 3.12: COD concentrations before and after flocculation and filtration through glass fibre or 0.45 μm filter paper with calculated biodegradable COD (as a % of diluted leachate COD, S_{ii}) for various acid leachate samples (Kimaru *et al.*, 1996)

Number	Diluted Leachate COD (S_{ii}) mgCOD/ ℓ	Flocculated/ Filtered COD mgCOD/ ℓ	Unbiodeg. Soluble COD ($S_{ii} * f_{us}$) [#] mgCOD/ ℓ	Biodegradable Soluble COD as % of S_{ii}
1	521	431	6.77	81
2	500	439	6.50	87
3	534	498	6.94	92
4	466	399	6.06	84
5	547	463	7.11	83
6	551	467	7.16	83
7	534	540	6.94	100
8	579	476	7.53	81
9	575	488	7.48	84
10	558	486	7.25	86
11	568	466	7.38	81
12	568	436	7.38	75
13	602	494	7.83	81
14	602	499	7.83	82
15*	521	469	6.77	89
16*	500	439	6.50	87
17*	534	423	6.94	78
18*	466	490	6.06	104
19*	547	469	7.11	84
20*	551	469	7.16	84
21*	568	456	7.38	79
22*	568	420	7.38	73
23*	602	494	7.83	81
24*	602	492	7.83	80
Avg.	548.5	466.8	7.13	84.1

[#] $f_{us} = 0.013$ (see section 3.3.2)

* Used Whattmans 0.45 μm filter paper instead of Schleicher & Schiill 0.45 μm glass fibre membrane

value calculated earlier which again indicates that not all the soluble biodegradable COD in the leachate is RBCOD.

3.5.5 Comparison of P Removals Obtained in this Study to Those Obtained in Other Studies

Comparing the P removals obtained in this investigation (influent COD concentration of 660 mgCOD/ℓ) to those obtained in previous work on wastewater from the same source (see Table 3.13), it is apparent that the P removal is higher in this investigation even though the influent COD was considerably lower than that in the previous work (influent COD concentration of 1 000 mgCOD/ℓ).

Prior to 1990, in studies in the UCT Water Treatment laboratory, the ratio of P removal to influent COD was found to be in excess of 0.02 (see Wentzel *et al.*, 1985; Lakay *et al.*, 1988 and

Table 3.13: Overall COD and N balance results and P removal performance of the M/UCT systems.

Parameter	Clayton	Musvoto		Pilson		Mellin	This Investigation	
	1989	1992		1995		1996	CTL	EXP
Temperature (°C)	20	20	20	12	20	30	20	20
N Balance (%)	91	105	98	94	99	82	88	93
COD Balance (%)	92	106	107	84	84	92	90	88
Total P removal (mgP/ℓ)	21.0	12.2	11.3	12.0	10.9	11.4	15.2	19.6
Total P release (mgP/ℓ)	63.0	32.0	32.1	15.0	14.6	19.9	33.2	57.8
% Release in anaerobic	95	64	64	47	15	98	93	85
% Release in 1st anoxic/anoxic	5	36	36	48	56	1	7	15
% Release in settling tank	0	0	0	5	29	1	0	0
Total P uptake (mgP/ℓ)	84.0	44.2	43.4	26.9	26.4	31.0	48.4	77.3
% Uptake in 2nd anoxic/anoxic	5	27	47	47	16	29	0	0
% Uptake in aerobic	95	73	53	53	84	68	99	99
P release/P removal ratio	3.3:1	2.44:1	2.70:1	1.34:1	1.24:1	1.75:1	2.18:1	2.95:1
P rem/infl RBCOD ratio	0.105	0.063	0.060	0.069	0.063	0.082	0.131	0.131 ²
P rem/Total infl COD ratio	0.0210	0.0123	0.0118	0.0121	0.0110	0.0156	0.022	0.024
Remarks ¹	(1)	(2)	(2)	(2)	(2)	(2)	(1)	(1)

¹ Total P removal *does* (1; $f_{x_{bg,p}}=0.38$) and *does not* (2; $f_{x_{bg,p}}\ll 0.38$) conform to Wentzel *et al.* (1990).

² Used same value as CTL system to calculate the VFA and RBCOD available for BEPR in leachate.

Clayton *et al.*, 1989), but since then it has decreased by up to 40 % for no apparent reason (see Table 3.13). In this investigation however, the ratio has risen again to the values obtained prior to 1990. There is no obvious explanation for the poor P removal during this period, however, it does appear to be linked to anoxic P release/uptake, which if significant, reduces the overall P removal. It seems that a different species of PAOs find a niche in the system which are able to accomplish anoxic P removal/uptake and denitrify thereby utilizing the internally stored PHAs less effectively than aerobic PAOs, and also containing a lower concentration of polyphosphates i.e. $f_{x_{bg,p}}$ is lower ~ 0.15-0.20 (Ekama and Wentzel, 1997). This explanation finds support from the anoxic batch tests done on the sludge from the EXP and CTL systems of this investigation and on that of Mellin *et al.* (1997): - No P uptake under anoxic conditions was observed in the EXP and CTL systems (like in Clayton *et al.*, 1991), whereas Mellin *et al.* (1997) observed significant P uptake during anoxic conditions.

3.5.6 Anaerobic Batch Tests

To investigate further the results obtained so far with regard to the proportion of leachate COD taken up for BEPR, anaerobic batch tests were carried out on the EXP system. Six batch tests were carried out, two using the standard leachate/sewage mixture, one using an acetate/sewage mixture with the acetate at the same concentration as the leachate, and three with leachate only diluted with tap water to the same concentration as in the leachate/sewage mixture; these last three being done by Kimaru *et al.* (1996) as part of this investigation. A sewage only batch test was not carried out in practise, but was simulated using the results calculated for the steady state.

The dates on which the anaerobic batch tests were carried out can be seen in Figure 3.2. The batch test method attempts to simulate the anaerobic reactor in the parent system by taking 1.5 litres of raw sewage/leachate mixture (or 1.5 l sewage/acetate mixture) and blending it with 1.5 litres taken from the anoxic reactor i.e. the r-recycle (The batch tests carried out by Kimaru *et al.*, 1996 are explained later in this section). During the test the mixture was continuously stirred and nitrogen bubbled through at a very low rate. The surface of the batch test was closed off to the air with polystyrene balls which kept the liquid anaerobic. The pH was kept constant at about 7.3 by adding very small amounts of hydrochloric acid or sodium hydroxide. Samples were drawn at various intervals during the test which were later tested for nitrate and nitrite, soluble Total Phosphorus (TP), and soluble COD. A typical TP verses time plot (from batch test 01) can be seen in Figure 3.12.

The P-time plot (see Figure 3.12) suggest that the phosphorus release is made up of two different rates; an initial fast rate (denoted rate A) and a second slower rate (denoted rate B). Both rates

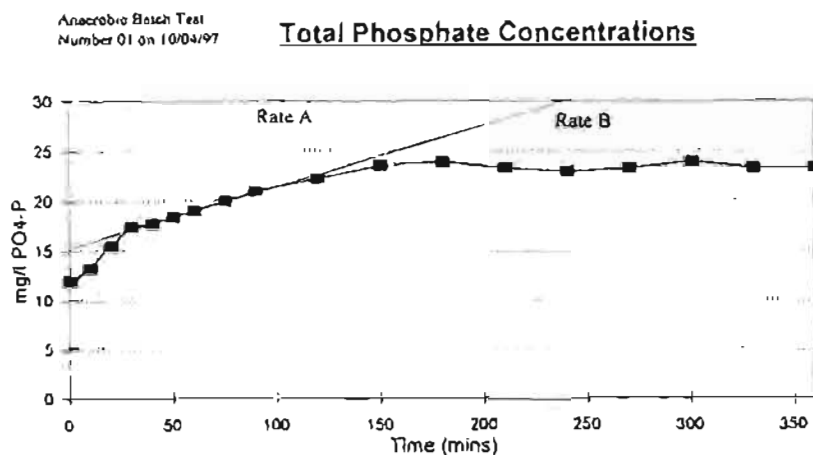


Figure 3.12: Typical P-time plot during an anaerobic batch test.

seem to be linear with the first rate lasting for approximately 30 minutes and the second rate lasting for about 120 minutes after the first rate ceases. The soluble COD was measured using the flocculation/filtration method which, as already stated, seems to be an unreliable test for the RBCOD concentration in the leachate/sewage mixture available to the PAOs. However, the *change* in the filtered COD does give a measure of the COD taken up during P release. Nitrate and nitrite concentrations were found to be negligible which is expected in the anaerobic environment of the batch test. The P release rates calculated in the anaerobic batch tests can be seen below in Table 3.14. A graphical representation of the P and COD concentrations during each of these batch tests is shown in Figures 3.13 to 3.15.

Table 3.14: P release rates in anaerobic batch tests for EXP system.

Batch Test No.	Day No.	EXP System (mgP/mgPAOVSS.d)		P Release mgP/l	COD Taken up mgCOD/l	$\Delta P / \Delta COD$
		Fast Initial Rate A	Secondary Rate B			
1	389	0.8522	0.2526	11.6	23.1	0.502
2	396	0.7567	0.2651	13.2	25.4	0.519
3*	414	2.1108	1.4507	23.8	26.9	0.886
Average #		0.8045	0.2589	12.4	24.3	0.510

* Batch test using acetate/sewage mixture and not leachate/sewage mixture.

Averages excluding batch test 3.

Comparing the results in Table 3.14 between batch tests 1 and 2 (sewage/leachate mixture) with

that of batch test 3 (sewage/acetate mixture), it can be seen that the initial rate A in batch test 3 is significantly faster than that in the other two batch tests (2.1108 versus 0.8522 and 0.7567 mgP/mgPAOAVSS.d). This confirms, qualitatively at least, the results observed in the EXP system, a low proportion (18.4 %) of the leachate COD was taken up for BEPR. This was surprising because it was expected that unstabilized leachate, with its expected high VFA content (30 % - see footnote on page 3.4), would stimulate a high P release and hence BEPR. This set of batch tests indicates that unstabilized leachate did not contain much VFA, in that the COD part taken up was not taken up as fast as acetate.

Kimaru *et al.* (1996) carried out 3 anaerobic batch tests (denoted as K1, K2 and K3) on the same leachate that was dosed to the EXP system. These batch tests comprised of 1,5 litres of activated sludge from the anoxic reactor of the EXP system, which was blended with 1,5 litres of leachate diluted with tap water to the same concentration that was being dosed to the influent of the EXP system i.e. 147 mgCOD/ℓ. During the batch tests, nitrogen gas was bubbled through the batch reactor to prevent any oxygen from entering the liquid. The pH in the batch reactor was kept at approximately 7.3 throughout the duration of the batch test. Samples were drawn at various intervals and immediately filtered, after which Mercuric Chloride (poison) was added to prevent any further biological action from taking place. The samples were then also tested for Total Phosphorus (TP), Soluble COD and Nitrate concentrations. The results of the leachate only anaerobic batch tests carried out by Kimaru *et al.* (1996) can be seen in Table 3.15. Graphical representations of the P and COD concentrations during these batch tests are shown in Figures 3.16 to 3.18.

Table 3.15: P release rates in leachate only anaerobic batch tests (Kimaru *et al.*, 1996).

Batch Test No.	Day No.	EXP System (mgP/mgPAOAVSS.d)		P Release mgP/ℓ	COD Taken up mgCOD/ℓ	ΔP / ΔCOD
		Fast Initial Rate A	Secondary Rate B			
K1	226	Batch test ignored due to irregular results				
K2	228	1.3360	0.2206	21.2	Not supplied	
K3	229	0.9260	0.2551	22.5	49.0	0.459
Average		1.1310	0.2375	21.9	47.6 [#]	0.459

[#] Average shown is not average of column but that recalculated using values in average row.

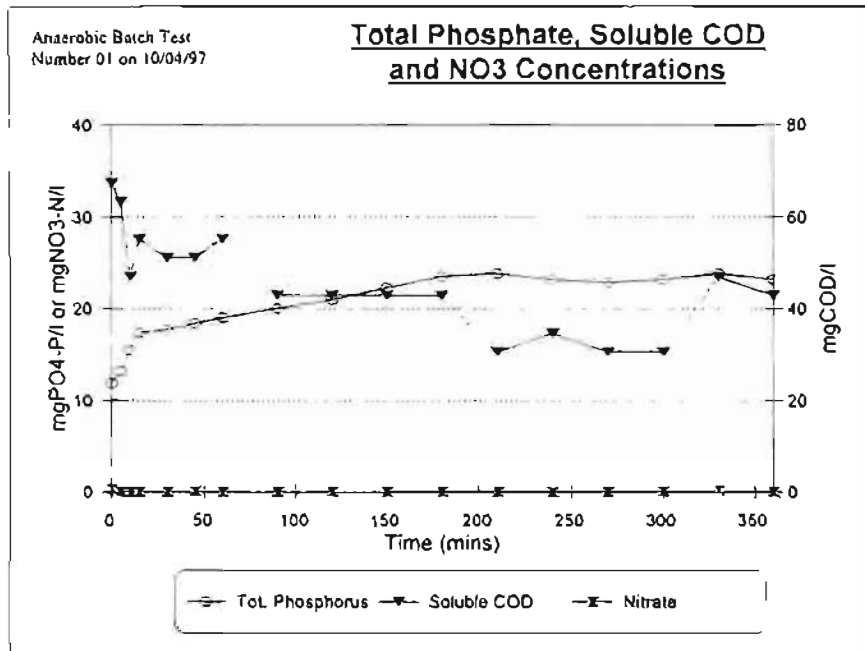


Figure 3.13: Total Phosphorus, Soluble COD and Nitrate concentrations for batch test 01.

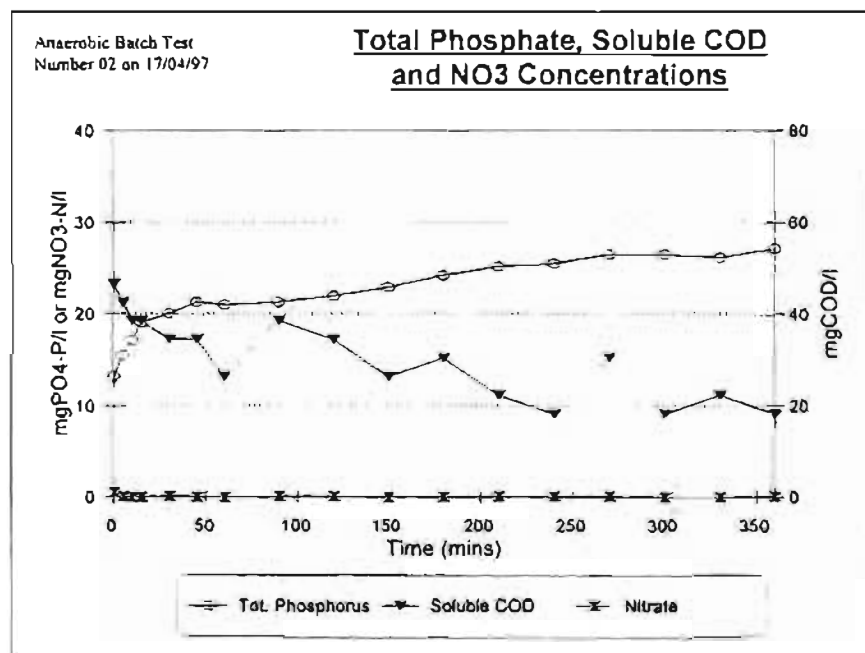


Figure 3.14: Total Phosphorus, Soluble COD and Nitrate concentrations for batch test 02.

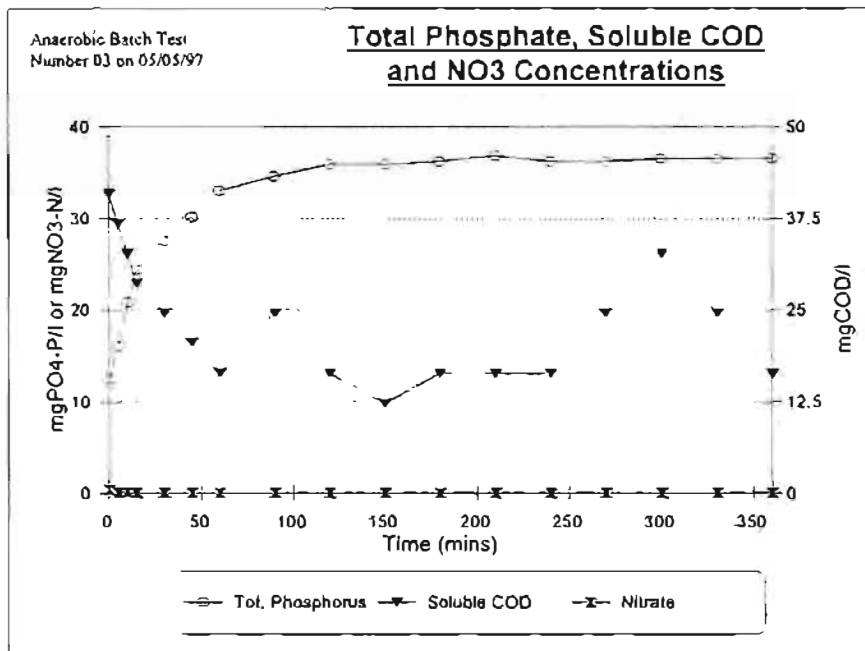


Figure 3.15: Total Phosphorus, Soluble COD and Nitrate concentrations for batch test 03.

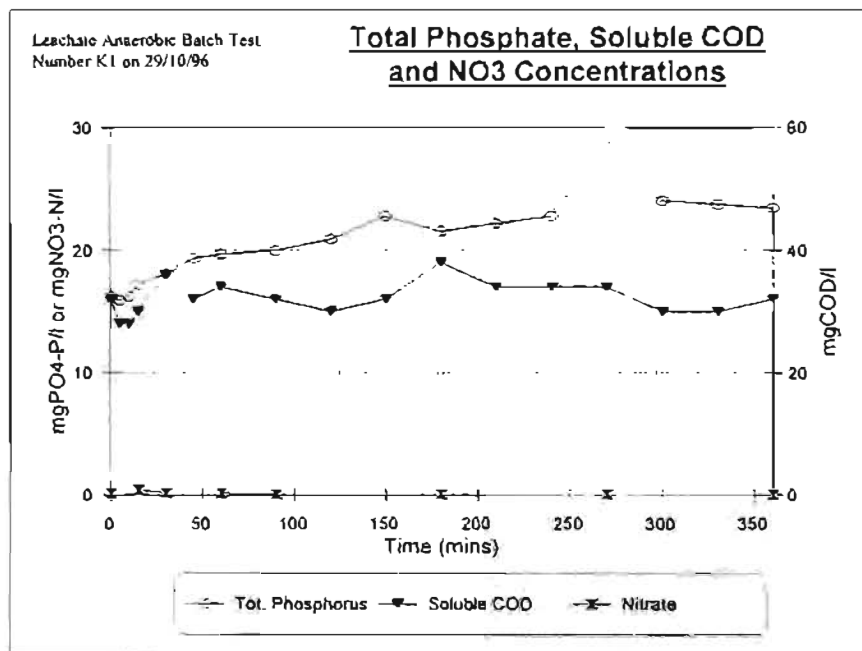


Figure 3.16: Leachate Total Phosphorus, Soluble COD and Nitrate concentrations for batch test K1. (Kimaru et al. 1996)

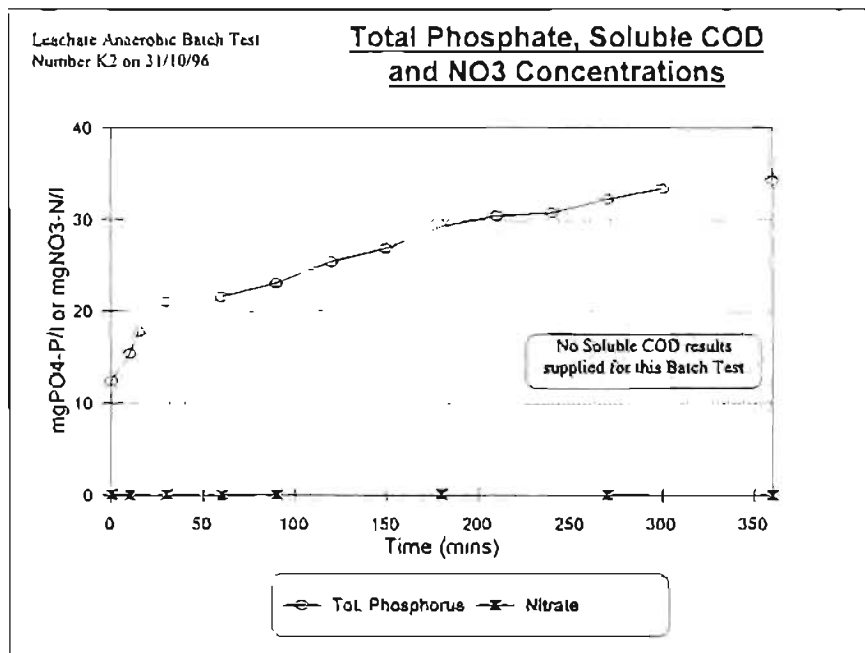


Figure 3.17: Leachate Total Phosphorus, Soluble COD and Nitrate concentrations for batch test K2. (Kimaru et al. 1996)

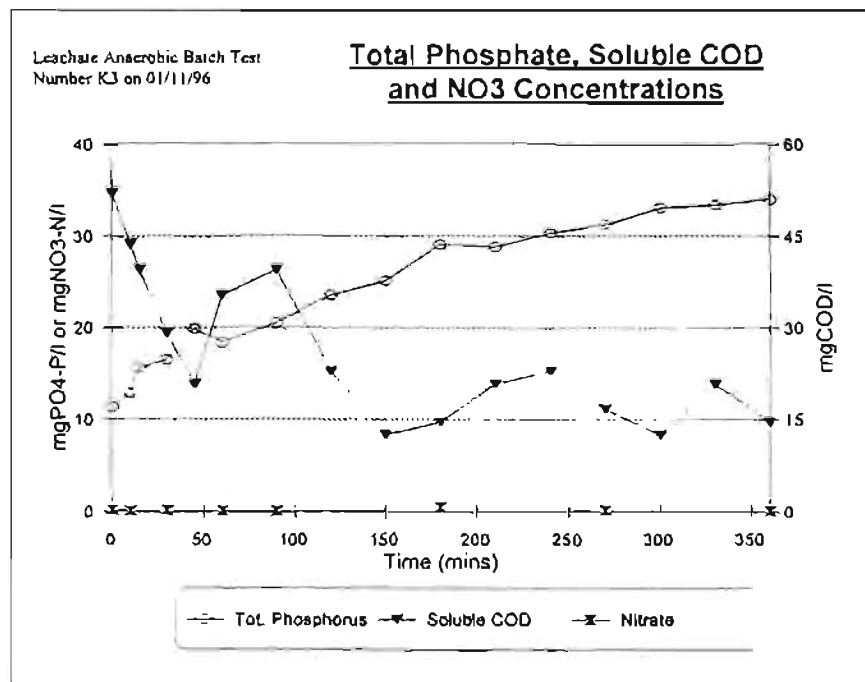


Figure 3.18: Leachate Total Phosphorus, Soluble COD and Nitrate concentrations for batch test K3. (Kimaru et al. 1996)

From the results shown in Table 3.15 it is possible to calculate the amount of leachate COD taken up for P removal by dividing the observed COD removal (47.6 mgCOD/ℓ) by the leachate COD added to the batch test (147 mgCOD/ℓ). The leachate COD taken up for P removal is thus 32.4 % which does however differ from the 16.8 % calculated above in Section 3.5.4. The value of 32.4 % however cannot be relied upon too greatly as it is the result of only one batch test (K3) and therefore more confidence is attached to the value of 16.8 % obtained from the continuous EXP system. In order to determine the proportion of the leachate taken up in the sewage/leachate mixture batch tests it is necessary to estimate the proportion of the sewage COD taken up. As no anaerobic batch test on sewage only was undertaken, this was calculated theoretically from the model of Wentzel *et al.* (1985, 1990).

The result of the simulated sewage only batch test, denoted as batch test S1, can be seen in Figure 3.19 and was calculated using the following assumptions:

- i) The batch test took place during the same steady state period as the other batch tests (i.e. during steady state 25).
- ii) The batch test had a duration of 5½ hours.
- iii) The batch test was diluted in the same proportion as the other batch tests (i.e. 1½ litres anoxic sludge mixed with 1½ litres tap water)
- iv) The calculation was split into 100 equal time periods so that an accurate concentration-time profile could be calculated for plug flow conditions.

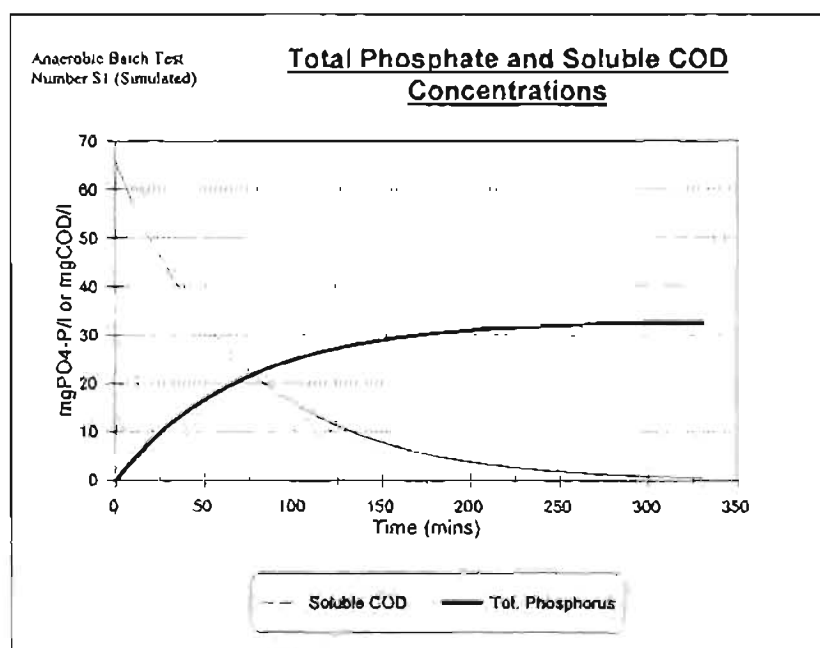


Figure 3.19: Total Phosphorus and Soluble COD concentrations for simulated batch test S3.

The total P and soluble COD concentrations are then calculated as follows:

Using values of steady state period 25 (see Appendix C) then dividing by 2 (dilution factor):

Total influent COD (S_{ii})	=	374.9	mgCOD/ℓ
Biodegradable influent COD (S_{bi})	=	347.7	mgCOD/ℓ
RBCOD available for conversion per litre influent (S'_{bsi})	=	65.9	mgCOD/ℓ

Then the remaining RBCOD concentration in the n^{th} reactor (S_{bsn}) is given by:

$$S_{bsn} = \frac{S'_{bsi}}{(1 + K \cdot X_{ahn} \cdot R_N / 100)^n} \quad (3.2)$$

where:	K	=	First order rate constant (0.06 /d) (Wentzel <i>et al.</i> , 1990).
	X_{ahn}	=	Concentration of OHO in batch test.
	R_N	=	Nominal retention time (5½/24 d)
	n	=	Retention time (batch test duration) fraction varying from 1 to 100,
		=	1 for completely mixed flow through reactor,
		=	100 for batch test (plug flow).

Theoretically, with sewage only, a COD uptake and P release of 64 mgCOD/ℓ and 32 mgP/ℓ respectively takes place in 5½ hours (Figure 3.19). This compares well with the measured P release of 29.2 mgP/ℓ influent in the CTL system during steady state period 25; the average anaerobic P release in the CTL system over the investigation (steady state periods 19 - 31) is 30.7 (standard deviation 6.3) mgP/ℓ.

Table 3.16 shows the average results obtained in all the anaerobic batch tests. The results of the batch tests do not correlate very well with one another or the results observed for the steady state systems. From the batch tests with leachate only and sewage only (simulated), P releases of 21.9 and 32.6 mgP/ℓ respectively were attained. This implies that the expected P release in the batch test with the leachate/sewage mixture should have been 21.9 + 32.6 = 54.5 mgP/ℓ. However, this is much greater than the measured 12.4 mgP/ℓ. This difference cannot be explained in this investigation and may need many more batch tests to be carried out on similar EXP and CTL systems. The P release that was simulated for the sewage only anaerobic batch test compares very favourably to that measured for the CTL steady state system. While this is to be expected because the CTL steady state systems characteristics were used to simulate that particular batch test, the fact remains that in the CTL system a mean P release of 30.7 mgP/ℓ was measured, so

Table 3.16: Comparison of P release and COD uptake for the 5½ hour anaerobic batch tests on leachate and sewage.

Anaerobic Batch Test	P Release mgP/ℓ	COD Taken up mgCOD/ℓ	ΔP / ΔCOD
Leachate only (Kimaru <i>et al.</i> , 1996)	21.9 *	47.6	0.459
Sewage only (Simulated) [#]	32.6	65.3	0.500
Sewage and Leachate	12.4 *	24.3	0.510
Steady state CTL system [†]	29.2	58.4	0.500
Steady state EXP system [†]	49.9	99.8	0.500

[#] The sewage only batch test was not carried out in practise but was calculated using the steady state system characteristics (see above).

[†] The results given by the steady state are equivalent to a batch test with duration of 7.2 hours (sludge retention time in anaerobic reactor). It can be seen in Figures 3.13 to 3.18 that if the duration of the batch tests were increased to 7.2 hours, the P release and COD uptake would not change significantly. Therefore, a direct comparison between the steady state and batch test results can be made.

*

Although these values are not measured in the same units (mgP/ℓ batch test versus mgP/ℓ influent), they are still comparable as the load rate in the batch tests was the same as that in the parent system i.e. the mass of COD per mass of sludge was the same.

why so little P was released in the leachate/sewage mixture anaerobic batch test cannot be explained. In the leachate only batch tests, 47.6 mgCOD/ℓ i.e. 32.4 % of the leachate COD, was taken up in 5½ hours (Figures 3.16 to 3.18). In section 3.5.4, it was stated that from the EXP and CTL systems steady state results that the leachate COD taken up by the PAOs amounted to 20.2 mgCOD/ℓ i.e. 13.7 % of the 147 mgCOD/ℓ influent added. Why so much relatively, was taken up in the batch test compared with that in the continuous system, cannot be explained. Overall it can be said that the anaerobic batch tests did not perform as expected as they did not confirm the results measured in the steady state systems. Also, why so (disappointingly) little of the unstabilized leachate COD, with reportedly 30 % VFA, was taken up in the anaerobic reactor for BEPR, cannot be explained - it should have been much more, at least the 30 % VFA. Perhaps the unstabilized leachate did not have as high VFA content (see footnote on page 3.4).

3.6 DENITRIFICATION KINETICS

3.6.1 Introduction

To see the effect of the leachate on denitrification, 12 denitrification batch tests were carried out; six each for the EXP and CTL systems. Two batch tests were carried out simultaneously, one EXP and the other CTL. The dates on which the batch tests took place are shown in Figure 3.2.

To simulate the anoxic reactor, 1.2 litres of mixed liquor was drawn from the anaerobic reactor and mixed with 1.8 litres taken from the aerobic reactor. This made up the 3 litre batch test which was continuously stirred. To avoid oxygen entering the batch test mixed liquor, nitrogen gas was bubbled through the mixture causing a nitrogen blanket to form above the liquid surface. Polystyrene balls were placed on top of the mixed liquor also to prevent this from occurring. Nitrate was dosed ($20 \text{ mgNO}_3\text{-N}/\ell$) at the start of the batch tests so that the nitrate concentration in the batch test reactor did not approach zero before the end of the test. This ensured that there was sufficient nitrate for denitrification throughout the duration of the batch test which resulted in more accurate rates being measured. Samples were drawn at various intervals and were tested for nitrate, nitrite and total phosphorus concentrations.

3.6.2 Calculation of Denitrification Rates

Stern and Marais (1974) found that when the rates of denitrification were divided by the VSS concentration to obtain specific denitrification rates ($\text{mgNO}_3\text{-N}/(\text{mgVSS}\cdot\text{d})$), a decrease in the rate was observed as sludge age increased. When however, denitrification rates were divided by the Active VSS concentration, they were found to be independent of sludge age (i.e. $\text{mgNO}_3\text{-N}/(\text{mgAVSS}\cdot\text{d})$). They concluded that this was because the Active VSS relates the biological rate of denitrification to the particular component of the VSS mass that is responsible for this rate. This approach has been found to work well for nitrogen removal plants, because from a modelling perspective, the Active mass (AVSS) comprises only one heterotrophic organism group i.e. “ordinary” facultative heterotrophs (OHOs) and these obtain all the biodegradable COD. However, for N and P removal plants, the active heterotrophic organism mass comprises two distinct active organism groups viz. (1) the OHOs mentioned above and (2) the polyphosphate accumulating heterotrophs (PAOs) which effect the biological excess P removal. When anoxic P uptake does not take place, this latter group is considered not to contribute to denitrification (Wentzel *et al.*, 1990; Ekama and Wentzel, 1997) so that for N and P removal systems, the OHO and PAO active masses need to be “separated” so that the denitrification can be linked to the organism group and mass that performs the denitrification process. The VSS “fractionation” was done in section 3.5.2.1 above when calculating the BEPR stimulated by the leachate COD from which the active OHO fraction of the measured VSS also was obtained for each of the 31 steady state periods (see Table 3.11). The denitrification rate therefore is specified in terms of the OHO active mass only (i.e. $\text{mgNO}_3\text{-N}/(\text{mgAVSS}\cdot\text{d})$) by dividing the observed denitrification rate ($\text{mgNO}_3\text{-N}/\ell/\text{d}$) by the OHO calculated concentration

($\text{mgOHOAVSS}/\ell$, $X_{B,H}$) of the steady state period during which the anoxic batch tests were carried out.

3.6.3 Denitrification Batch Test Results

Denitrification and/or reduction rates can be presented in various ways. The approach adopted in this analysis is described in Figure 3.20 below which shows typical nitrate and nitrite profiles observed in the anoxic batch tests. From an anoxic batch test two profiles are generated, one for nitrate concentration and one for nitrite concentration. The first is a nitrate concentration profile which is the measure of the disappearance of nitrate from the bulk liquid, and is called nitrate reduction. The second is the nitrite concentration profile which can take one of two forms (i) accumulation, while nitrite is being produced or (ii) reduction, while nitrite is reduced. If nitrification is complete (i.e. no nitrate is recycled to the anoxic reactor from the aerobic reactor) then nitrate entering the anoxic zone can be visualised as being reduced to N_2 gas in two steps. In the first step it accepts 2 electrons to form nitrite and in the second it accepts a further 3 electrons to form N_2 gas. These two steps take place simultaneously. The nitrite accumulation (or reduction) is therefore accepted to occur as a consequence of the reduction of nitrate taking place more rapidly (or slowly respectively) than the denitrification of nitrite. The observed result is a gradual build-up (or decline) of nitrite in the bulk liquid while nitrate is being reduced. Only

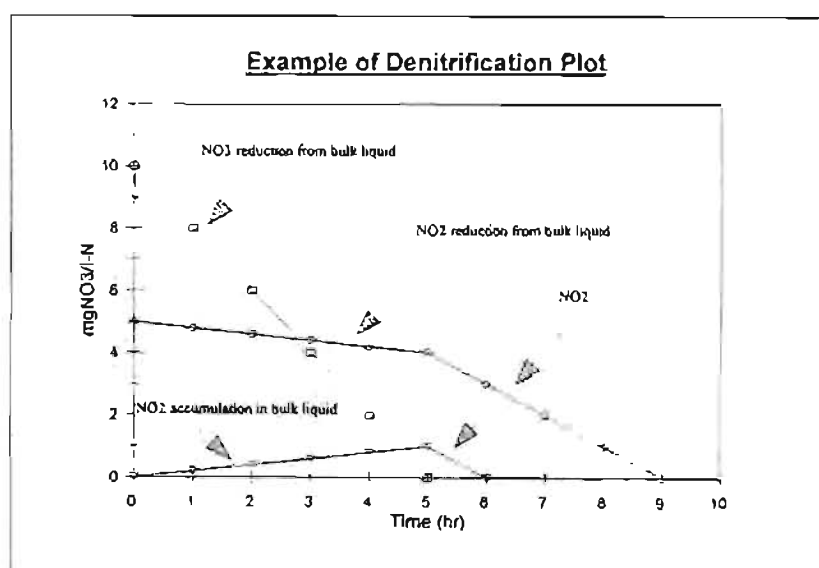


Figure 3.20: Typical example of nitrate/nitrite concentration - time batch test profile illustrating nitrate reduction, nitrite reduction and nitrite accumulation/reduction rates. The nitrate denitrification rate is not shown but can be calculated from the nitrate reduction rate suitably adjusted for nitrite accumulation/reduction (from Pilson *et al.*, 1995; see also Ekama and Wentzel, 1997).

when the nitrate concentration has been reduced to low values ($<1 \text{ mgNO}_3\text{-N/l}$) does net nitrite denitrification commence (i.e. conversion of nitrite to N_2 gas). If no nitrite enters the anoxic reactor then nitrite denitrification while nitrate is reduced is of course impossible. In the EXP and CTL systems, both with completely mixed anoxic reactors, nitrate supply to the anoxic zone is continuous and hence if, as is generally the case at 20°C , nitrate is reduced more rapidly than nitrite, a slow accumulation of nitrite in the bulk liquid will take place. If the anoxic reactor is under-loaded (received less nitrate than its denitrification potential) then the accumulated nitrite concentration will also be denitrified and complete denitrification is achieved in the anoxic reactor. If the anoxic reactor is overloaded (receives more nitrate than its denitrification potential) then both the accumulated nitrite and non-reduced nitrate concentrations will flow from the anoxic reactor to the aerobic reactor, which in terms of the Casey *et al.* (1994) bulking hypothesis, will cause a poor settling sludge to develop. If however a batch test is considered, sufficient nitrate can be dosed at the start of the test to ensure that complete denitrification is achieved during the test. Once the nitrite supply from the reduction of nitrate has ceased, then the rate of nitrite denitrification is no longer exceeded by the rate of nitrate reduction and this manifests as a reduction of nitrite in the bulk liquid and can be observed graphically as the actual nitrite denitrification rate (see Figure 3.20). In four of the six batch tests carried out in this investigation, sufficient nitrate was dosed so that the nitrate concentration at the end of the batch test (after $5\frac{1}{2}$ hours) was greater than zero. In these tests therefore, a nitrite reduction rate was not observed directly, however, in the other two batch tests, where the nitrate concentration was zero before the end of the batch test, a nitrite denitrification rate was evident once the nitrate concentration was zero. In these two cases the nitrite denitrification rate was ignored because of the low concentration of nitrite denitrified ($< 3 \text{ mgNO}_2\text{-N/l}$) and only the nitrite accumulation rate was calculated.

In this study the nitrate denitrification rate was calculated, so therefore only the nitrate reduction rate and the nitrite accumulation rate were of significance. The former is the measure of the specific rate of disappearance of nitrate from the bulk liquid irrespective of the product (i.e. NO_2 and/or N_2) and the latter is the measure of the specific rate of appearance of nitrite in the bulk liquid from the nitrate reduction. Nitrate reduction is therefore regarded as the rate of nitrate disappearance from the bulk liquid not corrected for nitrite accumulation - nitrite which can still accept 3 electrons in the denitrification to N_2 . Nitrate denitrification is the equivalent reduction rate of nitrate from the bulk liquid if all the nitrate had accepted 5 electrons to form N_2 gas.

The nitrate denitrification rate (product is N_2 gas) is the most important because it is customarily used in design of nitrogen and nutrient removal systems and N_2 gas forms the datum for the electron accepting capacity. The modification of the nitrate reduction rate to obtain the nitrate denitrification rate is made in terms of the relative abilities of nitrate and nitrite to accept electrons as follows: Nitrate is able to accept 5 electrons on reduction to nitrogen, while nitrite is able to accept three electrons on denitrification to N_2 gas. If denitrification is complete (i.e. all nitrate is converted to N_2 gas), five electrons are accepted altogether. However, if denitrification is incomplete (i.e. some nitrite accumulation), then the nitrate reduction rate must be adjusted to give the nitrate denitrification rate in accordance with the proportion of electrons which have been transferred to form N_2 gas. The nitrate denitrification rate is calculated as follows:

$$NO_3^- \text{ denitrification rate} = (NO_3^- \text{ reduction rate}) - (3/5) \cdot (NO_2^- \text{ accumulation rate}) \quad (3.3)$$

Equation (3.3) applies to situations where nitrate denitrification is not complete (i.e. nitrite accumulation) and conditions in the sludge become aerobic before nitrate and nitrite concentrations have been reduced to zero.

Table 3.10 shows that negligible P uptake took place in the anoxic reactor which indicates that all the denitrification was mediated by the OHOs and none by the PAOs. The specific rates of nitrate reduction, nitrite accumulation, nitrate denitrification (adjusted for nitrite accumulation) and nitrite denitrification were calculated by the following, the second of the approaches for determining the active OHO mass performing the nitrate and/or nitrite denitrification in the systems i.e.

- i) *without polyP organism mass* - which assumes that no conversion of RBCOD to VFA takes place in the anaerobic reactor ($K=0$) with the result that all the influent biodegradable COD is obtained by the OHOs, as if it were an N removal system i.e. in accordance with WRC (1984) or Clayton *et al.* (1991).
- ii) *normal polyP organism mass* - which assumes that the biological P removal observed resulted from normal conversion of RBCOD to VFA (at K rate = 0.06 l/mgVSS/d) and VFA uptake PAOs in the anaerobic reactor (see section 3.5.2 above) (Wentzel *et al.*, 1990), but higher P removal observed is accounted for by increasing $f_{x_{bg,p}}$ to 0.471 mgP/mgPAOAVSS.

- iii) *high polyP organism mass* - which assumes that all the influent RBCOD is converted to VFA in the anaerobic reactor (at K rate = 0.16 $\ell/\text{mgVSS}/\text{d}$) in accordance with the Wentzel *et al.* (1990) model to correctly reflect the observed high biological P removal and the P content of the PAOs ($f_{\text{xbg,p}}$) remains unchanged at 0.38 mgP/mgPAOAVSS.

In deciding which of the three approaches to adopt for discussion and comparison of the denitrification rates, it was noted that: (1) On the same wastewater used as influent in this investigation, Wentzel *et al.* (1995) measured the soluble COD concentration on a continual basis and found that it did not vary substantially from one sewage batch to another. Further, the soluble COD fraction was similar to results which have been obtained for the same wastewater as in previous investigations (i.e. $f_{\text{bs}} \approx 0.24$). (2) If leakage of soluble COD had taken place from the anaerobic reactor to the anoxic reactor in appreciable quantities, then it is likely that an initial high K'_1 denitrification rate would have been observed during some of the batch tests. No K'_1 rates were however observed and hence appreciable leakage was accepted not to have taken place. This implies that conversion of soluble COD to VFA was substantially complete. Accepting (1) and (2) above, approach (ii) is accepted and using the Wentzel *et al.* (1990) BEPR model with its defined value of $K=0.06/\text{d}$, it yields the appropriate concentration of PAOs based on their obtaining all the RBCOD converted to VFA. This approach is also the most appropriate for design because in design situations the active PAO mass will be calculated using the Wentzel *et al.* (1990) model from the influent RBCOD concentration with the “standard” conversion rate ($K=0.06/\text{d}$). With a value of $f_{\text{xbg,p}}=0.428$, the calculated and observed P removals are equal (See section 3.5.2.1 above), and the OHO active mass will be correctly reflected in terms of the model and hence the denitrification rates appropriately specified. With this approach, a changed P content in the PAOs ($f_{\text{xbg,p}}$) would be accepted for the EXP and CTL systems so as to correctly reflect the P removal observed. With the P content of the PAO active mass ($f_{\text{xbg,p}}$) at the Wentzel *et al.* (1990) model standard value ($f_{\text{xbg,p}}=0.38$ mgP/mgPAOAVSS), the calculated P removal is lower (13.56 mgP/ ℓ influent) than that observed in the CTL system with $f_{\text{xbg,p}} = 0.428$ (15.80 mgP/ ℓ influent).

The denitrification rates obtained in the anoxic batch tests for the EXP and CTL systems are shown in Table 3.17. Figures 3.22 and 3.23 provide a graphical representation of the degree of normality for the nitrate denitrification rates in the EXP and CTL systems respectively. Both sets of data, although small in number, are close to being normally distributed and therefore the

means and standard deviations can be calculated from the two data sets. From Table 3.17 it is apparent that the average denitrification rate in the EXP system (-0.0845 mgNO₃-N/mgOHOAVSS.d) is 19 % higher than that in the CTL system (-0.0711 mgNO₃-N/mgOHOAVSS.d). This is however not a consequence of the higher active OHO mass in the EXP system due to the leachate addition because this is taken into account when calculating the K₂' rates. Because so little of the leachate COD was taken up in the anaerobic reactor, it is likely that this increase in the K₂' rate is due to leakage of non taken up leachate biodegradable COD from the anaerobic reactor. Although no K₁ rate was observed in the batch tests, this COD may be more easily degraded than the sewage SBCOD leading to a faster rate. This can be explained as follows: If 17.7 % of the leachate was taken up in the anaerobic reactor, then (100 % - 17.7 %) 82.3 % of 98.7 % (leachate COD degraded in EXP system) of 147 mgCOD/ℓ (leachate COD added to EXP system) is available for denitrification = 119 mgCOD/ℓ. Using the constant 8.6 mg mass of COD utilized per mgNO₃-N nitrate denitrified, we see that (119/8.6) 13.9 mgN/ℓ can be denitrified. This is large enough to last the entire duration of the batch test and could therefore lead to the increased rate being observed for the duration of the batch test.

Table 3.17: Denitrification rates from anoxic batch tests for the EXP and CTL systems.

Batch Test No.	Day No.	EXP System (mgNO ₃ -N/mgOHOAVSS.d)	CTL System (mgNO ₃ -N/mgOHOAVSS.d)
1	334	-0.0859	-0.0623
2	344	-0.0714	-0.0501
3	347	-0.1155	-0.0877
4	355	-0.0701	-0.0743
5	358	-0.0939	-0.0860
6	361	-0.0701	-0.0664
Average		-0.0845	-0.0711
Standard Deviation		0.0165	0.0132

To determine if the means shown in Table 3.17 are *not* statistically different, a statistical analysis was performed on the data. The 95 % confidence interval for the EXP systems' data was calculated to be $(0.0845 \pm 0.0132) = 0.0713$ to 0.0977 , and for the CTL Systems' data was $(0.0711 \pm 0.0106) = 0.0605$ to 0.0817 . This is illustrated below in Figure 3.21. For the means *not* to be statistically different, with a 95 % confidence interval, there must be an overlap of the 95 % confidence intervals in the normal distribution graphs. It can be seen in Figure 3.21 that

there is an overlap between the two 95 % confidence intervals of the two data sets and therefore, the means shown in Table 3.17 are *not* statistically different.

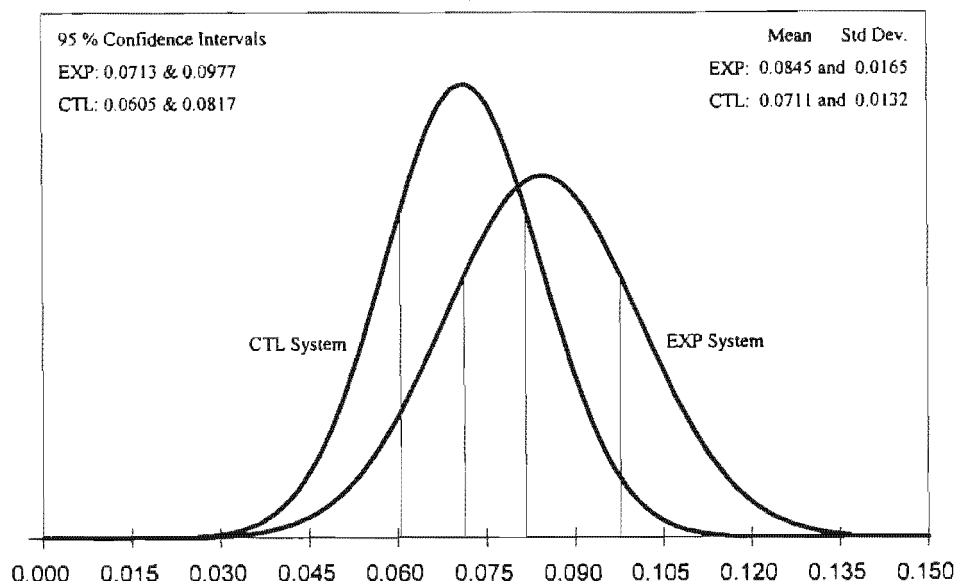


Figure 3.21: Normal distribution graphs for the denitrification rates obtained in batch tests performed on the EXP and CTL systems.

Table 3.18: Comparison of primary anoxic denitrification rates K'_2 at 20°C obtained by Clayton *et al.* (1989), Musvoto *et al.* (1992) and Pilson *et al.* (1995) with those obtained in this investigation.

System	Nitrate Denitrification Rate K'_2				Active ($f_{av,OHO}$)	No. of Tests*
	Mean	Std Dev	Max	Min		
Clayton (1989)	0.255	-	-	-	0.21	48 / 0
Musvoto (1992)	0.335	0.113	0.517	0.193	0.130	11 / 7
Pilson (1995)	0.181	0.0076	0.300	0.111	0.327	34 / 2
CTL System	0.0711	0.0132	0.088	0.050	0.435	6 / 0
EXP System	0.0845	0.0165	0.115	0.070	0.478	6 / 0

* Number of Nitrate / Nitrite tests

Table 3.18 shows a comparison between the denitrification rates obtained in this investigation with those obtained by other researchers also using laboratory scale activated sludge systems. It should be remembered when comparing denitrification rates that several factors influence these rates, the most important of which are the following:

- Reactor from which sludge is harvested (i.e. anaerobic; anoxic; aerobic, K'_1 or K'_2).
- Proportions of sludge blend in the batch tests (e.g. 2 anaerobic : 3 aerobic).
- Method used to calculate active fraction i.e. WRC (1984) or Wentzel *et al.* (1990) models.

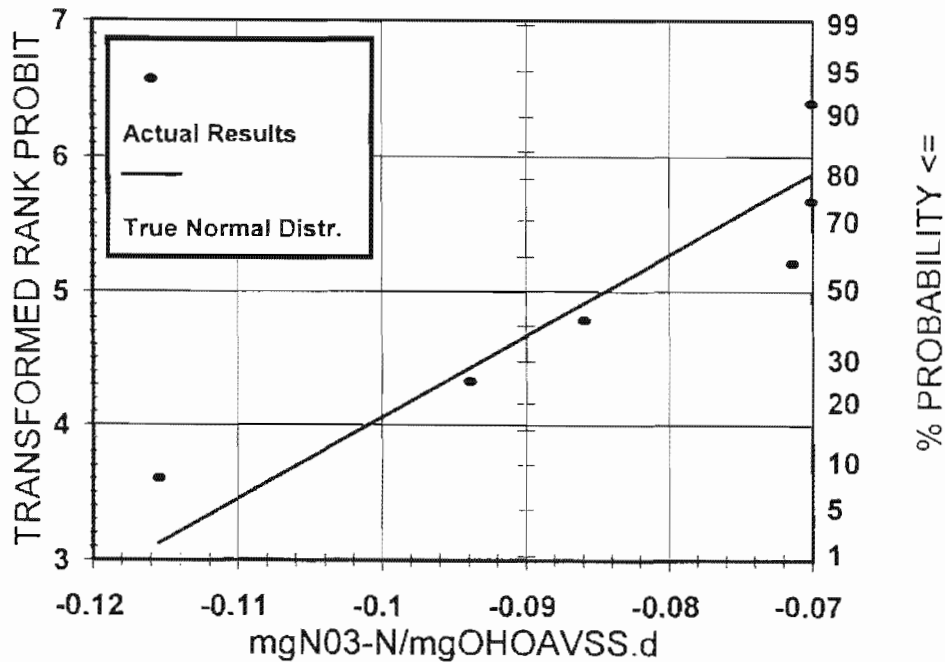


Figure 3.22: Probability distribution of the K'_2 nitrate denitrification rates for the EXP system. The mean is $-0.0845 \pm 0.0165 \text{ mgNO}_3\text{-N/mgOHOAVSS.d}$ for $K=0.06 \text{ /d}$ in the Wentzel *et al.* (1990) model.

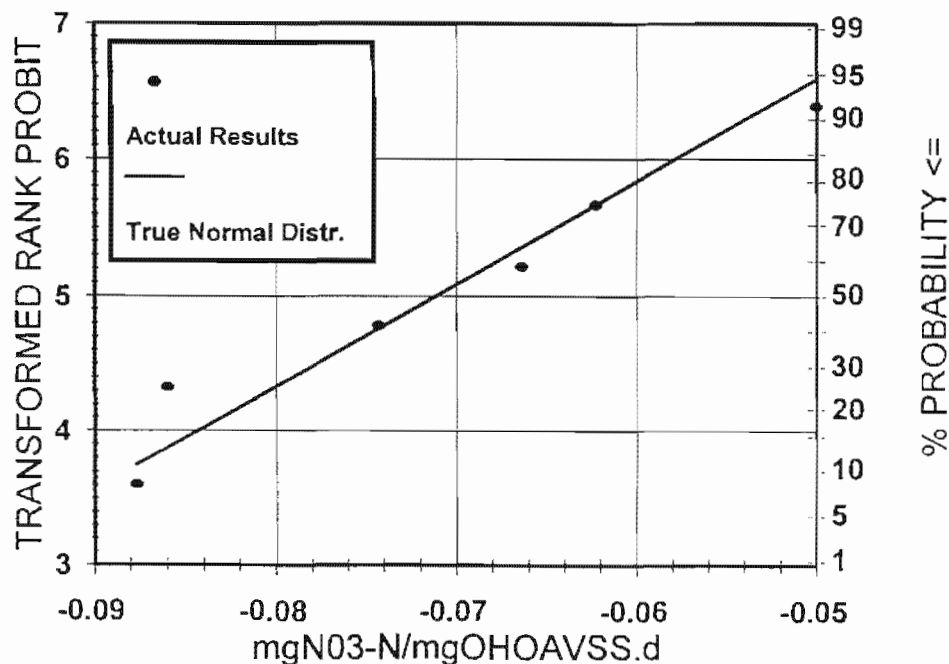


Figure 3.23: Probability distribution of the K'_2 nitrate denitrification rates for the CTL system. The mean is $-0.0711 \pm 0.0132 \text{ mgNO}_3\text{-N/mgOHOAVSS.d}$ for $K=0.06 \text{ /d}$ in the Wentzel *et al.* (1990) model. 17.7% of 98.7% (leachate COD degraded in EXP system).

Due cognizance (as was done in this investigation) must be taken of the above factors to ensure meaningful comparison between the various rates in Table 3.18. From the results in Table 3.18, it can be seen that the denitrification rates obtained in this study are below the rates obtained in previous studies. This is a consequence of the high active fraction of the OHOs ($f_{av,OHO}$) which is used to calculate the denitrification rate, which in turn is the consequence of the very low f_{up} value. For the purpose of this investigation, these differences between earlier investigations is not so important; what is important is the difference between the EXP and CTL denitrification rates to see the effect of the leachate dosing on the nitrogen removal of the systems. As already stated there is a 19 % increase in the EXP denitrification rate which thus means that a greater nitrogen removal can take place. It would therefore appear that while unstabilized leachate was dosed to the EXP system because of its expected greater influence on BEPR than on N removal, the leachate actually had a greater effect on the N removal than P removal. This arises from the nature of the organics in the leachate. While it was expected to have a high VFA content, it appears that it did not, and therefore did not stimulate a high BEPR but rather an improved N removal.

3.6.4 System Denitrification

The changes in nitrate/nitrite concentrations over time, obtained from anoxic batch tests enable the denitrification potential of an anoxic reactor to be calculated from the nitrate/nitrite concentration - time profiles. In contrast, it is not possible to calculate the denitrification potential for the completely mixed anoxic reactors of the parent systems from the concentrations of nitrate and nitrite unless the anoxic reactors receive a nitrate load greater than their denitrification potential i.e. only when the anoxic reactors are overloaded and nitrate and/or nitrite flows out of the anoxic reactor. In this event, the denitrification performance (i.e. measured system nitrogen removal) is equal to its denitrification potential (i.e. maximum nitrate/nitrite load that can be denitrified biologically). If the anoxic reactor is under-loaded, then negligible quantities of NO_x will leave this reactor and although nitrogen removal (i.e. denitrification) can be calculated, this is less than the denitrification potential i.e. denitrification is system limited by an a-recycle ratio that is too low. The NO_x concentrations in the EXP and CTL anoxic reactors were negligible, so therefore it can be concluded that the anoxic reactor was under-loaded.

Therefore, in the EXP and CTL systems with a-recycle ratio limited denitrification:

TKN added to EXP system via leachate added	5.35	mgN/ℓ
N in sludge wasted due to additional COD from leachate	2.01	mgN/ℓ
Increase in effluent TKN above CTL system	0.24	mgN/ℓ
Therefore leachate TKN nitrified	3.10	mgN/ℓ
Extra effluent nitrate in EXP system above CTL system	0.23	mgN/ℓ
Therefore leachate nitrate denitrified	2.87	mgN/ℓ
Therefore leachate nitrate not denitrified	0.23	mgN/ℓ

Therefore, in the EXP system, due to the low a-recycle ratio, the leachate COD did not contribute to the denitrification of the nitrate formed from the sewage TKN. Indeed, the nitrate formed from the leachate TKN was not all denitrified in the EXP system. If the a-recycle was increased to the optimum value, the denitrification potential in the anoxic reactor (D_{pl}) of the EXP and CTL systems can be calculated using the batch test measured denitrification rates as follows:

$$D_{pl} = \frac{S_{ii} (1-f_{us}-f_{up}) (1-f_{bs}) f_{x1} K'_2 Y_h R_s}{(1+b_h R_s)} \quad \text{mgNO}_3\text{-N/ℓ influent} \quad (3.4)$$

where:

- S_{ii} = Total influent COD concentration.
- f_{us} = Fraction of influent COD that is unbiodegradable soluble.
- f_{up} = Fraction of influent COD that is unbiodegradable particulate.
- f_{bs} = Fraction of influent biodegradable COD that is taken up by PAOs.
- f_{x1} = Anoxic sludge mass fraction.
- K'_2 = Measured denitrification rate.

From the measured data, the average denitrification potential in the EXP and CTL systems is calculated to be 23.55 and 15.53 mgNO₃-N/ℓ influent respectively.

If the difference in the EXP and CTL system denitrification potential calculated from the batch tests is accepted (viz 23.55-15.53 = 8.02 mgN/ℓ), then the potential (i.e. when operated at the appropriate a-recycle ratios) improvement in effluent nitrate concentration due to leachate addition would be as follows:

TKN added to EXP system via leachate added	5.35	mgN/ℓ
N in sludge wasted due to additional COD from leachate	2.01	mgN/ℓ

Increase in effluent TKN above CTL system	0.24	mgN/ℓ
Therefore leachate TKN nitrified	3.10	mgN/ℓ
Additional denitrification potential	8.02	mgN/ℓ
Therefore leachate nitrate denitrified	3.10	mgN/ℓ
Therefore sewage nitrate denitrified (8.02-3.10)	4.92	mgN/ℓ
Leachate COD used for denitrification 4.92*8.6	42.3	mgCOD/ℓ

which is $42.3/147 = 28.8\%$ of leachate COD.

3.7 NITRIFICATION

The relationship between the maximum unaerated sludge mass fraction (f_{xm}) and the maximum specific growth rate of the nitrifiers (μ_{nmT}) value is given in WRC (1984) as:

$$f_{xm} = 1 - S_f (b_{nT} + 1/R_s) / \mu_{nmT} \quad (3.5)$$

where:	S_f	=	Factor of safety of nitrification
	R_s	=	System sludge age (d)
	b_{nT}	=	Endogenous respiration rate of nitrifiers at T°C (/d)
		=	$b_{n20}(1.029)^{(T-20)}$
	b_{n20}	=	The rate at 20°C
		=	0.04 /d
	T	=	Temperature (°C)
	μ_{nmT}	=	Maximum specific growth rate of the nitrifiers at T°C (/d)
		=	$\mu_{nm20}(1.123)^{(T-20)}$
	μ_{nm20}	=	The rate at 20°C

Nitrification was complete in the EXP and CTL systems and hence it is only possible to estimate the minimum μ_{nm20} value from Eq. 3.8. Accepting $T = 20^\circ\text{C}$, $S_f = 1.0$, $R_s = 10$ d, $f_{xm} = 0.5$ and $b_{n20} = 0.04$ /d, then μ_{nm20} must have been at least 0.28 /d at 20°C or the EXP and CTL systems would not have nitrified.

3.7.1 Nitrification Batch Test Experimental Procedure and Setup

To see the effect of the leachate on nitrification, 10 nitrification batch tests were carried out at 20°C; five each for the EXP and CTL systems. Two batch tests were carried out simultaneously, one EXP and the other CTL. The dates on which the batch tests took place are shown in Figure 3.2. To simulate the aerobic reactor, 3 litres was drawn from the anoxic reactor and placed into a batch test reactor which was continuously stirred. The oxygen supply to the batch

reactor was controlled using a UCT dissolved oxygen (DO) controller/OUR meter (Randall *et al.*, 1991) with set points between 1.5 to 4.5 mgO/ℓ which measured the oxygen utilization rate (OUR) for the duration of the test. The influent wastewater fed to the parent systems was adequately buffered by the addition of sodium hydrogen carbonate (NaHCO₃) so that nitrification did not reduce the pH of the mixed liquor significantly during the batch tests. Ammonia, in the form of NH₄Cl was dosed at the start of the batch test (140 mgNH₄⁺-N into 3ℓ of batch volume) and allowed to mix thoroughly before the oxygen supply was commenced and the batch test was started. The high concentration of ammonia (46.7 mgNH₄⁺-N/ℓ) was dosed to ensure that the ammonia concentration did not approach zero and become a limiting factor for determining the nitrification rate i.e. nitrification was not complete. Samples were drawn at various intervals during the 5½ hour batch test and were tested for nitrate and nitrite concentrations. A typical nitrate/nitrite concentration - time plot for an aerobic batch test is shown in Figure 3.24.

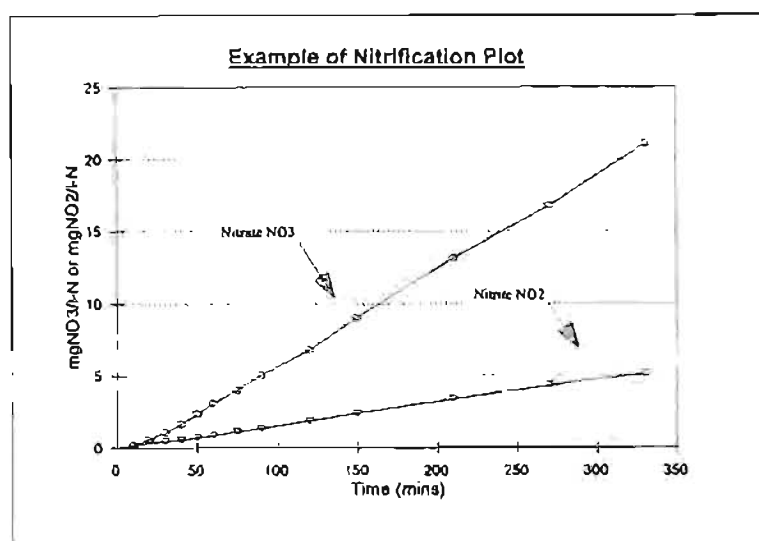


Figure 3.24: Typical example of nitrate/nitrite concentration - time aerobic batch test profile illustrating nitrate and nitrite accumulation rates.

3.7.2 Calculation for Maximum Specific Growth Rate of Nitrifiers

From Figure 3.24, the maximum specific growth rates for the nitrifiers in the EXP and CTL systems can be calculated from the slopes of the nitrate/nitrite time - concentration profile. The nitrate and nitrite generation rates (expressed in mgNO₃-N/ℓ/h or mgNO₂-N/ℓ/h) are determined from the slopes of the nitrate and nitrite concentration - time plots in Figure 3.24. The total ammonia conversion rate by the *Nitrosomonas* is the sum of the nitrate and nitrite generation rates. The μ_{nm20} is given by ammonia conversion rate multiplied by the concentration of nitrifiers in the batch test (X_n , mgNAVSS/ℓ). To calculate the concentration of nitrifiers in the mixed liquor harvested from the parent system, the nitrification capacity in the parent system needs to

be calculated by adding the mass of NO_x in the effluent to the mass of nitrate denitrified (Nitrification Capacity = $M(\text{NO}_3 \text{ generated})$). The mass of nitrifiers is then given by the following equation:

$$MX_n = \frac{M(\text{NO}_3 \text{ generated}) * (Y_n R_s)}{(1 + b_{nT} R_s)} \quad \text{mgNAVSS/l} \quad (3.6)$$

where: Y_n = Nitrifier organism yield coefficient = 0.10 mgVSS/mgN.
 R_s = Sludge age (days).
 b_{nT} = Endogenous respiration rate of nitrifying bacteria at $T^\circ\text{C}$ (/d).

Hence, the concentration of nitrifiers is given by:

$$X_n = \frac{MX_n}{\text{System Volume}} \quad \text{mgNAVSS/l} \quad (3.7)$$

Therefore, the maximum specific growth rate of the nitrifiers (μ_{nm20}) in the batch test is given by:

$$\mu_{nm20} = \frac{(\text{Total rate of } \text{NO}_3 + \text{NO}_2 \text{ generation})}{X_n} * 24 * Y_n \quad (3.8)$$

The maximum specific growth rates of the nitrifiers (μ_{nm20}) obtained in the aerobic batch tests for the EXP and CTL systems are shown in Table 3.19. From Table 3.19 it is apparent that the average maximum specific growth rate of the nitrifiers in the EXP system (0.3005 mg NO_3 -N/mgAVSS.d) is the same as that in the CTL system (0.3002 mg NO_3 -N/mgNAVSS.d). Figures 3.25 and 3.26 provide a graphical representation of the degree of normality of the μ_{nm20} rates in

Table 3.19: Maximum specific growth rates of nitrifiers calculated from the aerobic batch tests for the EXP and CTL systems.

Batch Test No.	Day No.	EXP System /d	CTL System /d
1	465	0.2184	0.2771
2	486	0.3469	0.3478
3	488	0.3228	0.3093
4	492	0.2969	0.2726
5	495	0.3175	0.2941
Average		0.3005	0.3002
Standard Deviation		0.0440	0.0271

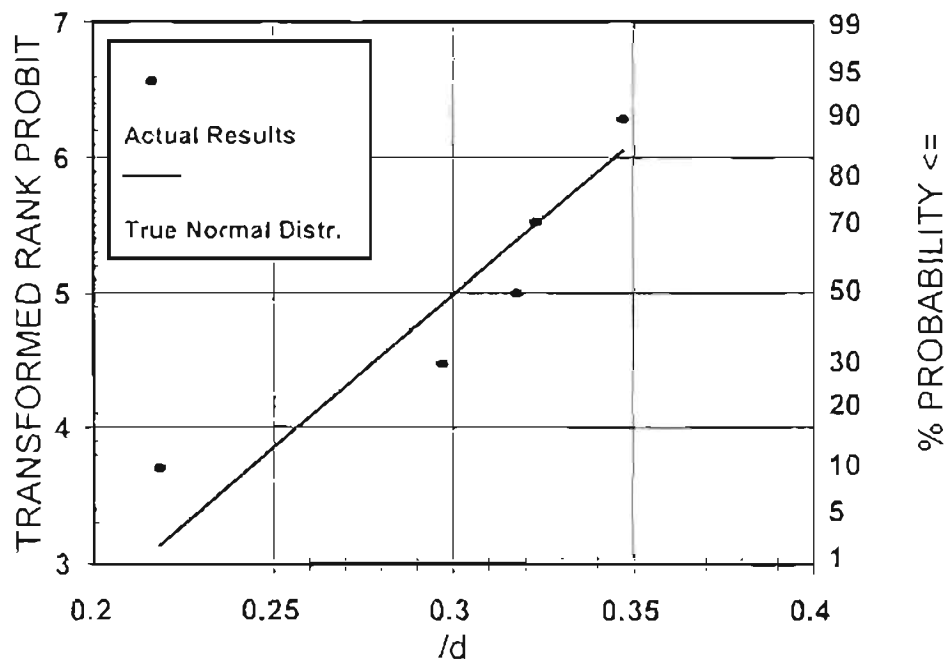


Figure 3.25: Probability distribution of the maximum specific growth rates for the EXP system. The mean is $0.3005 \pm 0.0440 /d$.

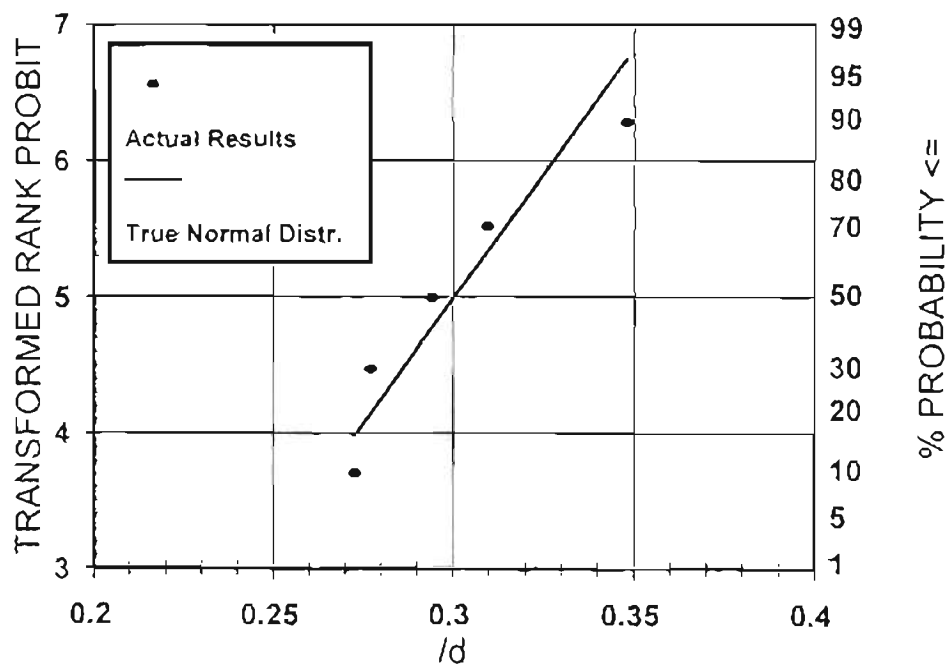


Figure 3.26: Probability distribution of the maximum specific growth rates for the CTL system. The mean is $0.3002 \pm 0.0271 /d$.

the EXP and CTL systems respectively. Both sets of data, although small in number, are close to being normally distributed and therefore the means and standard deviations can be calculated from the two data sets.

3.7.3 Temperature Sensitivity of Maximum Specific Growth Rate of Nitrifiers

From two batch tests at each of 12°C and 20°C, Pilson *et al.* (1995) calculated the nitrifier temperature sensitivity coefficient θ (comparing the measured maximum specific growth rate of the nitrifiers at 12°C and 20°C) using the following equation and obtained a value of 1.10 which is close to the standard value often used in design (1.123 - WRC, 1984) viz:

$$\begin{aligned} \mu_{nm12} &= \mu_{nm20} \theta^{(T-20)} \\ 0.314 &= 0.67 \theta^{(-8)} \\ \theta &= 1.10 \end{aligned} \quad (3.8)$$

Mellin *et al.* (1997) operated an identical UCT biological N and P removal activated sludge system during the same time as this investigation, but the system was operated at a temperature of 30°C. It was therefore possible to calculate θ using the $\mu_{nm30} = 0.781$ /d measured by Mellin *et al.* (1997) and the CTL systems' μ_{nm20} calculated in this investigation. i.e.

$$\begin{aligned} \mu_{nm30} &= \mu_{nm20} \theta^{(T-20)} \\ 0.781 &= 0.3002 \theta^{(+10)} \\ \theta &= 1.10 \end{aligned}$$

Comparing the θ calculated by Pilson *et al.* (1995) with that calculated using the more recent investigations (i.e. Mellin *et al.*, 1997 and this investigation), showed that there was no difference in the temperature sensitivity of the nitrifiers. However, a large difference was found between the μ_{nm20} calculated in this investigation ($\mu_{nm20} = 0.3002$) and that of Pilson *et al.* (1995) ($\mu_{nm20} = 0.67$). This can be ascribed either to changes in the sewage content that was collected from the Mitchells Plain Sewage Treatment Plant (the source sewage for all the investigations) or to adaptation of nitrifiers to system conditions. This latter cause is very plausible. Changes in μ_{nm20} have been observed in response to different system conditions, viz:

- Batch Feeding - In intermittently feed fill and draw systems μ_{nm20} was significantly higher than in equivalent continuously fed systems (Still *et al.*, 1996).
- Temperature - A temperature of 12°C and sludge age of 12 days initially stopped nitrification in Pilson *et al.* (1995) MUCT systems but over time, nitrification slowly

returned so that towards the end of the 582 day investigation it was again complete.

- Sludge Age - In a hybrid external nitrification BEPR system at 20°C nitrification was stopped at sludge age of 10 days and an aerated mass fraction of 20 %; however, slowly over time, nitrification returned and was again complete after 6 months of operation.

All these systems were fed from the same wastewater source (Mitchell's Plain) and yields μ_{nm20} values ranging from 0.30 (this investigation) to 0.65 /d (Pilson *et al.*, 1995).

Figure 3.27 illustrates the above in that the lines representing θ of Pilson *et al.* (1995) and the line representing θ of Mellin *et al.* (1997) and this investigation, are indeed parallel. The discontinuity in the lines result because the μ_{nm20} calculated by Pilson *et al.* (1995) and the μ_{nm20} calculated in this investigation are not the same.

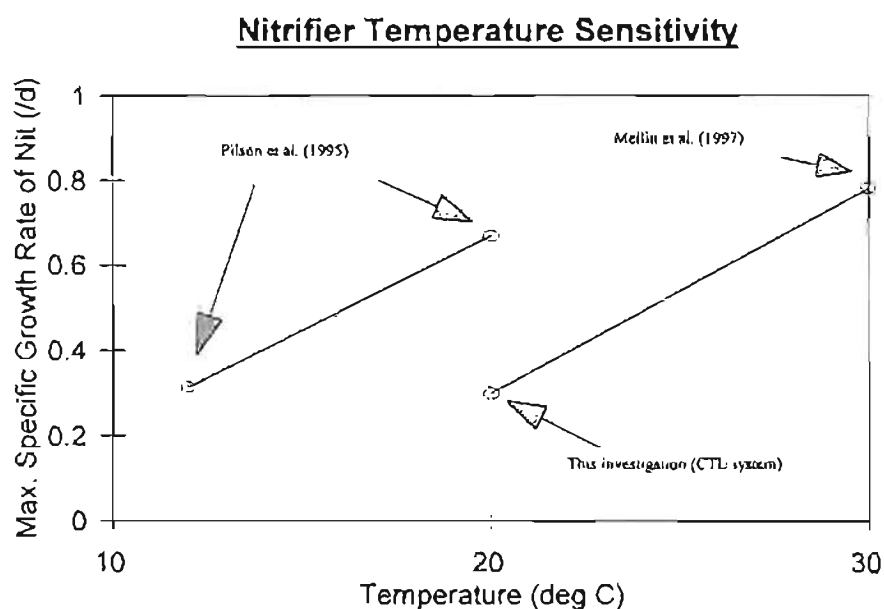


Figure 3.27: Temperature sensitivity of the maximum specific growth rate of the nitrifiers (μ_{nmT}). The slope of the lines represent the nitrifier temperature sensitivity coefficient (θ).

3.8 FILAMENT IDENTIFICATIONS

Approximately once every four weeks samples of mixed liquor were taken from each of the EXP and CTL systems and sent for microscopic analysis and filament identification. This was done for two reasons. Firstly, to ensure that the filaments occurring in the laboratory scale systems in this investigation are of the same type and relative abundance found at full scale and secondly to see if the leachate had any affect on the dominant and secondary filament types present in the EXP system. Comparing the filaments identified in the CTL system (see Table 3.20) with those

identified by Blackbeard *et al.* (1988) in full scale plants in South Africa, it appears that the frequent occurrence of type 0092, *M.parvicella* and type 1851 at both laboratory and full scale provides sufficient evidence that the CTL system can be used to model full scale plants with confidence.

Casey *et al.* (1994) proposed an hypothesis for the proliferation of anoxic-aerobic (AA) filamentous organisms in nitrification-denitrification (ND) and nitrification-denitrification biological excess phosphorus removal (NDBEPR) systems. Their hypothesis is as follows:

“The majority of heterotrophic organisms can be classified by their morphological characteristics as either filamentous or floc-forming organisms. The floc-forming organisms are aerobic-facultative; under aerobic conditions they utilize oxygen and under anoxic conditions they denitrify NO_3^- or NO_2^- to N_2 . The filamentous organisms are also aerobic-facultative but are nitrate reducers only; under anoxic conditions they reduce NO_3^- to NO_2^- only.

“When sludge is exposed to alternating anoxic-aerobic conditions (NO_3^- and/or NO_2^- present throughout anoxic period), nitrate and nitrite is denitrified during the anoxic period to nitrogen gas with some nitric oxide (NO) also being produced. When a floc-former with intracellular NO is subjected to aerobic conditions, the NO inhibits the utilization of oxygen. Also, while NO is present under aerobic conditions, the floc-formers continue to respire with NO_2^- . Under anoxic conditions, the filamentous organisms do not produce NO as an intermediate and hence do not accumulate NO intracellularly. Consequently, these organisms are not inhibited in their utilization of substrate under subsequent aerobic conditions.

“With intracellular NO present, and inhibition induced, floc-formers are placed at a disadvantage with respect to the filaments in competition for substrate under aerobic conditions. Consequently, the filamentous organisms utilize a greater proportion of the substrate under aerobic conditions than they would if the floc-formers were not inhibited. With floc-forming organisms inhibited, the filamentous organisms increase their relative mass in the sludge with each exposure to aerobic conditions, leading to the condition referred to as a bulking sludge.”

One aspect of their hypothesis that has significant support is that if the intracellular NO is reduced to near zero in the anoxic zone then the floc-formers will not be inhibited under subsequent aerobic conditions and significant bulking is unlikely to occur. However, NO itself cannot serve as a control or design parameter as it cannot be readily measured. Thus NO_2^- and NO_3^- must serve as the surrogate parameter because NO_2^- (and indirectly NO_3^-) is the source of NO through the denitrification process. To prevent high concentrations of NO_2^- prior to the aerobic zone, the most appropriate solution at present is to design the anoxic mass fraction/a-recycle aspects of the system so that the denitrification potential of the anoxic reactor is greater than the mass of NO_3^- and NO_2^- recycled to it (i.e. complete denitrification in the anoxic reactor is achieved i.e. $\text{NO}_x < 0.5 \text{ mgN/l}$).

From the results of this investigation, the nitrate and nitrite concentrations leaving the anoxic reactors of both the EXP and CTL systems were found to be negligible ($0.56 \text{ mgNO}_x\text{-N/l}$ and $0.85 \text{ mgNO}_x\text{-N/l}$ respectively). It can thus be concluded that complete denitrification was achieved in the anoxic reactors and therefore, according to the hypothesis of Casey *et al.* (1994), bulking should not occur.

The mean DSVI in the EXP and CTL systems were 139.7 (standard deviation 34.7) and 153.3 ml/g (standard deviation 16.5) respectively i.e. 10 % higher in the EXP system. Although these values are not ideal (not between 80 to 100 ml/g), they are however below (or near to) the upper limit for bulking (150 ml/g). Comparing the DSVIs measured in this investigation to those measured by Musvoto *et al.* (1992), Clayton *et al.* (1989) and Pilson *et al.* (1995), it can be seen that although the values measured in this investigation are not ideal, they are not excessively high. This indicates that the Casey *et al.* (1994) hypothesis does have value.

Figures 3.28 and 3.29 show the relationship between the nitrate and nitrite concentrations leaving the anoxic reactor and the Diluted Sludge Volume Index (DSVI) for the duration of the investigation. The days on which filament samples were taken for analysis are also indicated and these results are given in Table 3.20. It can be seen in Table 3.20 that the dominant and secondary filaments found in the EXP system very closely match the filaments identified in the CTL system which indicates that the addition of leachate to an activated sludge plant has very little effect on the types of filaments that proliferate. The most dominant filaments found in this investigation were type 0092, *M.parvicella* and type 1851; type 021N sometimes was dominant

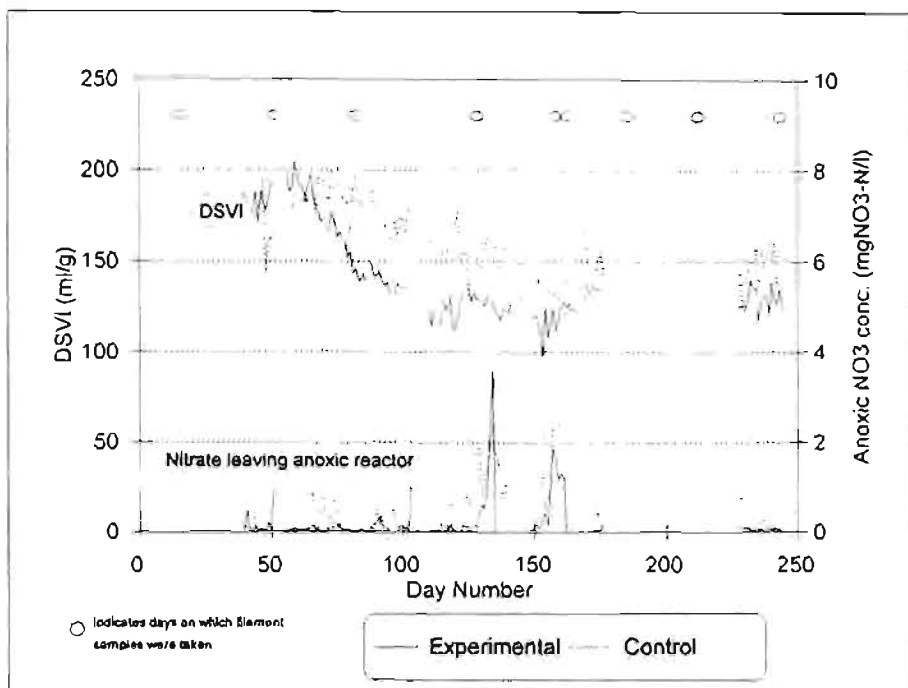


Figure 3.28: Relationship of the Diluted Sludge Volume Index (DSVI), effluent nitrate concentration and the filament identifications from day 1 to 250.

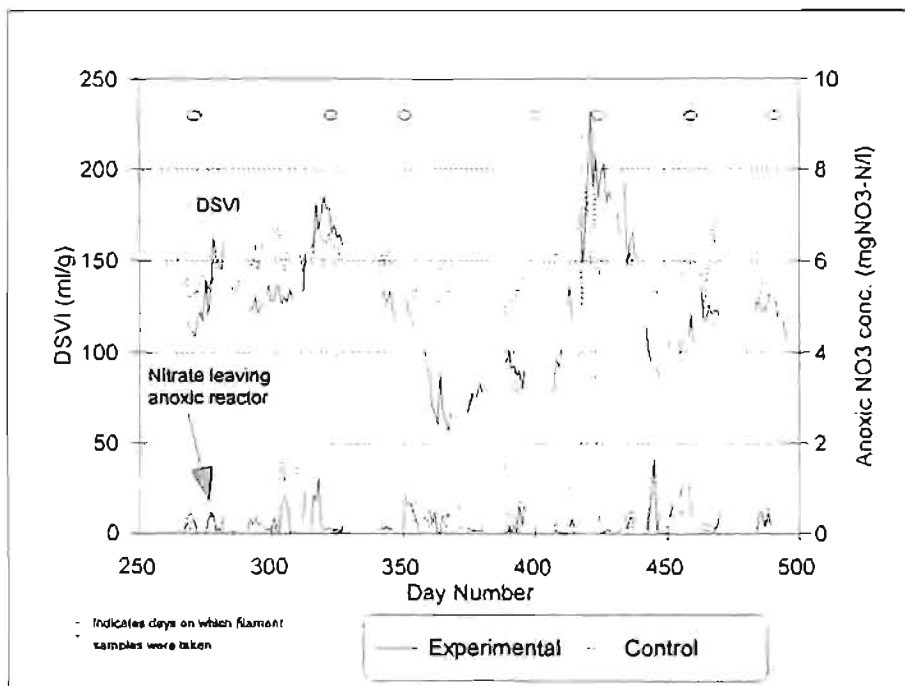


Figure 3.29: Relationship of the Diluted Sludge Volume Index (DSVI), effluent nitrate concentration and the filament identifications from day 251 to 495.

or secondary; being a septic wastewater filament, its presence in the biocenosis is probably due to storage of wastewater, for feed for up to two weeks albeit at 4°C.

Table 3.20: Filaments identified in the EXP and CTL systems.

Day	Analyst	DSVI		System	EXP System	CTL System
		EXP	CTL			
16	CMC	211	-	Dominant	type 0092	type 0092
				Secondary	<i>M.parvicella</i>	<i>M.parvicella</i>
				Other	<i>N limicola</i> , <i>S. natans</i>	Type 1851, <i>S. natans</i>
				Amount	Few	Some
16	JHB	211	-	Dominant	type 0092	type 0092
				Secondary	type 0803	type 021N, <i>H hydrossis</i>
				Other	Type 0041, type 021N	type 0803, <i>Thiothrix</i>
				Amount	Very common	Very common
				Remarks	No bridging	Few rotifers, No bridging
51	CMC	184	167	Dominant	type 0092	type 0092
				Secondary	<i>M.parvicella</i> , <i>S. natans</i>	<i>M.parvicella</i> , <i>S. natans</i>
				Other	<i>N limicola II</i>	type 1851, type 0914
				Amount	Some	Some
82	CMC	144	183	Dominant	<i>M.parvicella</i>	<i>M.parvicella</i>
				Secondary	type 0092, type 1851	type 0092, type 1851
				Other	<i>Beggiatoa spp.</i>	<i>Beggiatoa spp.</i>
				Amount	Some	Common
128	CMC	127	156	Dominant	type 0092	type 0092
				Secondary	<i>M.parvicella</i> , type 021N	<i>M.parvicella</i> , type 1851
				Other	type 1851, <i>H hydrossis</i>	type 021N, <i>Spirochetes</i>
				Amount	Common	Some
158	CMC	122	137	Dominant	<i>M.parvicella</i>	<i>M.parvicella</i>
				Secondary	type 0041, type 021N	type 0092, <i>Thiothrix</i>
				Other	<i>H hydrossis</i> , type 0092	<i>H hydrossis</i> , type 021N, type 1701
				Amount	Very common	Common
				Remarks	<i>M.parvicella</i> damaged	<i>M.parvicella</i> damaged
162	CMC	122	137	Dominant	type 0092	type 0092
				Secondary	<i>M.parvicella</i> , type 021N	<i>M.parvicella</i> , type 1851
				Other	<i>Thiothrix</i>	type 021N
				Amount	Common	Common
185	CMC	128	146	Dominant	type 0092	type 0092
				Secondary	<i>M.parvicella</i> , type 021N	<i>M.parvicella</i> , type 1851
				Other	type 1851	type 021N, <i>Acineto bact</i>
				Amount	Some	Some

212	JHB	128	146	Dominant	type 0041	type 0092
				Secondary	type 0092, type 0675	type 0041, <i>Thiothrix II</i>
				Other	<i>M.parvicella</i> , <i>H hydrossis</i>	<i>H hydrossis</i> , <i>M.parvicella</i>
				Amount	Common	Common
				Remarks	<i>M.parvicella</i> damaged	
243	CMC	131	155	Dominant	type 1851	<i>M.parvicella</i>
				Secondary	<i>M.parvicella</i> , type 021N	type 1851, type 021N
				Other	type 0092	type 0092
				Amount	Some	Common
243	JHB	131	155	Dominant	type 0092	type 0041
				Secondary	type 0041, type 0675	type 0092
				Other	type 0803, <i>H hydrossis</i> , <i>M.parvicella</i>	type 0675, <i>H hydrossis</i> <i>M.parvicella</i>
				Amount	Common	Abundant
				Remarks	Various Protozoa common, Amor Zoogloea	Heavy bridging, Protozoa common
271	CMC	115	142	Dominant	type 1851	type 021N
				Secondary	<i>M.parvicella</i>	type 0092
				Other	type 021N, type 0092	type 1851, <i>M.parvicella</i>
				Amount	Some	Some
323	CMC	170	157	Dominant	type 021N	type 021N
				Secondary	type 1851	type 1851
				Other	<i>M.parvicella</i> , type 0092 <i>H hydrossis</i>	type 0092, <i>M.parvicella</i>
				Amount	Common	Common
351	JHB	128	144	Dominant	type 021N	type 0092
				Secondary	type 0092	type 021N
				Other	type 0041, <i>H hydrossis</i> <i>M.parvicella</i> , type 1851 <i>Beggiatoa spp.</i>	type 0041, type 1851 <i>M.parvicella</i> , <i>H hydrossis</i>
				Amount	Common - very common	Very common
351	CMC	128	144	Dominant	type 1851	type 1851
				Secondary	<i>M.parvicella</i>	<i>M.parvicella</i>
				Other	type 021N, type 0092	type 021N, type 0092
				Amount	Common	Common
400	JHB	90	129	Dominant	type 0092	type 0092
				Secondary	type 0041, type 021N	type 021N
				Other	type 0041, <i>H hydrossis</i>	type 0041, type 1851 <i>H hydrossis</i> , <i>M.parvicella</i>
				Amount	Common - very common	Very common - abundant
				Remarks	Large flocs, Many Protozoa	Medium to large flocs. Bridging

400	CMC	90	129	Dominant	type 1851	<i>M.parvicella</i>
				Secondary	<i>M.parvicella</i>	type 1851
				Other	type 021N, type 0092 <i>H hydrossis</i>	type 0092, type 021N
				Amount	Common	Common
424	JHB	162	147	Dominant	type 0092	type 0092
				Secondary	type 021N	type 0803
				Other	type 0961, type 0041 <i>H hydrossis</i>	type 021N, <i>M.parvicella</i> <i>H hydrossis</i> , type 0041
				Amount	Very common	Very common - abundant
				Remarks	Bridging. Free swimming ciliates.	Bridging. Crawling ciliates. Zoogloea.
424	CMC	162	147	Dominant	type 1851	<i>M.parvicella</i>
				Secondary	<i>M.parvicella</i>	type 1851
				Other	type 0092	type 0092, type 021N
				Amount	Common	Common
459	JHB	120	153	Dominant	type 0092	type 0092
				Secondary	type 0803, <i>M.parvicella</i>	<i>M.parvicella</i>
				Other	type 021N, type 0041	type 0803, type 021N <i>H hydrossis</i> , <i>N limicola II</i>
				Amount	Very common	Very common
				Remarks	Medium to large flocs Protozoa. Bridging.	Large flocs. Amorphous Zoogloea. Scanty Rotifers.
459	CMC	120	153	Dominant	<i>M.parvicella</i>	type 1851
				Secondary	type 1851	<i>M.parvicella</i>
				Other	type 0092, type 021N	type 021N, type 0092, <i>Nocardia</i>
				Amount	Common	Common
491	CMC	123	135	Dominant	<i>M.parvicella</i>	<i>M.parvicella</i>
				Secondary	type 1851	type 1851
				Other	<i>H hydrossis</i> , type 0092	type 0092, <i>H hydrossis</i>
				Amount	Common	Scant

3.9 METAL ANALYSIS

Over the study period, nine influent and effluent samples were sent to the Scientific Services Branch of the Cape Metropolitan Council for metal analysis. The metals that were of interest to this study consisted of the following: Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Zinc (Zn), Arsenic (As) and Boron (B) because these are the Potentially Toxic Metals or Elements (PTMEs) specified in the Sewage Sludge Utilization and Disposal Information Document (WISA, 1993). The leachate that was

used in the investigation was also analysed for these PTMEs. The influent, effluent and leachate samples were analysed in an unfiltered and filtered state and the averages of the 9 analyses are shown in Table 3.21.

From Table 3.21 it can be seen that the only metal that has any significant amount present in the systems is Zn and therefore the others are ignored. The higher concentration of Zn is due to the fact that the source of the leachate is from lysimeters situated on the UCT campus and not that taken from an actual landfill. The lysimeters are a simulated landfill and the leachate PTME content depends on the waste initially placed within them. As the lysimeters were originally constructed and filled with selected waste such as restaurant waste, paper, and some ash, for previous studies, metals were not introduced into them. The high Zn concentrations is from the corrosion of the lysimeters themselves fabricated from galvanized 210 l oil drums. It is assumed that other heavy metals that would be present in landfill leachate would follow the same course

Table 3.21: Averages and standard deviations of unfiltered and filtered heavy metal concentrations in influent, reactor, effluent and leachate samples.

Heavy Metal		Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Zn	As	B
		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Unfiltered Influent	EXP	2.7 [#]	8.1	9.8	44.8 [#]	3.5 [#]	5.2	12.4	32.0	545.4	3.7	
	±	0.4	2.0	3.2	6.8	4.0	3.5	4.0	7.6	181.7	1.2	
	CTL	2.1 [#]	6.1	9.1	42.5 [#]	3.3 [#]	5.3	11.2	27.0 [#]	158.9	3.5	
	±	0.3	1.3	2.8	3.9	4.1	5.4	3.0	4.5	15.7	0.9	
Filtered Influent	EXP	1.8	5.4	3.3	6.9	0.8 [#]	1.4 [#]	8.2	12.4 [#]	152.3	2.0	117.0 [#]
	±	0.3	1.5	2.5	1.5	0.7	1.5	2.3	2.8	43.6	0.6	40.0
	CTL	1.4	4.9	2.9 [#]	5.9	0.9 [#]	2.8	7.9	11.8	18.0	1.9	154.7
	±	0.4	1.7	1.3	1.5	0.8	3.5	2.1	2.8	4.1	0.3	60.6
Unfiltered Reactor	EXP	6.8	14.8	79.5 [#]	742.6	8.5 [#]	9.6	48.5 [#]	153.8	4648.9	20.2	
	±	1.5	4.0	23.4	179.2	6.6	5.2	13.8	34.9	723.4	4.9	
	CTL	6.0	13.0	130.0	525.4 [#]	7.4 [#]	18.9	65.8	160.3	1312.6	14.0	
	±	1.4	3.9	27.5	83.9	4.9	9.0	16.8	40.2	219.5	5.9	
Filtered Effluent	EXP	1.6	5.6	2.3	4.2	0.1 [#]	2.3 [#]	8.4	12.0 [#]	29.4	1.2	140.5 [#]
	±	0.3	1.2	1.3	0.9	0.1	1.9	2.1	1.2	6.5	0.5	47.4
	CTL	1.6	5.4	2.1	5.1	0.7 [#]	1.6	8.0 [#]	12.3 [#]	17.6	1.1	144.2
	±	0.4	1.0	1.1	1.7	0.6	1.3	1.2	2.2	3.3	0.5	66.6
Leachate	Unfl	47	260	18	176	46	80	202	438	431000	129	
	Fill	41	234	17	65	10	55	186	311	230000	65	2520

[#] Statistical outliers have been ignored in these averages.

through the activated sludge plant as that of Zn. The study therefore focuses only on the path that Zn takes through the activated sludge system.

3.9.1 Mass Balance on Zinc

To ascertain the path that Zn takes when entering an activated sludge system, a mass balance with respect to Zn was carried out on the EXP and CTL systems. The results of the mass balances are shown in Table 3.22.

Table 3.22: Mass balance on zinc for the EXP and CTL systems.

	EXP System		CTL System	
	mg/d	out / in %	mg/d	out / in %
Mass Zn in with influent	10.91	100 %	3.18	100 %
Mass Zn out with waste flow	9.30	85.2 %	2.63	82.7 %
Mass Zn out with Effluent	0.53	4.9 %	0.32	10.1 %
Zn Mass Balance	90.1 %		92.6 %	

From Table 3.22 it can be seen that the Zn content in the EXP system is increased by $(10.91 - 3.18) = 7.73$ mgZn/d due to the leachate. This increase however has an insignificant effect on the mass of Zn leaving the system via the effluent as the mass leaving the EXP system is 0.53 mgZn/d and that leaving the CTL system is 0.32 mgZn/d. This indicates that nearly all the Zn is taken into the sludge mass and an insignificant amount remains in a soluble phase. The bulk of the Zn is removed via the waste flow as 85.2 % of the Zn in the influent to the EXP system and 82.7 % of that to the CTL system is removed in this way. It is therefore likely that if leachate which is high in PTMEs is treated in an activated sludge plant, care must be taken with the disposal of the sludge that is wasted from the system, as it will contain high concentrations of PTMEs which accumulates from the leachate. It also indicates that if the leachate that is to be treated in an activated sludge plant contains high concentrations of PTMEs, and provided that those concentrations are not so high as to inhibit the biomass in the system, then most of the PTMEs will leave the system via the sludge waste flow and not via the effluent. Hence leachate dosing to the activated sludge plant is not likely to result in PTME contamination of the receiving water body.

CHAPTER 4

CONCLUSIONS

4.1 INTRODUCTION AND OBJECTIVES OF INVESTIGATION

Management and operation of landfill sites has become necessary due to the ever decreasing amount of land available for landfills. This decrease in available land has resulted from increased urban population and an increase in environmental awareness. The result of these factors has led to the need to maximise the life of a landfill. The most serious threat to the environment is posed by the pollution of groundwater by leachate and to avoid this pollution the leachate needs to be collected and treated. Two types of leachates can be formed in a sanitary landfill, viz. acid (unstabilized) leachate and methanogenic (stabilized) leachate.

Various treatment processes have been used to treat the two types of leachate generated in a landfill, but relatively little is known on the treatment process by an activated sludge wastewater treatment plant. A study has previously been undertaken (Hansford *et al.*, 1993) to see the effect of stabilized leachate on a nitrogen removal activated sludge plant. Accordingly, this study focuses on the effect of unstabilized leachate on a nutrient removal activated sludge plant and in particular, the feasibility of adopting an integrated approach to municipal waste management by operating conventional sewage treatment plants (liquid waste treatment) and sanitary landfill sites (solid waste management) in conjunction with each other. In terms of this approach, the excess liquid leachate stream produced in the landfill is treated in the sewage treatment plant and the solids sludge stream generated in the sewage treatment plant is disposed of to the landfill (Novella *et al.*, 1995). The sites of both the sewage treatment plant and the sanitary landfill site are thus very important as they would need to be close to each other so that transport costs are kept to a minimum. The experimental data for this study have been obtained from two laboratory scale UCT nitrification/denitrification biological excess phosphorus removal (NDBEPR) systems operated at 20°C and 10 days sludge age; one experimental (EXP) system receiving a dose of unstabilized leachate as well as influent sewage, and the other control (CTL) system receiving only influent sewage. The investigation took place over a 495 day period and the results of the experiments on both systems are summarized below in Sections 4.2 to 4.7.

4.2 SYSTEM COD AND N REMOVAL PERFORMANCE

1. Over the 495 day investigation the average COD balance in the EXP and CTL systems were 92 % and the average N balance 90 % and 88 % respectively. Although considerably lower than 100 %, these are acceptable and similar to COD and N balances observed in other investigations on nutrient removal systems.
2. A 42 ml dose of 46 000 mgCOD/l acid leachate was added to the 20 l/d influent sewage feed of 660 mgCOD/l. Although this was expected to increase the influent COD of the EXP system by 96.4 mgCOD/l, it in fact increased the COD concentration by 147 mgCOD/l. The additional 51 mgCOD/l measured cannot be explained and therefore the measured COD concentration of 147 mgCOD/l was used in all calculations. The leachate increased the influent TKN to the EXP system by 5.4 mgN/l. The additional COD and TKN in the influent of the EXP system amounted to 22.3 % and 8.1 % of the sewage only organic COD and TKN loads. The leachate did not increase the total P content of the sewage/leachate feed.
3. The percentage COD removal in the CTL system was 94.1 %. Of the 100 % influent COD, 6.9 % passed out of the system via the effluent, 37.4 % via the waste sludge, 12.8 % via nitrate denitrified and 34.3 % via oxygen utilized with 8.6 % unaccounted for. The percent COD removal in the EXP system was 95.0 %. Of the 100 % influent COD, 6.1 % passed out of the system via the effluent, 36.7 % via the waste sludge, 11.0 % via nitrate denitrified and 37.1 % via oxygen utilized with 9.1 % unaccounted for.
4. The percentage N removal in the CTL system was 96.7 %. Of the 100 % influent TKN, 18.2 % and 4.2 % passed out of the system via the effluent as nitrate and TKN respectively, 21.7 % via the waste sludge and 44.6 % via denitrification with 11.3 % unaccounted for. The percentage N removal in the EXP system was 96.6 %. Of the 100 % influent TKN, 16.9 % and 4.4 % passed out of the system via the effluent as nitrate and TKN respectively, 25.2 % via the waste sludge and 43.5 % via denitrification with 10.0 % unaccounted for.
5. The overall average 0.45 µm membrane filtered effluent COD concentrations from the EXP and CTL systems were 40.8 and 38.8 mgCOD/l respectfully, giving

unbiodegradable soluble COD fractions (f_{us}) of 0.052 (sewage/leachate mixture) and 0.056 (sewage only) respectively. The difference of 2.0 mgCOD/ℓ represents the additional unbiodegradable soluble COD concentration from the leachate which as a fraction of the leachate COD is 1.3 %. Hence 98.7 % of the leachate COD was biodegraded in the system (leachate unbiodegradable particulate COD fraction was zero - see 10 below).

6. The overall average 0.45 μm membrane filtered effluent TKN concentrations from the EXP and CTL systems were 2.45 and 2.21 mgN/ℓ respectively, giving unbiodegradable soluble TKN fractions (f_{nu}) of 0.034 (sewage/leachate mixture) and 0.033 (sewage only) respectively. The difference of 0.24 mgN/ℓ represents the additional unbiodegradable soluble TKN concentration from the leachate which as a fraction of the leachate TKN is 4.5 %. Hence 95.5 % of the leachate TKN was biodegraded in the system (leachate unbiodegradable particulate TKN fraction, like its COD counterpart, was zero - see 10 below).
7. The oxygen utilization rate was 21.3 % higher in the EXP system (37.8 compared with 31.2 mgO/ℓ aerobic reactor/h). This is due to the additional organic COD and TKN load from the leachate.
8. The TSS and VSS sludge production and TSS and VSS concentrations in the EXP system (5408 mgTSS/d, 4196 mgVSS/d, 2704 mgTSS/ℓ, 2098 mgVSS/ℓ) were 25.1 % and 19.7 % higher compared with those in the CTL system (4321 mgTSS/d, 3507 mgVSS/d, 2161 mgTSS/ℓ, 1753 mgVSS/ℓ). The higher TSS and VSS in the EXP system is due to the leachate COD load and additional BEPR it stimulates.
9. To determine the unbiodegradable particulate COD fraction (f_{up}) of the sewage fed to the CTL system, the appropriate f_{up} value was selected so that the system VSS mass calculated with the BEPR model of Wentzel *et al.* (1990) was equal to that measured using the measured readily biodegradable (RB) COD concentration (see 17 below) and influent characteristics of the sewage (f_{us} , S_{ii}) and the system parameters as input. This procedure fractionates the VSS mass into its hypothetical constitutive components viz. active ordinary heterotrophic organisms (OHOs), polyphosphate accumulating organisms

(PAOs), endogenous residue of OHOs and PAOs and unbiodegradable particulate COD (X). This fractionation also is required to determine the P removal (see 12 below) and specific denitrification rates (see 20 below). An average f_{up} value of 0.062 was found for the CTL system. After reconciling the calculated VSS mass in the CTL system with that measured, the calculated P removal for the standard PAO P content ($f_{xbg,p}$) of 0.38 mgP/mgPAOAVSS was lower than that measured (14.52 versus 15.80 mgP/ℓ). One of two Wentzel *et al.* (1990) model parameters could be increased to increase the calculated P removal; either (1) the conversion rate (K) of RBCOD to VFA, which increases the proportion of the RBCOD obtained by the PAOs and hence increases their mass in the system, or (2) the P content of the PAOs $f_{xbg,p}$. Approach 2 does not affect the calculated VSS mass and fractionation. Approach 1 increases the calculated VSS mass and results in a lower f_{up} and OHO concentration, which in turn affects the measured specific denitrification rates (see 20 below). Because the f_{up} value was already low compared to other NDBEPR systems treating the same wastewater, it was decided to accept approach 2. This approach was also the most appropriate for design because in design situations the active PAO mass will be calculated using the Wentzel *et al.* (1990) model from the influent RBCOD concentration with the “standard” conversion rate of $K=0.06 \ell/(mgOHOAVSS.d)$. A $f_{xbg,p}$ value of 0.428 mgP/mgPAOAVSS set the calculated P removal equal to that measured in the CTL system (15.80 mgP/ℓ).

10. The CTL system $f_{xbg,p}$ value of 0.428 mgP/mgPAOAVSS was then applied to the EXP system results. Using the Wentzel *et al.* (1990) model in reverse, the RBCOD taken up in the anaerobic reactor was selected so that the calculated P removal was equal to that measured (20.06 mgP/ℓ). From this, the fraction of leachate COD taken up in the anaerobic reactor was calculated (see 13 below). With the BEPR correctly calculated, the f_{up} value was found by adjusting the f_{up} value until the calculated VSS mass was equal to that measured in the EXP system. The f_{up} of the EXP system (sewage/leachate mixture) was 0.045. Because the f_{up} of the sewage/leachate mixture was lower ($0.045 \cdot 807 = 36.3 \text{ mgCOD}/\ell$) than the CTL system ($0.062 \cdot 660 = 40.9 \text{ mgCOD}/\ell$) it was concluded that the unbiodegradable particulate COD fraction of the leachate itself was zero.

4.3 BIOLOGICAL EXCESS PHOSPHORUS REMOVAL

The effluent P concentrations in both the EXP and CTL systems were kept above 2 mgP/ℓ by dosing P to the influent. This allowed the system P removal capacities of the two systems to be measured and compared. Six anaerobic batch tests, in which the post flocculation 0.45 μm filtration soluble COD and total P concentrations were measured over 5.5 hours, were done on sludge harvested from the anoxic reactors of the CTL and EXP systems - 2 with the sewage/leachate mixture, 3 on leachate only diluted into tap water to the same concentration as the leachate in the sewage, and 1 on a sewage/acetate mixture with the acetate at the same concentration as the leachate in the sewage. The mass of COD added per VSS mass was the same in all the batch tests and equal to that in the anaerobic reactor of the parent systems.

11. The overall average P removals in the EXP and CTL systems for the steady state periods 1 to 31 were 16.84 and 13.12 mgP/ℓ respectively; thus 3.7 mgP/ℓ higher in the EXP system. However, only the average of the final 13 steady state periods (19-31), excluding steady state periods 26 & 27, were used for detailed analysis because these results were deemed the most reliable. For this period, the average P removals in the EXP and CTL systems were 20.00 and 15.80 mgP/ℓ respectively; i.e. 4.20 mgP/ℓ higher in the EXP system. The P uptake was confined to the aerobic reactor of both systems with none occurring in the anoxic reactor. Indeed, in the latter part of the final 13 steady state periods, P release took place in the EXP systems' anoxic reactor - 9.3 mgP/ℓ compared with 49.5 mgP/ℓ in the anaerobic reactor.
12. From the Wentzel *et al.* (1990) model, the calculated P removal for the CTL system was lower than that measured (14.52 versus 15.80 mgP/ℓ). In order to reconcile the calculated and measured P removals, the P content of the PAOs ($f_{x,b,p}$) was increased from the "standard" value of 0.38 to 0.428 mgP/mgPAOAVSS (see 9 and 10 above).
13. Following the procedure described in 9 and 10 above, 18.4 % of the biodegradable COD of the sewage/leachate mixture was taken up for BEPR in the anaerobic reactor. In the CTL system this was 18.8 %. Hence the leachate COD concentration taken up was $0.184 \cdot (1 - 0.045 - 0.052) \cdot 807 - 0.188 \cdot (1 - 0.062 - 0.056) \cdot 660 = 24.6$ mgCOD/ℓ which is $24.6/147 = 16.8$ % of the leachate COD.

14. The additional P removal to added COD ratio was found to be 0.029 (4.2/147) mgP/mgCOD. Theoretically with the model of Wentzel *et al.* (1990), if all the influent is VFA type RBCOD, then the P removal/COD ratio expected is 0.19 mgP/mgCOD. Comparing this with the 0.029 value measured, gives a result of 15.4 % (0.029/0.190) of the leachate COD being taken up in the anaerobic reactor which compares very well with the 16.8 % from 13 above.
15. In all the anaerobic batch tests except the one on the sewage/acetate mixture, the COD taken up to P released ratio was around the expected Wentzel *et al.* (1985) value of 0.5 mgP/mgCOD; the sewage/acetate mixture yielded 0.89 mgP/mgCOD. All the batch tests showed a two phase P release behaviour, with a fast first phase and a slower second. The initial rate for the sewage/acetate mixture was 2.62 times faster than that for the sewage/leachate mixture and 1.87 times faster for the leachate only. This indicated that the soluble COD in the leachate did not stimulate an acetate type P release response. In the leachate only batch tests, an average of 32.4 % (47.6 out of 147 mgCOD/l) was taken up. Why this was so much higher than the average 18.4 % determined for the EXP system, cannot be explained. The batch tests confirmed that the acid leachate appeared to contain an unexpectedly low concentration of organic compounds that stimulate BEPR like acetate. Clearly, the high P removal expected from the acid leachate with an anticipated 30 % VFA content (from Novella *et al.*, 1995) was not realized.
16. The total and biodegradable soluble COD in the sewage only and sewage/leachate mixture was determined from the difference in the flocculation/filtration COD concentration of influent and effluent. The biodegradable soluble COD of the sewage only was used as the input RBCOD concentration for the CTL system BEPR calculations (see 10 above). The biodegradable soluble COD of the sewage/leachate mixture was determined to be 27.7 % (i.e. 72.3 % is colloidal and can be flocculated out). From 13 above, 18.4 % of the sewage/leachate mixture was taken up for BEPR. Hence 27.7-18.4 = 9.3 % of the sewage/leachate mixture soluble biodegradable COD was not taken up in the anaerobic reactor for BEPR. A possible reason for this could be that the leachate contains slowly biodegradable soluble COD (see 19 below).

17. The average ratio of P removal to influent COD was 0.025 (20.06/807) and 0.024 (15.80/660) mgP/mgCOD for the EXP and CTL systems respectively. For the EXP system this was higher than the usual 0.022 mgP/mgCOD expected for the sewage only because a part of the influent COD (leachate) is more amenable for BEPR than influent slowly biodegradable COD. Interestingly, for the CTL system, the 0.024 mgP/mgCOD is higher than the ratios calculated for the same wastewater in investigations during the previous 7 years (Kaschula *et al.*, 1993, Musvoto *et al.*, 1992; Pilson *et al.*, 1995 and Mellin *et al.*, 1997). However, it is very similar to ratios calculated in investigations prior to 1990 (Wentzel *et al.*, 1985, 1989, 1990; Clayton *et al.*, 1989). In the first mentioned investigations, significant P uptake (~ 40 %) under anoxic conditions was observed, whereas in the last mentioned, like in this investigation, P uptake was confined exclusively to the aerobic reactor. It seems that when significant P uptake takes place under anoxic conditions, the BEPR is suppressed to about 60 % of that when P uptake takes place only under aerobic conditions (Ekama and Wentzel, 1997)

4.4 NITROGEN REMOVAL PERFORMANCE AND DENITRIFICATION KINETICS

As mentioned in 11 above, no P uptake was observed under anoxic conditions in the EXP and CTL systems. The denitrification therefore was mediated by the ordinary heterotrophic organisms (OHOs) and the denitrification rates are defined in terms of active OHO mass (OHOAVSS) which was calculated using the Wentzel *et al.* (1990) BEPR model (see 9 and 10 above).

18. Twelve anoxic batch tests were conducted on sludge harvested from the EXP and CTL systems - 6 on each. No initial rapid rate of denitrification (K'_1) associated with utilization of RBCOD was noted. This implies that no RBCOD “leaked” from the anaerobic reactor despite the low proportion of leachate COD taken up in the anaerobic reactor (18.4 %).
19. The average denitrification rate on slowly biodegradable COD (K'_2) in the EXP system was 0.0845 mgNO₃-N/(mgOHOAVSS.d); that in the CTL system was 0.0711 mgNO₃-N/(mgOHOAVSS.d). This means that the denitrification rate in the EXP system is 19 %

higher than in the CTL system. This is not a consequence of the higher OHO active mass in the EXP system due to the leachate addition because this is taken into account when calculating the K'_2 rates. It is likely that this is due to leakage of leachate slowly biodegradable soluble and colloidal COD from the anaerobic reactor. This COD seems more easily degradable than the sewage particulate slowly biodegradable COD leading to the faster rate.

20. In the EXP and CTL systems, 31.3 and 29.7 mgN/ℓ nitrate was denitrified in the anoxic reactors respectively. The nitrate denitrified is similar because both systems were operated at the same a-recycle ratio (2:1) and in both systems the denitrification was recycle limited (zero nitrate in the anoxic reactor). Based on the batch test K'_2 denitrification rates, the denitrification potential for the EXP and CTL systems were 23.55 and 15.53 mgNO₃-N/ℓ respectively. These potentials are lower than the nitrate denitrified in the continuous systems. The batch test K'_2 denitrification rates therefore underestimate the nitrate denitrified. (During the steady state periods in which the batch tests were carried out, the denitrification potentials in the EXP and CTL systems were 29.5 and 25.5 mgN/ℓ respectively. Although these potentials are both lower than the measured overall average nitrate denitrified (31.3 and 29.7 mgN/ℓ), they are still higher than the denitrification potentials calculated from the denitrification rates measured in the batch tests).

21. In the EXP and CTL systems with a-recycle ratio limited denitrification -

TKN added to EXP system via leachate added	5.35	mgN/ℓ
N in sludge wasted due to additional COD from leachate	2.01	mgN/ℓ
Increase in effluent TKN above CTL system	0.24	mgN/ℓ
Therefore leachate TKN nitrified	3.10	mgN/ℓ
Extra effluent nitrate in EXP system above CTL system	0.23	mgN/ℓ
Therefore leachate nitrate denitrified	2.87	mgN/ℓ
Therefore leachate nitrate not denitrified	0.23	mgN/ℓ

In the EXP system, due to the low a-recycle ratio, the leachate COD did not contribute to the denitrification of the nitrate formed from the sewage TKN. Indeed, the nitrate formed from the leachate TKN was not all denitrified in the EXP system.

22. If the *difference* in the EXP and CTL system denitrification potential calculated from the batch tests is accepted (viz 23.55-15.53= 8.02 mgN/ℓ), then the potential (i.e. when operated at the appropriate a-recycle ratios) improvement in effluent nitrate concentration due to leachate addition would be as follows -

TKN added to EXP system via leachate added	5.35	mgN/ℓ
N in sludge wasted due to additional COD from leachate	2.01	mgN/ℓ
Increase in effluent TKN above CTL system	0.24	mgN/ℓ
Therefore leachate TKN nitrified	3.10	mgN/ℓ
Additional denitrification potential	8.02	mgN/ℓ
Therefore leachate nitrate denitrified	3.10	mgN/ℓ
Therefore sewage nitrate denitrified (8.02-3.10)	4.92	mgN/ℓ
Leachate COD used for denitrification 4.92×8.6	42.3	mgCOD/ℓ

which is $42.3/147 = 28.8\%$ of leachate COD.

4.5 MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS

Nitrification was complete in both the EXP and CTL systems throughout the 495 day investigation. In order to achieve this, the maximum specific growth rate of the nitrifiers at 20°C (μ_{nm20}) at 10 days sludge age and 0.50 unaerated sludge mass fraction was at minimum 0.285 /d. The maximum specific growth rate of the nitrifiers (μ_{nmT}) was measured using the aerobic batch test method in WRC (1984). The results of the 5 aerobic batch tests on anoxic reactor sludge from each of the systems are as follows:

23. The average maximum specific growth rate of the nitrifiers at 20°C (μ_{nm20}) in the EXP system was 0.3005 /d and in the CTL systems was 0.3002 /d i.e. no difference between the two systems so that the leachate did not influence the μ_{nm20} rate.
24. The temperature sensitivity coefficient θ calculated from this investigation and that of Mellin *et al.* (1997), who carried out an investigation using the same sewage and system configuration but at 30°C, was calculated to be 1.10. This value is identical to the value calculated by Pilson *et al.* (1995) who carried out an investigation at 12 and 20°C. However, there was a difference between the μ_{nm20} of this investigation (0.3002 /d) and

that of Pilson *et al.* (1995) (0.67 /d). This difference can be ascribed either to changes in the sewage content that was collected for the investigations or to adaptation of nitrifiers to system conditions.

4.6 FILAMENT IDENTIFICATIONS

The AA filament bulking hypothesis of Casey *et al.* (1994) describes how a bulking sludge is the result of the nitrate and nitrite concentrations (NO_x) leakage from the anoxic reactor to the aerobic reactor. If these concentrations are high ($> 1 \text{ mgN}/\ell$) in conjunction with a low aerobic mass fraction (< 0.70), then a bulking sludge with a DSVI $> 150 \text{ ml}/\text{g}$ would prevail. The filament analyses that were carried out on the EXP and CTL systems approximately every 4 weeks during the 495 day investigation.

25. Anoxic-Aerobic (AA, low F/M) filaments type 0092, *M. parvicella* and type 1851 were most frequently dominant. Type 021N also occurred often in both systems but being septic sewage filaments (Jenkins *et al.*, 1984) this was probably due to aging of the sewage during storage. Apart from type 021N, these filaments are almost always observed in full scale NDBEPR systems (Blackbeard *et al.*, 1988).
26. The NO_x concentrations leaving the anoxic reactor in the EXP and CTL systems in this investigation were 0.56 and 0.85 $\text{mgNO}_x\text{-N}/\ell$ respectively, which according to the hypothesis of Casey *et al.* (1994) means that a bulking sludge should not occur.
27. The mean DSVI in the EXP and CTL systems were 140 (standard deviation 34.7) and 153 ml/g (standard deviation 16.5) respectively i.e. 10 % higher in the EXP system. Although these DSVIs are not ideal (not between 80 to 100 ml/g), they are however below (or near to) the upper limit for bulking (150 ml/g). Comparing the DSVIs measured in this investigation to those measured by Musvoto *et al.* (1992), Clayton *et al.* (1994) and Pilson *et al.* (1995), it can be seen that although the values measured in this investigation are not ideal, they are relatively quite good. This provides supporting evidence that the Casey *et al.* (1989) hypothesis does have value.

4.7 METAL ANALYSES

Over the study period, nine influent and effluent samples were analysed for their metal content between days 390 and 490. The metals that were of interest to this study were those Potentially Toxic Metals or Elements (PTMEs) specified in the Sewage Sludge Utilization and Disposal Information Document (WISA, 1993) and were Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Zinc (Zn), Arsenic (As) and Boron (B).

28. Due to the nature of the refuse contents of the lysimeters (filled with selected refuse, Chapman and Ekama, 1993), the only PTME to have any significant concentration was Zn which resulted from the corrosion of the galvanized lysimeters themselves. It is likely that other PTMEs that would be present in landfill leachate would follow a similar course through the activated sludge plant as Zn.

29. The leachate in the influent of the EXP system increased the mass of Zn added to the system per day from 3.18 mgZn/d (CTL system) to 10.91 mgZn/d. In both systems, the bulk of the Zn left the system via the waste sludge (85.2 % in the EXP system and 82.7 % in the CTL system) with only 4.9 % and 10.1 % leaving the systems via the effluent in the EXP and CTL systems respectively (9.9 % and 7.2 % was unaccounted for respectively). Due to the high Zn concentration in the waste sludge, care should be taken in disposing of waste activated sludges from plants to which leachate has been dosed as they will contain increased concentrations of PTMEs from the leachate. This is even more important if co-disposal is to be undertaken i.e. if the solid sludge stream is disposed of to a landfill, as the recycling of the metals in the leachate could reach extremely high and dangerous concentrations. With most of the Zn leaving the system via the waste sludge, leachate dosing is unlikely to result in PTME contamination of the receiving water body.

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APPENDICES

APPENDIX A

Day to day results of the Experimental System.

Day to day results of the Control System.

Figures A1 to A58: graphs of daily results.

APPENDIX B

Nitrogen Mass Balance.

COD Mass Balance.

APPENDIX C

Steady State Results.

APPENDIX D

Anaerobic Batch Tests.

APPENDIX E

Denitrification Batch Tests.

APPENDIX F

Nitrification Batch Tests.

Maximum Specific Growth Rate of the Nitrifiers.

APPENDIX G

Metal Analysis.

APPENDIX A

- Day to day results of the Experimental System.
- Day to day results of the Control System.
- Figures A1 to A58: Graphs of daily results.

Water Treatment Plant Operational Summary

Day No	1998	DST	TSS	VSS	pH		COD		BOD		TKN		NH ₄		NO ₃		NH ₃		
					Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	Monday	18 March																	
2	Tuesday	19 March																	
3	Wednesday	20 March																	
4	Thursday	21 March	220.1	2272	1854	7.49	7.98	1.48	0.10	27.1	1.2	58.0	189.7	1.4	0.1	159	2750	45	53
5	Friday	22 March	230.0	2174	1770	7.51	8.00	1.51	0.10	37.5	1.1	84.4	170.4	3.0	1.6	155	2696	39	45
6	Saturday	23 March	207.2	2257	1884	7.57	7.84	1.53	0.10	38.8	1.8	56.7	182.8	4.1	2.4	150	2709	33	40
7	Sunday	24 March	206.3	2327	1814	7.47	7.98	1.48	0.09	37.9	1.3	57.1	189.4	3.3	2.2	146	2710	35	43
8	Monday	25 March	213.3	2343	1842	7.58	8.01	1.48	0.10	38.4	1.3	58.1	186.0	3.3	2.2	147	2871	41	55
9	Tuesday	26 March	213.9	2260	1806	7.58	7.70	1.68	0.10	40.0	1.3	59.6	186.4	2.5	0.8	157	2823	37	41
10	Wednesday	27 March	197.5	2532	2102	7.61	7.73	1.40	0.10	34.1	2.1	50.7	200.2	2.5	0.8	157	2823	37	41
11	Thursday	28 March	196.6	2458	2048	7.67	7.59	1.55	0.09	38.8	1.1	58.7	193.2	1.5	1.8	159	2716	37	51
12	Friday	29 March	213.3	2344	1938	7.54	7.56	1.67	0.09	38.5	1.1	56.8	182.0	2.5	1.4	160	2337	43	53
13	Saturday	30 March	197.1	2452	2132	7.48	7.61	1.58	0.09	36.5	1.2	54.9	189.0	1.4	1.4	148	2858	33	75
14	Sunday	31 March	204.8	2604	2248	7.45	7.75	1.81	0.10	39.8	8.6	57.0	218.1	10.4	9.8	150	2474	41	69
15	Monday	01 April	237.8	2534	2144	7.47	7.55	1.60	0.10	43.0	2.4	59.4	204.4	5.9	4.3	131	2427	49	67
16	Tuesday	02 April	217.6	2523	2136	7.50	7.60	1.58	0.09	39.8	1.2	54.7	196.0	5.4	4.1	146	2378	45	55
17	Wednesday	03 April	211.0	2303	2000	7.53	7.71	1.56	0.10	45.18	1.50	64.08	198.58	3.0	2.0	167.51	3184.83	41.67	55.99
18	Thursday	04 April	218.5	2818	2198	7.81	7.58	1.49	0.08	41.6	1.4	60.5	184.4	1.8	2.3	177	3255	39	41
19	Friday	05 April	208.9	2578	2138	7.84	7.58	1.53	0.11	47.2	1.0	81.3	238.0	2.5	4.1	184	3058	43	57
20	Saturday	06 April	200.0	2490	2056	7.53	7.48	1.60	0.10	44.4	0.8	84.1	203.0	4.2	4.3	160	3390	47	57
21	Sunday	07 April	210.4	2378	1962	7.54	7.39	1.60	0.09	46.2	1.1	82.7	182.0	4.1	3.5	160	3178	41	57
22	Monday	08 April	205.7	2274	1907	7.56	7.41	1.64	0.10	43.8	1.7	82.6	184.4	3.0	4.1	173	3145	47	53
23	Tuesday	09 April	206.6	2326	1876	7.55	7.40	1.68	0.10	58.2	2.4	88.1	198.1	3.1	4.1	160	3071	47	53
24	Wednesday	10 April	202.4	2348	1924	7.57	7.50	1.55	0.10	48.8	2.6	88.8	203.3	3.4	4.1	145	3084	39	51
25	Thursday	11 April	201.8	2478	2080	7.53	7.48	1.60	0.10	49.2	2.5	87.8	201.8	3.4	5.1	145	3294	45	59
26	Friday	12 April	200.5	2484	2082	7.54	7.40	1.60	0.10	70.3	2.9	80.8	212.1	3.8	3.9	170	3058	38	47
27	Saturday	13 April	205.01	2448.89	2033.11	7.50	7.45	1.57	0.10	45.18	1.50	64.08	198.58	3.0	2.0	167.51	3184.83	41.67	55.99
28	Sunday	14 April	179.9	2584	2148	7.49	7.42	1.57	0.11	51.4	2.2	66.4	233.8	4.0	2.5	160	3380	43	61
29	Monday	15 April	211.9	2360	2017	7.44	7.42	1.60	0.11	48.6	2.5	67.2	207.5	3.2	3.7	160	3218	41	63
30	Tuesday	16 April	204.3	2488	2038	7.59	7.48	1.50	0.10	59.4	2.9	87.2	191.9	4.7	4.7	164	3056	40	51
31	Wednesday	17 April	204.4	2578	2074	7.60	7.56	1.59	0.11	51.9	1.5	70.1	208.4	2.2	2.8	180	3187	34	51
32	Thursday	18 April	214.9	2404	2038	7.58	7.51	1.71	0.11	58.7	2.0	70.5	213.3	3.4	4.1	147	3478	44	45
33	Friday	19 April	193.0	2764	2258	7.53	7.61	1.54	0.10	58.3	2.4	74.3	212.2	2.5	3.8	158	3474	41	44
34	Saturday	20 April	196.6	2840	2184	7.54	7.64	1.55	0.11	56.4	2.3	78.7	208.0	2.5	4.1	162	3380	37	43
35	Sunday	21 April	192.3	2740	2258	7.57	7.57	1.54	0.10	61.5	2.3	79.1	231.7	2.9	4.7	148	3474	33	52
36	Monday	22 April	176.0	2840	2184	7.51	7.45	1.50	0.10	57.3	1.4	79.7	218.8	2.5	3.7	167	3347	35	45
37	Tuesday	23 April	191.4	2612	2168	7.54	7.58	1.52	0.10	56.8	2.5	77.8	210.7	2.5	4.1	160	3201	31	45
38	Wednesday	24 April	178.4	2710	2220	7.57	7.53	1.57	0.08	56.3	2.6	85.4	200.4	1.5	1.3	173	3037	29	47
39	Thursday	25 April	179.8	2828	2099	7.44	7.44	1.59	0.08	48.6	2.8	67.3	186.3	1.5	1.6	185	2914	18	14
40	Friday	26 April	183.30	2593.83	2137.33	7.53	7.54	1.51	0.10	54.18	2.63	71.31	217.81	3.1	3.1	167.51	3184.83	41.67	55.99
41	Saturday	27 April	181.6	2578	2108	7.48	7.51	1.55	0.08	48.9	2.2	58.8	178.9	3.0	3.8	172	3066	37	49
42	Sunday	28 April	183.9	2542	2080	7.51	7.60	1.44	0.10	43.4	2.0	64.0	200.2	3.8	4.7	172	2996	37	41
43	Monday	29 April	183.3	2518	2060	7.48	7.61	1.40	0.08	43.1	2.5	66.1	178.4	2.4	2.4	168	2817	46	40
44	Tuesday	30 April	177.4	2538	2088	7.48	7.60	1.36	0.08	41.0	2.7	57.0	185.9	2.4	2.8	161	2937	74	34
45	Wednesday	01 May	187.6	2674	2142	7.49	7.61	1.37	0.08	43.4	1.8	67.2	188.5	2.5	1.5	153	2938	38	37
46	Thursday	02 May	186.5	2652	2182	7.51	7.63	1.37	0.08	38.8	2.7	58.2	182.7	3.4	2.1	161	2994	46	38
47	Friday	03 May	171.3	2770	2228	7.56	7.71	1.50	0.08	44.1	2.8	65.7	210.9	2.8	1.8	169	3083	24	49
48	Saturday	04 May	188.1	2644	2170	7.47	7.70	1.49	0.08	41.8	1.5	65.9	188.9	4.1	3.1	175	3276	41	58
49	Sunday	05 May	183.4	2728	2234	7.48	7.70	1.49	0.09	41.2	2.2	68.1	180.4	4.1	3.1	175	3276	41	58
50	Monday	06 May	177.4	2818	2312	7.48	7.84	1.44	0.08	45.4	0.8	64.8	184.1	3.0	2.6	163	3438	40	45
51	Tuesday	07 May	183.2	2730	2204	7.38	7.51	1.44	0.10	38.2	1.4	58.8	210.9	4.1	3.0	173	3184	45	41
52	Wednesday	08 May	190.4	2672	2182	7.38	7.50	1.33	0.09	48.0	0.8	60.8	187.7	3.0	3.0	172	2828	48	35
53	Thursday	09 May	184.4	2612	2128	7.57	7.45	1.37	0.08	44.6	0.9	60.8	188.9	3.8	2.9	169	2828	38	35
54	Friday	10 May	183.25	2643.30	2163.08	7.48	7.51	1.38	0.08	42.78	1.87	62.50	188.99	3.17	1.97	168.54	3008.31	43.91	41.00
55	Saturday	11 May	188.1	2600	2180	7.54	7.54	1.42	0.08	44.8	2.5	63.9	207.5	4.5	2.5	172	3058	36	41
56	Sunday	12 May	185.4	2604	2204	7.48	7.48	1.45	0.10	45.8	0.8	65.0	208.4	4.1	1.8	172	3058	36	41
57	Monday	13 May	188.7	2622	2212	7.47	7.42	1.54	0.10	51.1	3.1	67.9	218.8	3.8	3.3	156	3508	53	45
58	Tuesday	14 May	187.8	2676	2428	7.33	7.53	1.45	0.09	45.0	1.4	64.9	216.4	3.5	2.1	179	3608	41	37
59	Wednesday	15 May	188.9	2684	2468	7.44	7.53	1.41	0.09	48.0	1.3	72.1	217.0	3.2	2.8	177	3468	37	37
60	Thursday	16 May	184.8	2650	2258	7.43	7.65	1.48	0.09	44.1	0.8	70.3	215.8	2.9	3.2	188	3467	37	39
61	Friday	17 May	184.8	2612	2240	7.48	7.78	1.48	0.10	48.4	0.8	72.2	224.0	2.9	2.7	197	3466	37	37
62	Saturday	18 May	191.1	2680	2454	7.46	7.71	1.42	0.08	46.8	0.1	72.0	198.7	7.8	2.4	196	3415	38	35
63	Sunday	19 May	190.0	2670	2466	7.47	7.72	1.38	0.09	51.8	2.7	74.8	212.5	3.7	3.8	163	3380	38	38
64	Monday	20 May	191.2	2652	2396	7.42	7.80	1.51	0.10	51.1	1.8	71.7	226.4	3.8	2.9	176	3475	45	41
65	Tuesday	21 May	192.0	2682	2422	7.47	7.65	1.44	0.08	48.8	0.8	67.1	221.3	3.8	3.3	188	3495	41	37
66	Wednesday	22 May	197.7	2698	2466	7.48	7.64	1.48	0.09	47.80	1.40	70.75	217.00	3.39	2.92	174.64	3470.91	40.69	37.31
67	Thursday	23 May	197.1	2680	2468	7.50	7.64	1.48	0.09	56.6	0.7	88.8	221.9	3.5	2.9	167	3414	39	41
68	Friday	24 May	178.9	2682	2468	7.50	7.64	1.48	0.09	56.6	1.7	81.5	217.0	2.7	2.8	168	3454	47	43
69	Saturday	25 May	177.7	3002	2504	7.43	7.57	1.41	0.08	37.5	0.8	68.1	188.1	4.4	3.7	116	3562	43	33
70	Sunday	26 May	171.6	3104	2548	7.52	7.65	1.32	0.09	54.3	0.7	78.7	217.0	1.5	1.3	111	3379	39	33
71	Monday	27 May</																	

Day No.	1997	Day	Date	DSM		TSS		VLS		pH		COND		TURB		FSA		FE		TRN		ZOO		
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
371		Sunday	23 March	88.32	3220.00	2320.00				7.00	7.75	1.40	0.00	17.32			65.57	160.00	4.34	1.98	163.34	1004.77	85.51	37.01
372		Monday	24 March	59.91	3004.00	2108.00						1.47	0.00	48.34			65.53	184.50	3.70	2.57	163.34	1004.77	85.51	37.01
373		Tuesday	25 March																					
374		Wednesday	26 March	87.33	2922.00	2092.00				7.18	7.38	1.34	0.00	48.20			65.50	187.30	2.73	2.73	161.46	2606.88	83.17	42.76
375		Thursday	27 March	70.82	3874.00	2042.00				7.04	7.15	1.37	0.00	15.64			61.13	183.18	2.31	0.14	68.46	1948.33	81.78	45.77
376		Friday	28 March	74.70	3736.00	1894.00				7.53	7.63	1.48	0.00	18.44			61.46	170.10	2.34	2.24	157.39	2809.58	81.08	52.94
377		Saturday	29 March	74.63	3814.00	2030.00				7.57	7.90	1.37	0.00	47.16			67.70	180.60	2.87	2.10	167.34	2808.88	38.68	38.58
378		Sunday	30 March	76.25	3754.00	1978.00				7.58	7.66	1.30	0.00	48.48			63.70	150.50	1.61	1.01	177.73	2607.52	47.76	36.81
379		Monday	31 March	61.32	2810.00	1848.00				7.59	7.83	1.30	0.00	45.36			62.80	138.80	1.89	1.34	157.74	2807.08	59.51	51.20
380		Tuesday	01 April	77.37	2836.00	2182.00				7.81	7.81	1.31	0.00	49.42			70.28	170.10	2.36	2.38	1168.06	2852.28	42.09	38.98
381		Wednesday	02 April	71.62	2819.45	2048.55				7.50	7.78	1.37	0.00	45.84	ERR		65.47	172.33	3.27	2.15	817.62	2803.44	87.86	44.62
382		Thursday	03 April																					
383		Friday	04 April																					
384		Saturday	05 April																					
385		Sunday	06 April																					
386		Monday	07 April																					
387		Tuesday	08 April																					
388		Wednesday	09 April	95.44	2410.00	1890.00				7.58	7.75	1.40	0.00	40.18			92.54	181.70	2.94	1.82	902.13	2647.98	57.46	45.14
389		Thursday	10 April	99.10	2322.00	1874.00						1.40	0.00	47.78			85.13	170.68	3.58	0.14	1150.36	2778.18	39.51	45.77
390		Friday	11 April	101.63	2460.00	1900.00				7.37	7.44	1.39	0.00	45.71			94.14	158.70	2.94	2.52	836.64	2736.78	67.45	43.09
391		Saturday	12 April	91.03	2358.00	1842.00				7.27	7.71	1.36	0.00	46.40			92.00	141.42	1.82	1.88	915.37	2636.78	55.18	47.01
392		Sunday	13 April	83.46	2354.00	1830.00						1.43	0.00	61.32			87.18	145.60	2.03	1.76	821.78	2618.17	57.33	49.06
393		Monday	14 April	67.18	2524.00	1918.00				7.46	7.81	1.38	0.00	50.58			78.25	150.50	3.66	2.52	659.29	2636.78	47.01	47.01
394		Tuesday	15 April	90.24	2438.00	1882.00				7.45	7.54	1.31	0.00	46.32			79.68	141.40	2.34	1.62	825.78	2473.74	49.06	36.79
395		Wednesday	16 April	79.30	2522.00	1904.00				7.48	7.54	1.38	0.00	58.50			83.10	144.90	2.10	1.62	813.51	2636.78	44.37	46.88
396		Thursday	17 April	90.50	2318.00	1712.00						1.49	0.00	83.84			85.96	149.10	2.52	2.38	920.71	2555.28	52.73	44.02
397		Friday	18 April																					
398		Saturday	19 April																					
399		Sunday	20 April																					
400		Monday	21 April	79.78	2382.00	1928.00				7.84	7.72	1.30	0.00	68.74			84.28	128.80	1.90	1.90	1289.81	2514.72	60.84	40.56
401		Tuesday	22 April																					
402		Wednesday	23 April	90.38	2445.00	1877.00				7.50	7.64	1.35	0.00	44.48			84.85	148.24	2.50	2.03	831.84	2608.38	55.14	44.12
403		Thursday	24 April																					
404		Friday	25 April																					
405		Saturday	26 April																					
406		Sunday	27 April																					
407		Monday	28 April	77.28	2078.00	1568.00				7.45	7.41	1.44	0.00	40.18			90.42	134.40	1.75	1.88	897.63	2291.84	64.50	48.87
408		Tuesday	29 April	98.70	2222.00	1740.00				7.35	7.46	1.38	0.00	42.00			60.48	135.10	2.03	1.98	614.46	2399.04	84.51	46.38
409		Wednesday	30 April	92.17	2116.00	1838.00				7.37	7.53	1.43	0.00	46.10			80.90	140.70	2.84	2.57	705.60	2238.58	36.45	40.37
410		Thursday	01 May	101.65	2158.00	1840.00				7.47	7.70	1.42	0.00	48.18			84.67	142.50	2.32	2.57	741.59	2334.58	50.46	38.30
411		Friday	02 May																					
412		Saturday	03 May	125.89	2290.00	1690.00				7.64	7.90	1.39	0.00	54.04			68.72	147.00	1.64	3.36	778.19	2334.58	60.48	60.48
413		Sunday	04 May	133.75	2210.00	1634.00						1.42	0.00	45.18			68.36	126.00	1.64	1.64	659.29	2318.40	62.90	38.30
414		Monday	05 May	115.56	2250.00	1640.00						1.43	0.00	41.86			68.74	124.90	2.31	2.24	646.72	2308.58	97.74	66.54
415		Tuesday	06 May	108.19	2181.43	1653.43				7.48	7.68	1.41	0.00	43.16	ERR		63.97	135.00	2.41	2.28	147.98	2337.42	64.57	59.06
416		Wednesday	07 May	118.05	2068.30	1510.00						0.99	0.00	70.00			88.46	105.70	1.42	0.70	641.09	2068.64	64.51	40.12
417		Thursday	08 May																					
418		Friday	09 May	115.77	1860.00	1570.00				7.50	7.37	1.28	0.00	40.28			154.86	119.70	10.15	8.54	772.58	1967.24	86.94	69.50
419		Saturday	10 May	148.80	1884.00	1382.00				7.88	7.49	1.15	0.00	80.08			105.00	118.20	10.68	7.70	760.37	1888.48	65.11	52.14
420		Sunday	11 May	106.67	1860.00	1384.00						1.40	0.00	94.50			108.50	129.50	4.78	3.23	751.73	1987.24	67.46	47.01
421		Monday	12 May	107.13	1874.00	1248.00						1.38	0.00	84.70			112.28	112.70	2.38	1.88	818.33	1718.86	55.85	81.22
422		Tuesday	13 May	234.07	1538.00	1258.00						0.99	0.00	87.78			123.08	128.50	2.31	2.24	748.10	1900.92	51.11	44.67
423		Wednesday	14 May	198.07	1884.00	1448.00						1.43	0.00	81.34			114.80	118.00	2.03	1.98	738.84	2084.44	53.14	40.88
424		Thursday	15 May	175.63	1842.37	1391.72				7.58	7.43	1.40	0.00	43.84	ERR		108.28	118.30	1.74	3.72	736.37	1540.50	67.32	31.03
425		Friday	16 May																					
426		Saturday	17 May	184.65	2058.00	1548.00						1.38	0.00	56.14			78.13	138.60	2.73	2.38	808.42	1967.24	53.14	40.88
427		Sunday	18 May	187.78	2174.00	1672.00						1.36	0.00	53.00			88.96	128.10	3.08	2.74	768.98	2100.37	55.19	42.92
428		Monday	19 May	203.39	2380.00	1752.00						1.37	0.00	48.70			72.94	133.60	1.17	0.58	836.64	2506.71	69.50	46.26

APPENDIX 2: Environmental System (Systm No. 1)

Day No.	1995	Nitrate (mg N/5L)				Nitrate (mg N/5L)				Phosphorus (mg P/5L)					
		Amesbury	Amesbury	Amesbury	Filtered Effluent	Amesbury	Amesbury	Amesbury	Filtered Effluent	Influent	Amesbury	Amesbury	Amesbury	Unfiltered Effluent	Filtered Effluent
1	Monday 14 March														
2	Tuesday 15 March														
3	Wednesday 20 March														
4	Thursday 21 March	0.06	0.08	0.51	0.58	0.00	0.14	13.88	10.82	30.7	24.8	11.5	5.2	40.0	
5	Friday 22 March	0.04	0.04	0.32	0.32	0.00	0.13	13.88	14.08	14.0	23.6	14.1	9.5	40.0	
6	Saturday 23 March	0.04	0.12	0.53	0.58	0.00	0.16	13.88	14.08	14.0	23.6	14.1	9.5	40.0	
7	Sunday 24 March	0.06	0.07	0.58	0.60	0.00	0.00	13.16	13.59	15.3	21.1	13.8	8.5	38.7	
8	Monday 25 March	0.07	0.07	0.68	0.62	0.00	0.00	13.37	13.45	14.4	37.7	12.5	7.9	42.2	
9	Tuesday 26 March	0.06	0.07	0.73	0.72	0.00	0.00	13.56	13.26	32.1	71.3	17.5	9.8	1.9	
10	Wednesday 27 March	0.10	0.08	0.58	0.81	0.00	0.00	10.81	17.1	15.1	19.7	14.8	12.5	7.2	
11	Thursday 28 March	0.07	0.07	0.58	0.70	0.00	0.00	8.43	8.68	48.2	70.7	17.5	9.5	30.4	
12	Friday 29 March	0.07	0.08	0.56	0.70	0.00	0.00	8.20	8.08	75.3	71.0	11.3	3.7	4.3	
13	Saturday 30 March	0.07	0.07	0.58	0.84	0.00	0.00	8.22	8.06	14.7	21.0	26.0	23.3	74.0	
14	Sunday 31 March	0.05	0.07	0.83	7.01	0.02	0.00	0.00	4.20	14.7	18.1	21.3	18.7	7.7	
15	Monday 01 April	0.08	0.07	0.56	0.63	0.00	0.00	8.10	8.10	15.0	18.0	16.3	10.7	2.3	
16	Tuesday 02 April	0.07	0.08	0.61	0.93	0.01	0.05	8.13	5.94	15.3	17.7	7.3	7.0	2.0	
55.1	Wednesday 03 April	0.07	0.08	0.60	0.79	0.00	0.03	9.25	10.27	21.31	24.87	14.38	10.01	20.60	
17	Thursday 04 April	0.03	0.04	0.57	0.57	0.00	0.03	11.36	9.14	14.7	18.7	9.7	1.7	1.3	
18	Friday 05 April	0.04	0.07	0.47	0.32	0.02	0.12	12.45	11.80	14.0	20.7	8.2	4.7	3.0	
19	Saturday 06 April	0.03	0.07	0.38	0.60	0.02	0.12	12.45	11.80	14.3	21.7	8.2	4.7	3.0	
20	Sunday 07 April	0.03	0.08	0.29	0.77	0.01	0.32	14.40	13.61	15.0	22.0	8.2	4.7	3.0	
21	Monday 08 April	0.03	0.08	0.34	0.77	0.07	0.88	1.02	13.32	14.3	22.0	11.3	20.3		
22	Tuesday 09 April	0.04	0.08	0.42	0.22	0.07	0.48	13.69	13.55	14.3	19.7	10.1	6.0	4.0	
23	Wednesday 10 April	0.04	0.07	0.34	0.24	0.15	0.19	12.06	13.79	15.7	19.3	10.7	8.0	8.3	
24	Thursday 11 April	0.06	0.04	0.29	0.72	0.07	0.04	12.86	13.36	15.3	21.0	11.0	4.7	3.7	
25	Friday 12 April	0.03	0.04	0.27	0.72	0.12	0.11	11.87	12.70	15.7	21.0	11.0	4.7	3.7	
55.3	Saturday 13 April	0.03	0.04	0.15	0.33	0.11	0.34	11.22	12.59	14.85	20.87	10.78	8.81	5.04	
26	Sunday 14 April	0.03	0.03	0.17	0.22	0.07	0.08	10.54	10.54	14.7	18.3	7.8	3.3	2.7	
27	Monday 15 April	0.01	0.10	0.22	0.91	0.07	0.24	9.69	12.43	13.4	17.8	8.2	3.3	4.5	
28	Tuesday 16 April	0.03	0.04	0.17	0.20	0.07	0.09	9.75	9.99	13.7	17.0	7.2	2.0	2.0	
29	Wednesday 17 April	0.01	0.05	0.28	0.79	0.06	0.10	9.61	10.33	14.4	19.3	8.5	3.6	2.9	
30	Thursday 18 April	0.04	0.04	0.15	0.20	0.09	0.11	9.48	10.33	15.4	20.8	8.5	3.6	3.1	
31	Friday 19 April	0.03	0.04	0.17	0.17	0.10	0.09	8.78	10.69	15.0	21.2	8.8	3.9	3.9	
32	Saturday 20 April	0.04	0.04	0.21	0.23	0.04	0.06	8.46	10.51	16.3	20.2	9.7	7.8	12.4	
33	Sunday 21 April	0.03	0.04	0.21	0.21	0.17	0.13	9.76	10.48	13.8	20.2	7.8	2.8	2.4	
34	Monday 22 April	0.03	0.04	0.21	0.21	0.08	0.11	10.05	10.26	14.0	18.1	8.8	2.8	2.4	
35	Tuesday 23 April	0.03	0.04	0.18	0.18	0.08	0.05	10.07	10.73	14.3	20.0	8.8	2.8	2.8	
36	Wednesday 24 April	0.03	0.08	0.18	0.10	0.11	0.37	10.02	11.05	14.1	20.3	9.7	3.4	3.1	
55.3	Thursday 25 April	0.03	0.05	0.22	0.37	0.09	0.14	8.83	10.32	14.33	19.36	8.68	1.04	4.71	
37	Friday 26 April	0.03	0.05	0.16	0.18	0.05	0.28	8.73	10.18	15.9	20.7	10.3	3.4	3.4	
38	Saturday 27 April	0.03	0.03	0.16	0.18	0.07	0.07	8.96	8.60	16.6	20.8	10.7	4.1	3.4	
39	Sunday 28 April	0.04	0.12	0.23	0.20	0.02	0.48	7.95	8.51	15.3	23.0	12.3	3.7	4.1	
40	Monday 29 April	0.04	0.02	0.20	0.20	0.02	0.08	5.52	8.57	14.5	20.9	10.1	2.7	2.4	
41	Tuesday 30 April	0.04	0.05	0.18	0.20	0.03	0.20	7.20	8.48	14.5	23.3	11.1	2.7	3.0	
42	Wednesday 01 May	0.04	0.08	0.18	0.23	0.03	0.15	8.40	7.47	14.2	22.0	10.8	3.0	2.4	
43	Thursday 02 May	0.04	0.05	0.18	0.23	0.10	0.03	8.11	7.65	15.5	24.3	10.0	3.4	2.4	
44	Friday 03 May	0.05	0.04	0.43	0.20	0.01	0.08	6.88	7.07	15.3	25.3	11.5	3.0	2.7	
45	Saturday 04 May	0.06	0.04	0.20	0.20	0.05	0.07	8.83	5.31	17.9	25.0	10.1	2.0	3.0	
46	Sunday 05 May	0.06	0.04	0.23	0.24	0.11	0.07	2.78	5.90	15.9	26.7	10.8	2.0	2.7	
47	Monday 06 May	0.08	0.08	0.26	0.26	0.15	0.23	3.40	5.58	14.9	27.9	11.0	3.7	2.0	
48	Tuesday 07 May	0.04	0.05	0.23	0.34	0.03	0.02	3.90	6.43	15.0	26.8	9.8	1.7	2.0	
49	Wednesday 08 May	0.04	0.05	0.23	0.24	0.03	0.07	5.68	6.43	14.3	14.8	4.5	0.7	7.0	
50	Thursday 09 May	0.05	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
51	Friday 10 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
52	Saturday 11 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
53	Sunday 12 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
54	Monday 13 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
55	Tuesday 14 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
56	Wednesday 15 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
57	Thursday 16 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
58	Friday 17 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
59	Saturday 18 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
60	Sunday 19 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
61	Monday 20 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
62	Tuesday 21 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
63	Wednesday 22 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
64	Thursday 23 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
65	Friday 24 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
66	Saturday 25 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
67	Sunday 26 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
68	Monday 27 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
69	Tuesday 28 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
70	Wednesday 29 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
71	Thursday 30 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
72	Friday 31 May	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
73	Saturday 01 June	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
74	Sunday 02 June	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
75	Monday 03 June	0.04	0.08	0.22	0.22	0.07	0.20	8.70	7.47	15.45	23.38	10.33	2.55	2.81	
76	Tuesday 04														

Day No	1990	Nitrite (mg/L NO2-N)				Nitrate (mg/L NO3-N)				Phosphorus (mg/L PO4-P)											
		Amoxic		Aerobic		Filtered Effluent		Aerobic		Filtered Effluent		Influent		Anaerobic		Aerobic		Unfiltered Effluent		Filtered Effluent	
		ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
243	Sunday	17	November																		
245	Monday	18	November																		
247	Tuesday	19	November																		
248	Wednesday	20	November																		
249	Thursday	21	November																		
250	Friday	22	November																		
251	Saturday	23	November																		
252	Sunday	24	November																		
253	Monday	25	November																		
254	Tuesday	26	November																		
255	Wednesday	27	November																		
256	Thursday	28	November																		
257	Friday	29	November																		
258	Saturday	30	November																		
259	Sunday	01	December																		
260	Monday	02	December																		
261	Tuesday	03	December																		
262	Wednesday	04	December																		
263	Thursday	05	December																		
264	Friday	06	December																		
265	Saturday	07	December																		
266	Sunday	08	December																		
267	Monday	09	December	0.17	0.04	0.22	0.25	0.13	0.11	0.78	7.50	22.15	46.55	23.50	3.53	4.19	4.38	3.86	4.19	3.86	4.38
268	Tuesday	10	December	0.02	0.05	0.36	0.31	0.17	0.35	7.77	8.20	23.65	50.84	28.83	5.30	5.36	3.86	4.19	3.86	4.38	3.86
269	Wednesday	11	December	0.02	0.07	0.47	0.31	0.20	0.48	8.38	8.20	25.07	49.43	27.18	7.09	3.20	3.30	3.30	3.30	3.30	3.30
270	Thursday	12	December	0.04	0.08	0.77	0.53	0.20	0.37	8.55	8.31	24.12	50.84	28.83	7.09	6.06	6.06	6.06	6.06	6.06	6.06
271	Friday	13	December	0.01	0.09	0.73	0.23	0.15	0.74	1.19	9.24	23.55	48.35	28.45	1.10	5.81	5.81	5.81	5.81	5.81	5.81
272	Saturday	14	December	0.11	0.05	0.43	0.38	0.25	0.00	7.20	9.14	24.04	50.00	33.73	3.23	3.87	3.87	3.87	3.87	3.87	3.87
273	Sunday	15	December	0.09	0.08	0.50	0.47	0.18	0.23	7.80	6.73	24.48	45.60	29.40	5.46	3.11	4.27	4.27	4.27	4.27	4.27
274	Monday	16	December	0.11	0.13	1.19	0.94	0.09	0.00	6.60	9.41	25.18	45.18	33.87	10.00	9.03	9.03	9.03	9.03	9.03	9.03
275	Tuesday	17	December	0.04	0.06	1.34	1.34	0.03	0.00	8.14	9.48	24.16	43.55	33.25	5.61	6.45	6.45	6.45	6.45	6.45	6.45
276	Wednesday	18	December	0.51	0.07	1.06	1.11	0.09	0.00	6.32	9.71	28.13	48.77	34.18	5.48	5.48	5.48	5.48	5.48	5.48	5.48
277	Thursday	19	December	0.04	0.13	1.44	1.08	0.03	0.30	6.68	10.06	28.81	49.68	30.45	4.71	5.01	5.01	5.01	5.01	5.01	5.01
278	Friday	20	December	0.03	0.09	0.90	1.17	0.04	0.18	7.98	8.81	24.60	43.21	34.29	4.00	3.30	3.30	3.30	3.30	3.30	3.30
279	Saturday	21	December	0.07	0.08	0.80	1.01	0.03	0.30	9.27	6.50	23.08	47.97	27.78	4.81	4.00	4.00	4.00	4.00	4.00	4.00
280	Sunday	22	December	0.06	0.05	0.58	1.08	0.01	0.03	6.31	5.35	25.68	41.52	31.83	3.30	3.66	3.66	3.66	3.66	3.66	3.66
281	Monday	23	December	0.10	0.03	0.26	0.81	0.02	0.11	9.25	10.47	24.60	44.90	19.80	3.38	4.81	4.81	4.81	4.81	4.81	4.81
282	Tuesday	24	December	0.05	0.04	0.70	0.75	0.07	0.00	6.28	10.38	24.91	43.21	37.98	6.77	5.54	5.54	5.54	5.54	5.54	5.54
283	Wednesday	25	December	0.03	0.04	0.68	1.11	0.08	0.38	10.80	11.60	24.28	46.13	35.83	3.38	6.16	6.16	6.16	6.16	6.16	6.16
284	Thursday	26	December	0.15	0.08	0.82	1.23	0.48	0.08	8.54	10.43	24.01	48.62	23.70	5.17	6.38	6.38	6.38	6.38	6.38	6.38
285	Friday	27	December	0.09	0.07	0.84	1.40	0.25	0.04	8.11	9.57	24.01	48.50	23.10	10.33	8.21	8.21	8.21	8.21	8.21	8.21
286	Saturday	28	December	0.09	0.05	2.04	1.83	0.87	0.01	8.13	10.28	23.40	45.59	27.48	6.21	5.47	5.47	5.47	5.47	5.47	5.47
287	Sunday	29	December	0.09	0.07	1.01	1.13	0.14	0.14	8.94	9.80	24.57	45.91	23.62	6.40	5.71	5.71	5.71	5.71	5.71	5.71
288	Monday	30	December																		
289	Tuesday	31	December																		
290	Wednesday	01	January																		
291	Thursday	02	January	0.15	0.05	7.05	10.43	0.32	0.06	3.32	3.77	23.83	42.85	23.10	3.65	3.85	3.85	3.85	3.85	3.85	3.85
292	Friday	03	January																		
293	Saturday	04	January																		
294	Sunday	05	January																		
295	Monday	06	January																		
296	Tuesday	07	January																		
297	Wednesday	08	January																		
298	Thursday	09	January	0.11	0.08	3.22	5.17	0.25	0.08	8.21	8.88	23.40	43.21	21.66	3.63	4.55	4.55	4.55	4.55	4.55	4.55
299	Friday	10	January	0.07	0.08	3.47	4.27	0.18	0.11	9.83	10.63	23.40	43.50	22.19	6.58	4.58	4.58	4.58	4.58	4.58	4.58
300	Saturday	11	January	0.10	0.07	3.72	4.37	0.16	0.04	10.26	10.71	24.31	45.58	22.19	3.85	5.47	5.47	5.47	5.47	5.47	5.47
301	Sunday	12	January	0.09	0.08	2.91	4.07	0.13	0.37	10.46	11.13	23.40	45.68	22.70	3.63	4.47	4.47	4.47	4.47	4.47	4.47
302	Monday	13	January	0.01	0.00	2.91	3.37	0.18	0.08	10.85	11.29	24.01	45.28	21.66	4.25	5.47	5.47	5.47	5.47	5.47	5.47
303	Tuesday	14	January	0.06	0.10	3.62	3.37	0.12	0.01	11.24	11.34	21.89	45.59	20.97	4.25	5.77	5.77	5.77	5.77	5.77	5.77
304	Wednesday	15	January	0.08	0.11	3.04	3.37	0.08	0.00	11.04	11.07	23.73	48.90	21.19	2.43	3.08	3.08	3.08	3.08	3.08	3.08
305	Thursday	16	January	0.07	0.21	2.80	2.85	0.07	0.00	12.01	11.90	23.53	49.90	22.64	3.08	3.08	3.08	3.08	3.08	3.08	3.08
306	Friday	17	January	0.07	0.29	2.38	2.82	0.09	0.73	12.32	12.86	22.86	51.43	23.57	4.51	3.98	3.98	3.98	3.98	3.98	3.98
307	Saturday	18	January	0.10	0.07	3.04	2.65	0.20	0.00	10.80	12.84	22.65	49.90	22.90	4.80	3.70	3.70	3.70	3.70	3.70	3.70
308	Sunday	19	January	0.09	0.32	1.74	2.79	0.25	0.08	11.74	13.81	23.27	49.59	22.64	3.98	3.51	3.51	3.51	3.51	3.51	3.51
309	Monday	20	January																		
310	Tuesday	21	January	0.27	0.25	1.67	1.19	0.44	0.14	13.38	14.31	22.86	48.88	25.41	6.43	3.20	4.50	4.50	4.50	4.50	4.50
311	Wednesday	22	January																		
312	Thursday	23	January	0.09	0.18	1.54	1.43	0.13	0.34	13.77	14.38	22.25	49.14	22.23	5.01	10.96	1				

Day No	Date	Nitrate (mg/L NO ₃ -N)					Nitrate (mg/L NO ₃ -N)					Phosphorus (mg/L PO ₄ -P)				
		Anaerobic	Aerobic	Aerobic	Filtered Effluent	Filtered Effluent	Anaerobic	Aerobic	Filtered Effluent	Filtered Effluent	Influent	Anaerobic	Aerobic	Aerobic	Unfiltered Effluent	Filtered Effluent
371	Sunday 23 March	0.06	0.08	0.21	0.25	7.22	0.12	0.04	10.28	21.38	58.70	25.54	3.77	3.86	2.38	
372	Monday 24 March	0.05	0.03	0.27	0.25	0.13	0.13	8.12	10.18	21.04	57.60	25.83	3.71	3.66	2.97	
373	Tuesday 25 March															
374	Wednesday 26 March	0.04	0.04	0.27	0.33	0.22	0.12	8.80	10.34	21.84	53.15	25.54	8.53	3.68	3.77	
375	Thursday 27 March	0.07	0.08	0.28	0.33	0.33	0.12	9.07	10.31	20.49	52.85	24.84	3.58	3.68	3.77	
376	Friday 28 March	0.07	0.07	0.18	0.21	0.05	0.06	7.13	11.33	20.63	51.12	23.08	3.70	3.70	3.77	
377	Saturday 29 March	0.06	0.05	0.23	0.21	0.35	0.05	7.30	10.19	21.25	50.18	23.09	3.36	4.00	3.38	
378	Sunday 30 March	0.04	0.21	0.26	0.21	0.38	0.06	7.27	10.20	20.67	48.50	16.78	2.48	4.00	3.70	
379	Monday 31 March	0.04	0.05	0.15	0.21	0.24	0.07	7.63	9.75	21.35	48.21	22.44	3.21	4.02	4.00	
380	Tuesday 01 April	0.04	0.05	0.29	0.23	0.37	0.08	8.48	8.92	22.79	48.35	24.02	4.83	2.70	3.08	
381	Wednesday 02 April	0.08	0.08	0.22	0.25	0.48	0.18	8.05	10.04	21.18	52.11	24.20	4.00	4.00	3.77	
382	Thursday 03 April															
383	Friday 04 April															
384	Saturday 05 April															
385	Sunday 06 April															
386	Monday 07 April															
387	Tuesday 08 April															
388	Wednesday 09 April	0.07	0.11	0.98	1.20	0.37	0.15	13.98	17.03	21.58	43.18	21.27	2.54	3.18	2.54	
389	Thursday 10 April	0.05	0.08	0.09	1.10	0.01	0.07	71.82	10.12	22.23	45.94	27.73	7.98	3.18	2.80	
390	Friday 11 April	0.21	0.10	0.77	0.85	0.05	0.15	12.14	15.32	21.59	48.28	21.59	3.18	3.48	2.80	
391	Saturday 12 April	0.05	0.08	0.68	0.55	0.10	0.03	12.83	14.43	21.91	46.80	22.54	3.48	4.13	3.81	
392	Sunday 13 April	0.08	0.11	0.63	0.91	0.20	0.21	11.16	14.87	20.37	46.63	23.81	3.49	4.13	3.81	
393	Monday 14 April	0.08	0.07	0.55	1.10	0.11	0.03	11.34	14.77	20.37	46.63	23.81	3.49	4.13	3.81	
394	Tuesday 15 April	0.08	0.25	1.22	0.81	0.09	0.64	11.82	12.88	21.85	48.88	24.61	3.88	3.88	3.56	
395	Wednesday 16 April	0.09	0.25	1.13	1.18	0.26	0.18	9.33	15.01	20.07	49.22	22.34	2.21	3.56	3.24	
396	Thursday 17 April	0.12	0.21	1.51	1.23	0.11	0.64	12.34	12.43	22.90	50.83	24.91	3.89	3.89	3.56	
397	Friday 18 April															
398	Saturday 19 April															
399	Sunday 20 April															
400	Monday 21 April	0.19	1.28	2.56	5.14	0.40	0.81	10.48	13.18	24.28	44.03	21.68	4.53	4.86	4.86	
401	Tuesday 22 April															
402	Wednesday 23 April	0.10	0.28	1.14	1.44	0.18	0.26	11.83	14.36	21.84	47.20	22.07	3.37	3.78	3.40	
403	Thursday 24 April															
404	Friday 25 April															
405	Saturday 26 April															
406	Sunday 27 April															
407	Monday 28 April	0.07	0.05	0.48	0.84	0.42	0.05	8.48	8.27	22.45	42.98	19.24	2.57	8.09	5.45	
408	Tuesday 29 April	0.05	0.03	0.39	0.50	0.40	0.08	8.68	8.18	22.45	42.01	19.88	3.21	4.17	3.53	
409	Wednesday 30 April	0.04	0.03	0.37	0.37	0.12	0.01	8.33	9.15	22.77	41.94	20.85	3.71	3.21	2.89	
410	Thursday 01 May	0.05	0.04	0.48	0.45	0.17	0.03	9.31	9.92	23.72	44.90	21.61	3.85	2.85	3.53	
411	Friday 02 May															
412	Saturday 03 May	0.04	0.06	0.56	1.10	0.14	0.23	8.71	10.63	24.37	50.87	23.41	3.53	4.17	3.85	
413	Sunday 04 May	0.04	0.07	0.46	0.58	0.00	0.18	10.05	11.56	24.37	43.22	21.49	3.63	4.17	3.85	
414	Monday 05 May	0.06	0.13	0.85	0.38	0.48	0.34	8.78	11.34	24.37	50.87	23.41	4.58	4.70	4.07	
415	Tuesday 06 May	0.05	0.06	0.44	0.58	0.19	0.13	8.92	9.22	23.53	44.68	20.98	3.51	4.34	3.85	
416	Wednesday 07 May	0.08	0.69	3.03	3.18	0.18	0.00	15.15	14.64	20.81	48.22	22.54	5.03	5.03	4.38	
417	Thursday 08 May	0.09	4.82	7.33	8.04	0.37	0.00	13.43	17.63	22.23	43.84	24.42	8.77	7.33	7.20	
418	Friday 09 May	0.18	3.13	8.36	8.50	0.12	0.00	13.60	14.18	22.54	50.41	28.49	11.58	10.21	12.21	
419	Saturday 10 May	0.41	7.88	11.96	13.29	0.12	0.00	16.79	16.11	22.73	43.37	27.87	12.82	12.21	11.90	
420	Sunday 11 May	0.36	4.45	8.72	10.82	0.14	0.00	18.48	21.18	22.98	39.77	21.60	9.08	10.68	8.77	
421	Monday 12 May	0.29	4.87	8.46	10.48	0.31	0.00	22.32	20.45	26.18	43.50	26.18	8.53	10.04	9.43	
422	Tuesday 13 May	0.11	4.92	9.71	8.81	0.18	0.00	18.50	21.87	29.25	43.50	26.18	11.58	10.04	10.34	
423	Wednesday 14 May	0.22	4.32	8.03	8.83	0.29	0.00	17.09	19.38	28.87	44.63	25.15	9.58	10.34	11.88	
424	Thursday 15 May	0.14	0.23	0.75	3.96	0.57	0.00	12.17	10.50	24.54	45.93	22.21	4.54	8.21	7.91	
425	Friday 16 May	0.21	0.07	0.19	0.25	1.38	0.00	9.72	12.42	25.73	43.00	23.73	6.18	5.78	5.48	
426	Saturday 17 May	0.05	0.03	0.18	0.22	0.73	0.03	9.64	11.02	25.75	48.54	27.99	6.07	8.60	5.78	
427	Sunday 18 May	0.05	0.03	0.25	0.17	0.13	0.04	8.78	10.60	25.75	48.37	24.03	3.95	3.03	3.71	
428	Monday 19 May	0.18	0.02	0.21	0.13	0.73	0.12	8.37	11.07	28.40	43.38	23.77	4.83	8.53	4.04	
429	Tuesday 20 May	0.21	0.02	0.14	0.10	0.88	0.08	9.83	11.65	27.83	43.22	22.54	5.98	3.97	3.25	
430	Wednesday 21 May	0.03	0.07	0.31	0.10	0.25	0.05	8.91	11.19	33.64	42.81	27.17	4.01	3.78	3.09	
431	Thursday 22 May	0.07	0.02	0.46	0.78	0.18	0.07	9.30	11.63	24.04	44.77	23.77	5.87	6.18	5.58	
432	Friday 23 May	0.05	0.03	0.70	0.48	0.16	0.05	9.08	10.83	25.16	43.89	24.38	5.87	8.68	5.25	
433	Saturday 24 May															
434	Sunday 25 May	0.03	0.08	0.67	0.51	0.23	0.52	9.40	10.47	22.85	48.31	22.85	3.40	4.33	3.70	
435	Monday 26 May	0.09	0.07	0.38	0.33	0.30	0.09	7.12	8.90	22.30	43.47	24.21	4.48	4.48	4.13	
436	Tuesday 27 May	0.07	0.18	0.37	0.73	0.14	0.37	7.52	8.92	22.54	47.15	23.57	3.50	2.87	2.53	
437	Wednesday 28 May	0.02	0.07	0.77	0.48	0.11	0.20	8.31	8.18	22.57	48.74	24.21	4.48	4.14	3.50	
438	Thursday 29 May	0.03	0.08	1.08	0.70	0.12	0.32	7.98	8.98	23.69	48.42	25.17	5.73	4.78	4.48	
439	Friday 30 May															
440	Saturday 31 May															
441	Sunday 01 June															
442	Monday 02 June	0.04	0.10	0.33	0.33	0.15	0.07	10.08	10.33	23.88	55.43	27.08	4.46	4.40	3.02	
443	Tuesday 03 June	0.00	0.12	0.52	0.31	0.19	0.48	11.27	10.61	23.28	52.75	25.17	3.82	4.14	3.50	
444	Wednesday 04 June	0.13	0.51	0.40	0.53	1.44	0.72	11.63	12.70	25.09	53.11	23.80	3.78	3.78	3.44	
445	Thursday 05 June	0.02	0.58	0.65	0.75	0.11	1.64	13.89	14.58	25.09	53.77	22.56	5.53	4.07	3.78	
446	Friday 06 June	0.28	0.12	0.16	0.11	0.38	0.28	9.87	11.52	24.07	46.03	24.20	4.74	4.57	4.33	
447	Saturday 07 June	0.06	0.04	0.42	0.70	0.77	0.07	10.38	13.44	28.49	54.58	26.53				

City Term on Remedial System (Biosol) No. 1

Day No.	1998	Phosphorus (µg/l)					Nitrogen (µg/l)					COD (mg/l)					%	h.c.	
		Aerobic	Anoxic	Aerobic	Soluble	Removal	N gen	N in Wast	N in Eff	NO ₃ in Eff	MB	MOE	MOD	COD in W	COD in E				
1	Monday	18 March																	
2	Tuesday	19 March																	
3	Wednesday	20 March																	
4	Thursday	21 March	1.8		-24.9			900.7	378.4	28.0	348.0	148.7		2801.8	5499.4	902.4			
5	Friday	22 March		-4.2	-23.8	-2.0		864.3	341.6	117.8	304.5	125.9		2454.8	5335.2	779.9			
6	Saturday	23 March		-33.8	-18.4	-2.0		885.5	364.0		817.2	310.7	143.0		2475.4	5417.3	987.7		
7	Sunday	24 March	78.7	-8.4	-21.0	60.3	22.4	898.1	318.8	84.4	788.4	332.6		2300.5	5340.4	937.7			
8	Monday	25 March	18.5	-37.1	-16.4	0.7	-4.2	838.4	328.0	55.4	781.0	352.0		2387.7	5741.1	814.4			
9	Tuesday	26 March	-3.0	-7.9	-10.5	-3.4	-15.3	847.0	315.0		799.7	330.0	1568.3		2422.4	5845.1	851.5	70.0	
10	Wednesday	27 March	9.5	3.0	-10.5	27.5	29.5	1174.7	406.4	37.1	370.3	197.6	4252.7	3354.4	6730.9	732.0			
11	Thursday	28 March	-17.4	-36.4	-11.8	-71.5	5.9	422.1	386.4	29.4	147.3	84.0	5175.8	1207.1	8383.3	773.7	92.7		
12	Friday	29 March	12.7	0.3	-22.7	1.3	-9.0	400.7	364.0	30.4	335.7	93.8	6578.2	1145.8	6474.5	855.1	108.2		
13	Saturday	30 March	1.3	17.3	-10.7	0.7	7.3	50.3	178.0		317.2			143.9	6718.8	1303.0			
14	Sunday	31 March	2.7	23.0	-10.7	-22.0	-7.0	153.6	432.6	207.7	124.1	80.5	11815.7	439.2	7248.2	1221.6	138.8		
15	Monday	01 April	8.7	20.0	22.7	-18.7	-12.7	154.5	408.8	117.6	355.2	68.7	9438.7	441.8	6454.6	973.4	120.0		
16	Tuesday	02 April	12.7	-4.9	-21.3	48.7	33.3	403.1	397.0	107.8	137.4	91.6	8019.5	1152.8	8651.8	897.3	102.9		
55.1			14.00	-13.12	-17.45	13.57	4.15	604.17	408.75	163.50	238.07	171.10	6115.22	135.72	6157.88	848.33	101.54		
17	Wednesday	03 April	-4.4	-7.5	-7.7	-7.4	-8.3	412.4	412.4	112.4	412.4	112.4	6698.0	6698.0	6698.0	6698.0	6698.0	6698.0	6698.0
18	Thursday	04 April	14.0	1.3	-28.0	0.7	-13.2	623.3	368.2	36.4	188.2	77.4	5274.6	1865.5	6370.7	770.8	108.9		
19	Friday	05 April	18.0	-7.0	-18.7	-2.7	-10.2	737.9	476.0	49.0	243.8	92.1	4634.6	2110.1	6611.3	831.8	102.4		
20	Saturday	06 April	18.7	-15.7	-13.3	-2.7	-12.0	899.0	408.0	64.0	354.0	55.8	4781.0	1999.0	6506.6	1140.2	108.0		
21	Sunday	07 April	18.3	-10.3	-13.3	-3.3	-8.7	820.4	364.0	61.2	377.5	94.3	4107.4	2348.4	6357.3	814.4	108.1		
22	Monday	08 April	18.3	-33.3	-36.6	-30.0	-9.0	780.7	368.2	64.4	270.7	59.0	6670.4	736.7	8730.2	936.8	108.0		
23	Tuesday	09 April	12.7	-5.7	-17.3	0.0	-8.3	792.7	392.0	81.2	375.1	95.4	4216.3	2261.5	6148.7	733.7	90.5		
24	Wednesday	10 April	14.3	-3.7	-18.7	0.7	-2.3	749.1	309.6	34.6	270.7	85.1	4438.1	3447.5	6108.0	773.7	98.4		
25	Thursday	11 April	15.3	-2.0	-25.3	1.3	-10.7	748.0	403.2	67.2	371.9	87.2	4778.4	2533.7	6596.4	695.8	94.1		
26	Friday	12 April	15.3	-1.7	-25.3	0.7	-11.0	722.6	474.2	73.8	258.3	81.4	4437.7	2068.7	6112.5	568.7	86.0		
55.2			16.82	-6.67	-13.78	-4.07	-10.20	692.49	399.16	85.84	256.90	34.09	4781.33	1890.50	6369.85	831.41	100.29		
27	Saturday	13 April	74.7	-7.3	-14.3	2.0	-3.5	549.9	487.6	79.8	224.1	90.0	5583.0	1972.7	6760.2	850.1	122.4		
28	Sunday	14 April																	
29	Monday	15 April	13.1	-5.9	-19.8	7.2	-8.2	835.8	387.8	93.8	268.8	103.0							
30	Tuesday	16 April	13.1	-3.8	-20.8	0.0	-11.8	570.1	408.8	44.8	203.9	87.5	5016.6	1630.5	8314.9	888.2	103.4		
31	Wednesday	17 April	15.7	-5.9	-19.6	7.0	-11.8	603.3	487.6	87.2	210.6	98.1	4749.8	1734.8	8862.2	888.2	105.1		
32	Thursday	18 April	17.0	-7.5	-20.8	0.0	-12.7	545.3	447.4	48.0	210.6	88.6	5385.7	1614.8	8044.5	872.2	107.2		
33	Friday	19 April	17.6	-3.3	-37.4	1.3	-11.8	545.5	470.0	44.8	217.3	65.4	4786.4	1817.3	6783.0	517.7	100.8		
34	Saturday	20 April		-8.3	-27.6	0.7	-11.8	569.9	483.4	57.4	214.9	82.5		627.1	8548.5	581.6			
35	Sunday	21 April	18.0	-9.0	-20.7	-0.7	-11.4	383.5	439.0	50.4	212.8	81.2	5310.4	1668.9	6493.5	702.1	87.9		
36	Monday	22 April	14.5	-1.7	-24.6	-0.7	-12.6	858.4	414.4	30.4	209.5	82.8	6013.5	1740.1	9007.4	615.6	88.0		
37	Tuesday	23 April	16.9	-2.7	-23.4	0.0	-11.7	672.5	414.4	30.8	215.2	87.3	6186.0	1783.2	6073.9	574.8	108.0		
38	Wednesday	24 April	16.9	-2.4	-24.6	1.4	-11.1	672.5	414.4	30.8	215.2	87.3	6186.0	1783.2	6073.9	574.8	108.0		
55.3			15.84	-5.87	-22.58	0.42	-11.13	680.02	432.00	84.78	219.49	91.07	5416.67	1871.41	6572.30	657.30	102.1		
39	Thursday	25 April	15.3	0.0	-27.6	-1.4	-11.4	538.9	359.8	35.2	207.3	67.4	575.9	1541.3	5704.0	734.7	86.1		
40	Friday	26 April	20.3	-5.5	-28.2	-1.1	-13.4	534.4	404.8	77.0	175.6	90.1	5608.6	1578.5	5901.8	738.7	90.9		
41	Saturday	27 April	17.0	4.4	-36.1	2.0	-10.8	453.7	352.4	47.8	174.3	77.6	6811.7	1797.7	5634.8	985.0	87.8		
42	Sunday	28 April	17.2	-4.0	-39.2	2.0	-10.5	398.0	331.8	47.8	175.4	82.4	6689.7	1388.2	5613.8	482.9	87.3		
43	Monday	29 April	20.4	-9.7	-33.8	0.7	-12.8	448.7	378.0	18.0	174.3	78.7	6222.2	1343.3	5873.0	764.8	83.8		
44	Tuesday	30 April	18.9	-1.9	-35.1	0.0	-12.5	399.4	385.4	67.2	150.0	83.7	7106.6	1142.4	3968.8	924.5	99.7		
45	Wednesday	01 May	22.3	-1.7	-33.8	-0.7	-11.8	466.6	470.0	58.0	181.5	85.8	7081.9	1403.8	6138.7	845.3	98.0		
46	Thursday	02 May		0.6	-37.8	0.7	-10.2	438.4	379.4	78.4	165.5	80.2	7202.5	1254.7	6185.4	1014.0	98.4		
47	Friday	03 May	22.0	-4.4	-37.4	1.4	-15.5	357.6	380.8	32.8	163.7	86.8	6511.9	617.1	6651.6	1218.4	111.4		
48	Saturday	04 May	25.9	-6.0	-34.5	1.3	-13.3	284.1	368.2	60.2	122.8	67.5	6498.6	617.5	6651.6	1218.0	109.7		
49	Sunday	05 May	29.2	-7.0	-31.9	-1.3	-13.0	240.0	470.0	61.2	116.9	73.0	6728.7	686.4	6327.4	892.2	122.0		
50	Monday	06 May	27.9	-18.3	-21.8	0.7	-13.0	283.9	379.4	63.0	134.5	71.8	7862.6	840.7	5758.5	882.3	107.2		
51	Tuesday	07 May	19.1	-11.6	-14.8	1.3	-12.8	232.1	371.9	84.1	138.1	68.1	8992.5	863.8	5303.6	892.0	119.3		
55.4			20.78	-3.98	-31.11	0.10	-12.90	380.83	377.78	62.57	153.85	78.83	734.27	1177.77	8013.37	878.02	100.57		
52	Wednesday	08 May	22.5	-12.6	-28.2	-1.4	-12.5	410.5	424.4	64.0	170.6	81.2							
53	Thursday	09 May	20.8	-5.8	-28.2	-2.5	-11.8	465.5	404.8	58.0	175.6	85.8	6883.2	2003.5	6883.2	888.2	87.0		
54	Friday	10 May	27.6	-1.8	-30.8	-0.2	-10.8	413.0	453.3	77.0	208.0	62.5	5387.8	1847.5	6475.3	854.3	93.6		
55	Saturday	11 May	27.9	-10.0	-28.2	-0.2	-11.4	484.6	456.6	63.0	178.9	83.2	5445.6	1426.8	6496.9	782.8	93.6		
56	Sunday	12 May	28.2	-11.2	-30.8	-0.3	-16.8	448.2	448.2	75.2	172.2	81.2	6461.3	1296.2	6444.3	843.0	93.4		
57	Monday	13 May	28.3	-10.3	-32.0	1.3	-11.7	481.1	438.8	72.0	168.8	85.7	5934.4	1376.0	7018.9	1054.6	92.0		
58	Tuesday	14 May	28.0	-7.0	-34.7	0.0	-12.7	482.3	436.8	63.0	180.1	81.5	6171.2	1322.3	7018.9	817.2	95.2		
59	Wednesday	15 May	28.0	-5.1	-34.7	0.0	-12.0	486.7	436.0	63.0	174.4	80.3	5402.4	1392.1	6938.3	731.0	87.0		
60	Thursday	16 May	33.0	-4.7	-38.0	0.7	-13.2	481.1	431.2	61.0	151.9	74.1	5964.3	1143.1	6014.1	736.1	88.1		
61	Friday	17 May	33.0	-4.7	-37.3	0.7													

Day No.	1995	Phosphorus MB					Nitrogen MB					COD MB													
		Armed	Armed	Armed	Soluble	Removal	N plant	N in WWS	N in Eff	N in Eff	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB		
118	Saturday	13 July	40.0	1.7	12.0	0.7	19.0	981.4	404.6	81.0	748.7	83.1	5803.9	1891.7	7249.9	747.1	104.9								
119	Sunday	14 July	33.7	-6.7	-46.7	0.0	-19.7	719.3	364.0	78.4	379.8														
120	Monday	15 July	32.0	-4.0	-41.3	-0.7	-14.0	719.3	414.0	62.6	340.3	86.1	4026.5	2114.9	7210.9	563.0	90.1								
121	Tuesday	16 July	35.7	-11.3	-41.3	-1.3	-15.7	737.0	477.0	112.0	178.0	96.8	423.4	2153.1	7706.9	1474.0	117.0								
122	Wednesday	17 July	26.8	-3.6	-36.1	0.0	-15.1	719.3	386.7	75.0	320.3	91.7	4831.7	2047.8	7006.1	347.1	90.8								
123	Thursday	18 July	30.0	-7.6	-40.8	1.3	-18.0	738.2	434.0	67.2	310.7	94.8	4678.8	1111.2	7478.8	984.0	91.8								
124	Friday	19 July	18.0	-6.8	-36.1	0.0	-7.0	730.5	427.0	81.2	393.9	86.8	4048.0	7146.6	7271.7	863.4	91.5								
125	Saturday	20 July	35.1	6.9	-36.5	2.0	-14.8	729.5			364.0		4437.9	2169.9	7765.4	909.0	93.5								
126	Sunday	21 July	35.8	9.5	-40.6	2.0	-14.8	729.5			364.0		4437.9	2169.9	7765.4	909.0	93.5								
127	Monday	22 July	34.9	-13.3	-38.5	3.3	-14.5	467.8	396.2	91.0	373.2	101.8	4739.7	2885.8	7927.7	948.3	83.3								
128	Tuesday	23 July	35.2	12.6	-40.6	0.0	-18.4	699.7	477.0	84.0	367.0	96.8	4806.8	2051.1	6878.5	671.8	93.8								
129	Wednesday	24 July	38.5	-7.7	-37.7	3.3	-21.4	721.6	401.6	95.0	383.3	84.8	4641.1	2063.8	7823.4	1142.4	98.0								
130	Thursday	25 July	34.7	-11.7	-38.1	0.0	-18.1	693.1	421.6	84.6	383.3	84.8	4878.0	1862.1	7098.2	832.8	82.0								
131	Friday	26 July	70.0	-3.5	-43.3	3.5	-13.3	663.9	392.8	84.1	387.3	104.1	4891.3	1884.7	6487.7	936.4	108.0								
53.11	Saturday	27 July	33.17	9.44	-41.36	0.75	-18.97	720.70	412.18	79.16	304.11	84.14	4709.47	2081.31	7112.41	936.77	92.51								
132	Sunday	28 July	34.9	-11.5	-38.1	2.8	-11.9	664.5	424.4	84.4	358.7	107.0	4917.7	1800.4	6613.8	775.2	105.7								
133	Monday	29 July	34.9	-8.6	-40.5	1.4	-18.8	737.3	420.0	72.6	331.1	109.8	4735.9	2151.8	6588.8	818.0	113.3								
134	Tuesday	30 July	27.8	7.4	-40.5	0.0	-18.1	606.8	408.8	61.6	383.3	110.1	3650.4	2107.7	6448.4	1070.0	101.8								
135	Wednesday	31 July	27.8	-5.1	-37.9	1.4	-17.2	1029.3	310.6	61.6	102.1	114.8	2463.0	2941.9	6131.1	702.1	81.7								
136	Thursday	01 August	27.8	-8.6	-37.9	0.7	-18.3	325.2	396.0	89.0	174.1	120.7	2646.0	2041.0	5817.6	1408.2	82.1								
137	Friday	02 August	32.3	-10.8	-38.2	0.7	-18.9	708.3	380.6	74.2	348.9	101.4	4606.7	2784.7	6783.0	909.9	84.1								
138	Saturday	03 August	25.3	-7.7	-39.2	1.4	-14.6	197.9	378.0	67.2	444.5	102.7	4119.9	2282.0	6410.8	1075.4	82.1								
139	Sunday	04 August	26.0	-3.4	-35.7	0.7	-13.9	798.8	355.6	81.8	339.7	108.8	3878.9	2258.6	6245.4	703.1	90.9								
140	Monday	05 August	27.1	4.8	-38.5	-0.7	-18.2	841.7	360.8	79.8	349.3	103.1	4193.2	2483.6	6162.8	827.2	86.0								
141	Tuesday	06 August	24.7	-0.3	-39.2	-0.7	-15.9	719.0	389.6	71.4	348.2	108.0	4468.5	2051.1	5910.1	100.6	84.4								
53.12	Wednesday	07 August	29.75	7.06	-36.52	0.34	-15.88	817.47	379.15	70.42	354.23	107.94	3992.14	2337.96	6407.96	912.67	82.33								
142	Thursday	08 August	42.5	-26.8	-18.8	-2.8	-15.7	778.9	392.0	88.8	310.8	108.3	4152.3	2084.8	6717.7	931.0	91.2								
143	Friday	09 August	34.3	-4.9	-47.0	1.3	-16.5	584.3	388.2	67.2	354.9	88.0	3682.0	1977.0	6426.3	788.1	102.8								
144	Saturday	10 August	33.3	-3.8	-47.0	1.3	-16.0	671.3	378.0	67.2	242.7	89.3	3209.9	1970.1	6274.4	931.0	101.3								
145	Sunday	11 August	32.0	-4.6	-43.7	1.3	-17.0	707.2	383.4	72.9	257.3	91.0	3106.5	2002.8	6353.4	768.1	92.7								
146	Monday	12 August	35.3	-1.3	-47.0	-1.3	-18.5	678.3	358.6	84.4	254.8	96.1	4594.7	1985.4	6147.1	82.7	82.7								
147	Tuesday	13 August	29.1	2.0	-46.0	0.7	-16.7	694.3	380.7	57.4	254.8	96.1	4594.7	1985.4	6147.1	82.7	82.7								
148	Wednesday	14 August	41.2	-20.4	-37.5	2.7	-19.4	653.4	388.2	87.2	170.4	85.5	3155.2	1884.6	6616.5	947.1	123.9								
149	Thursday	15 August	36.1	-1.7	-50.8	-1.3	-17.7	674.9	404.8	60.2	260.5	85.8	3370.4	1830.7	6296.4	1074.0	84.4								
150	Friday	16 August	34.8	-4.3	-48.2	-0.7	-18.4	709.6	387.8	38.8	265.5	88.2	3473.9	2004.0	6717.4	901.1	95.5								
151	Saturday	17 August	29.1	3.7	-42.6	-0.7	-18.7	733.7	345.8	67.2	280.3	94.0	3000.3	2164.2	4307.8	860.2	84.1								
152	Sunday	18 August	31.1	7.4	-49.3	-0.7	-17.7	844.1	384.6	38.8	287.9	93.4	3268.2	1842.3	4307.3	880.2	89.8								
153	Monday	19 August	26.4	8.3	-37.9	0.7	-18.7	666.4	384.4	58.8	297.0	80.2	4484.2	1842.3	5784.8	768.1	88.4								
53.13	Tuesday	20 August	33.84	4.19	-45.23	-1.40	-17.84	677.79	379.28	61.83	268.38	82.61	3714.40	1836.47	5238.74	903.83	93.11								
154	Wednesday	21 August	29.0	-1.4	-48.1	2.0	-21.3	680.0	400.1	64.4	248.3	82.8	3791.7	1941.1	5354.6	808.6	83.9								
155	Thursday	22 August	34.1	-4.9	-44.7	-1.4	-17.5	751.5	345.0	51.8	377.1	92.1	4701.7	2144.4	6274.4	609.6	91.1								
156	Friday	23 August	27.3	-7.1	-40.3	-0.7	-18.9	780.4	338.8	43.4	366.8	90.7	4340.3	2174.8	6112.3	778.8	83.4								
157	Saturday	24 August	26.8	-1.6	-47.3	0.7	-17.1	746.8	352.8	84.4	357.6	84.4	4798.2	2155.4	6355.4	680.2	85.5								
158	Sunday	25 August	30.8	-3.5	-41.9	0.0	-14.7	674.9	372.2	86.6	330.9	89.3	4776.8	1979.7	6353.4	807.2	91.3								
159	Monday	26 August	34.3	-5.3	-48.9	0.0	-13.0	666.7	377.4	64.4	381.0	74.1	3416.3	2307.1	6387.9	851.8	80.8								
160	Tuesday	27 August	33.8	-2.4	-53.1	7.1	-19.6	674.0	358.4	54.8	311.3	64.9	652.4	1927.5	6453.8	973.4	88.1								
161	Wednesday	28 August	34.0	0.0	-51.7	-0.5	-22.0	675.8	381.2	85.8	313.3	68.9	6289.4	1850.9	6266.0	692.3	92.5								
162	Thursday	29 August	33.8	-4.0	-51.1	2.8	-18.8	674.5	386.0	70.0	283.0	77.9	5553.7	1979.8	6489.6	849.5	84.9								
163	Friday	30 August	38.0	-2.1	-51.7	-0.7	-18.5	890.9	350.0	58.0	311.5	83.8	5734.2	1889.4	6124.8	488.7	88.4								
53.14	Saturday	31 August	32.83	-2.99	-48.05	-0.25	-18.75	704.79	367.60	59.67	316.86	81.07	5260.30	2015.71	6343.63	731.55	87.78								
164	Sunday	01 September	37.8	1.7	-58.7	1.4	-17.8	459.3	371.0	64.4	188.9	86.3	3207.5	1315.8	5658.8	778.2	90.7								
165	Monday	02 September	34.1	1.6	-43.6	0.7	-17.7	430.3	369.8	88.2	181.1	86.3	3207.5	1315.8	5658.8	778.2	90.7								
166	Tuesday	03 September	33.1	3.3	-59.8	0.7	-17																		

City No	1998	Phosphorus MB						Nitrogen MB						COD MB						%	M.B.
		Atmospheric mg/L	Ambic mg/L	Aerobic mg/L	Serbar mg/L	Removal mg/L	N Name	N in Water mg/L	N in Eff mg/L	NO3 in Eff mg/L	MB mg/L	MOC mg/L	MOC mg/L	COO in W mg/L	COO in E mg/L	%	M.B.				
371	Sunday	23 March	58.11	0.29	-0.96	-1.78	-3.19	811.23	371.00	40.50	710.87	98.12	7695.27	1756.88	6513.80	1750.90	104.37	0.28			
372	Monday	24 March	68.79	3.36	-90.78	-0.58	-18.00	317.48	389.80	85.60	708.24	93.48	8148.97	1863.03	6189.64	1710.24	107.41	0.28			
373	Tuesday	25 March																			
374	Wednesday	26 March	59.09	1.45	-74.01	-0.53	-19.00	568.43	334.60	54.60	317.74	68.58	7744.84	1675.70	5818.36	1267.37	108.72	0.26			
375	Thursday	27 March	60.37	0.53	-44.53	-0.59	-17.07	307.71	370.70	44.20	712.96	91.00	7107.80	1885.40	5374.84	895.84	111.44	0.29			
376	Friday	28 March	58.31	2.18	-77.60	-0.89	-17.55	341.98	340.20	46.70	730.58	94.17	7012.70	1550.06	5618.36	1271.60	101.89	0.24			
377	Saturday	29 March	58.64	1.31	-74.83	-0.90	-16.48	338.73	361.20	37.40	711.83	68.99	7140.72	1540.78	5619.36	773.88	88.34	0.25			
378	Sunday	30 March	55.58	0.21	-45.78	-0.46	-17.74	485.83	310.80	32.90	708.06	80.59	7168.07	1386.31	5375.04	1350.12	95.19	0.27			
379	Monday	31 March	54.81	0.83	-72.47	-0.67	-17.60	509.84	377.20	37.80	748.10	61.39	8064.82	1457.18	5768.16	1190.18	83.98	0.22			
380	Tuesday	01 April	49.89	0.85	-78.37	-3.70	-20.32	457.73	340.20	51.80	753.12	73.48	7357.85	1509.04	5764.58	881.84	84.22	0.18			
55.74			58.07	4.70	-60.78	-1.57	-18.79	556.64	344.85	85.42	700.25	88.20	7167.91	7534.78	5668.87	1357.84	97.50	0.20			
381	Wednesday	02 April																			
382	Thursday	03 April																			
383	Friday	04 April																			
384	Saturday	05 April																			
385	Sunday	06 April																			
386	Monday	07 April																			
387	Tuesday	08 April																			
388	Wednesday	09 April	43.30	11.73	-74.93	0.00	-19.89	951.89	323.40	58.80	385.73	91.84	4329.70	2722.39	5294.48	1149.12	70.87	0.24			
389	Thursday	10 April	45.77	17.07	-77.47	0.00	-19.89	838.17	311.80	61.60	344.24	93.70	8896.64	2400.07	5450.72	1180.16	72.72	0.19			
390	Friday	11 April	53.34	1.59	-73.68	-0.64	-19.37	879.38	318.40	58.60	327.57	91.04	7120.30	2373.07	5273.52	1348.04	90.78	0.20			
391	Saturday	12 April	53.34	3.81	-76.20	-0.86	-16.42	841.60	397.80	36.40	306.03	68.80	7078.05	2407.54	5273.52	1103.78	84.31	0.21			
392	Sunday	13 April	54.25	9.26	-81.28	-0.83	-17.74	848.31	381.70	40.80	315.58	90.99	6834.28	2771.56	5272.64	1144.64	84.60	0.21			
393	Monday	14 April	47.92	4.39	-78.11	-0.60	-19.10	830.87	368.30	43.80	312.86	81.14	7607.41	1660.35	5273.52	940.24	92.86	0.15			
394	Tuesday	15 April	47.00	17.48	-83.89	-0.65	-14.48	770.87	382.00	36.80	270.03	83.87	7310.91	2058.13	4848.48	951.12	92.83	0.15			
395	Wednesday	16 April	56.02	3.89	-77.71	-0.65	-17.18	748.05	289.80	42.00	323.51	84.12	6509.71	2133.03	5273.52	839.36	91.06	0.24			
396	Thursday	17 April	54.07	8.71	-82.89	-0.55	-19.75	751.00	298.20	50.40	273.51	79.90	7848.42	2148.38	5150.58	1054.58	88.88	0.22			
397	Friday	18 April																			
398	Saturday	19 April																			
399	Sunday	20 April																			
400	Monday	21 April																			
401	Tuesday	22 April	42.09	8.48	-68.64	0.60	-18.43														
55.75			49.89	8.44	-77.71	0.00	-18.82	797.30	363.02	51.10	310.50	87.19	8023.93	2820.14	5237.39	1090.22	87.22	0.22			
402	Wednesday	23 April																			
403	Thursday	24 April																			
404	Friday	25 April																			
405	Saturday	26 April																			
406	Sunday	27 April																			
407	Monday	28 April	44.20	-0.96	-68.71	5.77	-17.84	463.78	268.80	35.00	178.11	83.81	5181.74	1228.42	4363.28	1297.92	88.65	0.26			
408	Tuesday	29 April	41.89	4.81	-68.71	0.64	-19.58	480.21	270.20	40.80	173.15	78.06	5104.36	1318.48	4788.88	1260.24	78.79	0.25			
409	Wednesday	30 April	44.70	8.74	-70.50	-0.64	-20.71	549.03	261.40	58.80	190.57	84.83	5209.87	1570.22	4877.12	1128.80	84.10	0.21			
410	Thursday	01 May	44.78	7.10	-71.84	0.64	-20.53	598.60	281.60	50.40	705.41	88.05	5234.30	1712.17	4877.12	1004.00	80.13	0.25			
411	Friday	02 May																			
412	Saturday	03 May	53.56	4.49	-78.54	0.64	-20.83	825.71	294.00	72.80	335.18	88.05	6788.08	1784.53	4677.12	1208.60	92.84	0.28			
413	Sunday	04 May	44.58	5.13	-70.50	0.80	-20.83	844.75	292.80	33.60	242.84	84.38	5838.84	1840.99	4630.80	1043.30	90.33	0.23			
414	Monday	05 May	37.19	9.06	-67.42	0.83	-20.86	648.97	301.80	53.90	298.86	81.14	7607.41	1660.35	5273.52	940.24	92.86	0.15			
55.76			43.68	3.78	-69.79	0.17	-20.00	535.53	271.60	48.20	242.08	78.64	5983.53	1582.83	4877.12	1854.22	82.80	0.25			
415	Tuesday	06 May	33.22	1.25	-69.14	-1.25	-18.91	798.51	211.40	39.40	334.11	77.02	5479.82	2648.83	4153.26	1260.24	108.16	0.21			
416	Wednesday	07 May																			
417	Thursday	08 May	41.02	9.68	-62.82	-1.13	-18.66	950.83	236.40	70.00	489.22	89.75	6804.03	2718.48	3974.48	1784.72	85.52	0.31			
418	Friday	09 May	49.79	8.20	-67.83	1.25	-10.33	894.00	222.40	70.80	478.71	90.85	3445.84	2843.07	5760.96	1308.16	74.80	0.26			
419	Saturday	10 May	38.95	13.34	-61.37	-1.25	-10.33	1165.56	298.00	26.70	604.08	36.84	2854.58	3300.77	3974.48	1165.52	77.59	0.30			
420	Sunday	11 May	35.07	1.22	-60.19	0.00	-14.40	1397.36	226.40	47.60	648.12	94.70	3797.36	3714.50	3433.92	1748.58	85.34	0.27			
421	Monday	12 May	54.88	18.21	-70.57	1.03	-17.34	1463.48	338.00	48.70	818.20	98.98	5171.97	1483.55	3801.64	1082.00	60.13	0.30			
422	Tuesday	13 May	38.33	5.17	-64.76	-1.13	-15.83	1778.84	338.00	40.80	638.62	99.86	1973.41	3735.47	4128.68	1892.88	78.43	0.35			
55.77			41.79	7.97	-67.46	-0.60	-14.02	1170.51	337.00	94.80	444.24	73.25	2827.11	3322.82	3641.27	1338.26	137.01	0.29			
423	Wednesday	14 May	42.77	1.63	-70.57	0.43	-17.34	1027.33	353.60	54.60	486.61	117.07	3020.41	7938.14	3924.48	1324.48	102.65	0.26			
424	Thursday	15 May	49.15	12.47	-69.30	-1.83	-16.58	828.58	258.20	61.80	255.58	22.75	4613.62	2088.57	4210.64	1103.78	76.01	0.28			
425	Friday	16 May	49.85	30.42	-93.48	1.03	-20.24	770.15	233.20	22.70	224.77	78.44	5642.25	1838.08	4115.04	1349.04	74.02	0.27			
426	Saturday	17 May	47.45	11.80	-60.31	-1.40	-20.42	395.42	268.00	22.40	317.00	75.40	5887.22	1702.91	4619.44	1789.92	81.74	0.28			
427	Sunday	18 May	38.99	14.20	-78.57	-2.19	-25.01	564.11	270.40	43.40	322.60	75.01	6003.60	1613.27	4946.48	1308.16	84.41	0.27			
428	Monday	19 May	41.00	9.78	-67.92	-0.67	-18.22	635.94	248.20	47.60	233.08	80.54	3438.42	1818.80	4511.20	1345.40	60.19	0.28			
429	Tuesday	20 May	25.61	38.90	-92.87	-1.45	-30.31	139.17	777.20	47.80	225.87	78.87	5829.64	1712.45	5100.00	1420.00	82.31	0.24			
55.78			41.79	7.97	-67.46	-0.60	-14.02	1170.51	337.00	94.80	444.24	73.25	2827.11	3322.82	3641.27	1338.26	137.01	0.29			
430	Wednesday	21 May	42.77	1.63	-70.57	0.43	-17.34	1027.33	353.60	54.60	486.61	117.07	3020.41	7938.14	3924.48	1324.48	102.65	0.26			
431	Thursday	22 May	49.15	12.47	-69.30	-1.83	-16.58	828.58	258.20	61.80	255.58	22.7									

Daily English Control System

Day No	Date	SSM			pH		COND/RES		TKN/SS		FSA		LYN		COD						
		mg/L	mg/L	mg/L	Amber	Amber	COND	RES	TKN	SS	Influent	FE	Influent	Reactor	UE	FE	Sys In	Reactor	UE	FE	
1	Monday 18 March																				
2	Tuesday 19 March																				
3	Wednesday 20 March																				
4	Thursday 21 March																				
5	Friday 22 March																				
6	Saturday 23 March																				
7	Sunday 24 March																				
8	Monday 25 March																				
9	Tuesday 26 March																				
10	Wednesday 27 March																				
11	Thursday 28 March																				
12	Friday 29 March																				
13	Saturday 30 March																				
14	Sunday 31 March																				
15	Monday 01 April																				
16	Tuesday 02 April																				
17	Wednesday 03 April																				
18	Thursday 04 April																				
19	Friday 05 April																				
20	Saturday 06 April																				
21	Sunday 07 April																				
22	Monday 08 April																				
23	Tuesday 09 April																				
24	Wednesday 10 April																				
25	Thursday 11 April																				
26	Friday 12 April																				
27	Saturday 13 April																				
28	Sunday 14 April																				
29	Monday 15 April																				
30	Tuesday 16 April																				
31	Wednesday 17 April																				
32	Thursday 18 April																				
33	Friday 19 April																				
34	Saturday 20 April																				
35	Sunday 21 April																				
36	Monday 22 April																				
37	Tuesday 23 April																				
38	Wednesday 24 April																				
39	Thursday 25 April																				
40	Friday 26 April																				
41	Saturday 27 April																				
42	Sunday 28 April																				
43	Monday 29 April																				
44	Tuesday 30 April																				
45	Wednesday 01 May																				
46	Thursday 02 May	180.7	1882	1848	7.43	7.48	5.51	0.09	45.1	2.5	60.3	151.2	8.3	2.5	857	249*	51	49			
47	Friday 03 May	197.8	1924	1890	7.36	7.47	5.47	0.08	42.8	7.8	60.5	159.8	11.0	11.0	657	277.8	71	73			
48	Saturday 04 May	142.7	1172	1806	7.50	7.85	4.82	0.04	42.7	0.1	51.9	144.8	12.9	9.1	868	308.3	93	77			
49	Sunday 05 May	161.5	2040	1746	7.43	7.59	5.51	0.04	43.4	1.3	53.8	145.4	12.9	7.2	558	283.6	63	77			
50	Monday 06 May	182.5	2092		7.42	7.41			40.9	0.1	62.0	156.1	13.0	3.4	548	235.5	72	68			
51	Tuesday 07 May	156.3	2048	1884	7.53	7.81	5.50	0.09	38.8	1.1	54.2	147.7	4.1	3.0	543	253.0	69	53			
52	Wednesday 08 May	168.30	2026.33	1775.20	7.43	7.54	5.52	0.10	42.28	3.71	58.30	150.85	6.87	5.28	628.23	2079.44	71.20	68.20			
53	Thursday 09 May	151.5	2264	1892	7.54	7.61	5.50	0.08	57.5	0.2	62.2	172.5	12.4	8.0	630	231.7	61	65			
54	Friday 10 May	151.0	2510	2142	7.42	7.44	5.50	0.08	50.0	0.2	58.8	200.9	8.0	7.0	558	253.6	58	67			
55	Saturday 11 May	160.8	2400	2056	7.55	7.51	5.50	0.10	45.9	0.4	54.0	207.9	8.0	8.0	594	250.9	58	68			
56	Sunday 12 May	177.5	2450	2003.87	7.42	7.53	5.55	0.10	50.10	2.45	60.95	193.05	2.0	2.0	554.44	3152.34	87.72	87.52			
57	Monday 13 May	178.2	2440	1994	7.21	7.42	5.74	0.10	48.7	0.4	62.0	184.1	5.1	6.0	736	348.4	91	79			
58	Tuesday 14 May	179.6	2450	2054	7.36	7.48	5.58	0.10	48.3	1.1	64.8	188.8	4.3	3.2	702	328.5	85	53			
59	Wednesday 15 May	176.6	2580	2124	7.41	7.54	5.51	0.09	44.4	0.8	63.0	193.9	3.9	2.3	581	370.4	71	55			
60	Thursday 16 May	187.1	2332	1866	7.44	7.60	5.57	0.08	41.0	0.1	60.1	178.5	4.1	2.5	677	308.2	59	61			
61	Friday 17 May	185.3	2374	1956	7.49	7.53	5.61	0.09	43.4	0.1	61.2	173.8	3.2	2.7	673	314.3	61	45			
62	Saturday 18 May	182.3	2488	2106	7.50	7.84	5.48	0.09	47.2	0.3	61.9	192.3	5.3	2.6	642	308.6	66	49			
63	Sunday 19 May	182.6	2410	2026	7.48	7.54	5.49	0.10	51.0	0.4	61.5	186.8	3.3	2.2	668	307.8	63	47			
64	Monday 20 May	187.2	2408	1996	7.51	7.60	5.58	0.10	45.2	1.5	58.9	183.7	1.9	2.8	630	318.0	57	47			
65	Tuesday 21 May	162.21	2423.00	2020.22	7.43	7.54	5.57	0.09	48.83	0.85	62.27	190.24	4.25	3.78	674.27	3168.35	68.01	52.80			
66	Wednesday 22 May	166.2	2114	1750	7.50	7.67	5.64	0.10	57.0	0.7	64.0	175.7	5.1	3.4	760	284.5	53	47			
67	Thursday 23 May	165.0	2378	2007	7.63	7.78	5.55	0.10	35.9	0.9	78.1	191.8	2.8	2.4	875	318.9	57	37			
68	Friday 24 May	177.8	2292	2004	7.48	7.73	5.47	0.09	38.1	1.0	78.3	184.2	3.1	3.3	775	294.9	53	45			
69	Saturday 25 May	183.1	2350	2046	7.46	7.47	5.62	0.09	36.2	0.4	77.8	191.1	4.2	3.3	980	331.6	61	59			
70	Sunday 26 May	183.1	2434	2046	7.60	7.63	5.43	0.09	54.3	1.0	71.1	182.0	3.6	3.8	823	297.9	51	47			
71	Monday 27 May	184.4	2381	2058	7.55	7.80	5.41	0.08	53.5	1.5	71.7	173.6	2.9	1.7	831	327.4	57	48			
72	Tuesday 28 May	185.2	2258	1992	7.51	7.84	5.42	0.09	53.2	1.6	70.0	161.7	1.4	2.8	651	277.4	57	48			
73	Wednesday 29 May	184.3	2188	2014	7.60	7.84	5.44	0.08	53.5	0.8	73.8	170.1	3.2	2.8	637	260.0	61	61			
74	Thursday 30 May	200.0	2350	1960	7.61	7.65	5.48	0.10	91.3	0.6	80.1	187.8	3.0	3.2	611	290.0	53	41			
75	Friday 31 May	185.2	2356	1984	7.40	7.51	5.31	0.09	51.4	0.4	71.1	170.1	2.9	2.6	578	258.0	57	32			
76	Saturday 01 June	183.5	2486	2092	7.54	7.47	5.55	0.08	50.8	0.8	69.4	174.3	4.8	3.4	672	281.3	43	43			
77	Sunday 02 June	180.30	2449.45	1987.80	7.53	7.82	5.47	0.09	54.98	0.92	75.00	178.56	3.51	1.98	862.50	2981.28	53.37	48.17			
78	Monday 03 June	184.4	2484	2118	7.43	7.83	5.45	0.09	38.8	0.5	61.8	184.6	3.9	2.5	754	3103	38	28			
79	Tuesday 04 June	183.1	2318	1930	7.44	7.57	5.45	0.08	40.3	1.1	58.0	178.5	3.5	3.3	610	278.7	37	34			
80	Wednesday 05 June	185.9	2408	2072	7.50	7.54	5.49	0.08	40.2	0.5	56.0	178.8	3.8	2.7	623	308.2	47	37			
81	Thursday 06 June	185.99	2430.00	2068.00	7.45	7.58	5.48	0.09	38.58	0.84	58.08	185.88	3.50	2.84	672.93	3018.92	38.75	35.17			
82	Friday 07 June	185.2	2542	2120	7.50	7.58	5.37	0.08	38.8	1.8	56.3	186.9	4.9	3.1	587	290.6	63	23			
83	Saturday 08 June	189.3	2430	2048	7.48	7.58	5.50	0.09	37.2	0.4	55.3	186.2	2.0	2.2	823	307.5	51	33			
84	Sunday 09 June	186.6	2540	1978	7.60	7.81	5.50	0.09	35.6	0.3	57.3	176.4	1.4	2.3	677	291.0	37	33			
85	Monday 10 June	179.4	2452	2078	7.52	7.75	5.40	0.08	37.4	0.1	57.7	188.0	3.2	3.3	644	294.0	53	45			
86	Tuesday 11 June	183.1	2406	1958	7.50	7.71	5.42	0.08	38.2	1.0	52.8	176.4	3.8	2.5	618	275.0	31	25			
87	Wednesday 12 June																				

Day No	1996	OSM			VSB	AS	COD/RES			TRN/VLS			FLX			TRN			COD		
		mg	mgd	mgd			Amberob	Arabic	mg	mgd	mgd	Inflow mgd	FE mgd	Inflow mgd	Reactor mgd	UE mgd	FE mgd	Syn m3	Reactor mgCOD	UE mgCOD	FE mgCOD
118	Saturday	13 July	159.3	2358	2006	4.17	6.07	1.44	0.04	56.1			23.1	161.7	3.3	2.0	608	1603	45	33	
119	Sunday	14 July	173.6	2662	2009	4.18	6.51	1.43	0.09	57.8			23.5	174.0	3.5	2.0	608	1607	45	33	
120	Monday	15 July	166.9	2354	1986	4.26	5.37	1.47	0.01	50.0			23.4	163.7	2.7	1.5	775	1916	39	30	
121	Tuesday	16 July	178.1	2354	2048	4.28	6.08	1.48	0.08	57.0			23.4	177.8	1.3	1.3	713	1990	40	31	
122	Wednesday	17 July	156.3	2398	2054	4.09	5.31	1.33	0.07	57.7			23.7	151.9	4.1	2.0	733	1974	47	34	
123	Thursday	18 July	151.1	2200	1976	4.06	6.07	1.34	0.04	55.6			24.1	147.0	4.5	3.2	672	1910	57	34	
124	Friday	19 July	154.3	2214	1983	4.06	6.05	1.31	0.09	53.2			24.5	171.5	3.8	2.8	674	1908	41	36	
125	Saturday	20 July	136.3	2298	1984	3.94	4.98	1.45	0.02	52.2			24.6	151.9	3.8	2.8	674	1845	41	36	
126	Sunday	21 July	157.8	2267	1985	4.01	5.59	1.53	0.04	58.4			24.6	151.9	3.5	2.7	644	1904	49	36	
127	Monday	22 July	152.6	1960	1714	3.97	5.34	1.38	0.08	51.1			24.2	144.2	4.7	3.6	597	1783	38	28	
128	Tuesday	23 July	154.7	2158	2110	3.93	4.88	1.31	0.07	53.8			23.9	155.4	3.8	2.3	652	1786	40	30	
129	Wednesday	24 July	134.6	2374	2042	3.61	4.48	1.45	0.08	55.7			23.0	163.1	4.0	4.0	641	1838	43	37	
130	Thursday	25 July	151.8	2374	2078	3.71	4.72	1.29	0.06	56.0			24.3	156.8	2.8	2.9	649	1872	42	39	
131	Friday	26 July	152.2	2220	1996	3.85	4.58	1.37	0.04	52.1			24.6	151.9	2.8	2.7	575	1951	41	34	
53.11			155.60	2307.14	1975.43	4.02	5.87	1.39	0.00	53.82			24.53	160.13	3.51	3.56	651.88	1950.41	42.13	31.24	
132	Saturday	27 July	164.8	2430	2096	3.84	4.45	1.39	0.09	50.5			24.0	178.5	3.1	3.1	620	1957	36	38	
133	Sunday	28 July	162.3	2347	1994	3.86	4.80	1.35	0.01	53.6			24.1	165.9	2.7	1.4	618	1830	37	31	
134	Monday	29 July	161.4	2270	1964	4.01	4.73	1.38	0.09	51.9			24.2	163.8	3.4	2.3	526	1910	35	35	
135	Tuesday	30 July	148.3	2022	1718	3.68	4.82	1.34	0.09	58.1			23.0	148.3	3.7	3.3	600	1965	25	31	
136	Wednesday	31 July	156.1	2434	2043	3.89	4.75	1.35	0.08	52.1			23.8	170.1	3.8	3.0	547	1950	33	31	
137	Thursday	01 August	146.3	2314	1946	3.90	4.91	1.37	0.01	53.2			23.2	181.0	3.5	3.4	608	1968	48	31	
138	Friday	02 August	154.8	2214	1970	3.88	4.75	1.38	0.08	49.8			23.0	160.1	3.4	2.8	575	1958	31	35	
139	Saturday	03 August	157.7	2156	1820	3.81	4.68	1.40	0.08	51.5			23.3	140.5	3.2	2.9	542	1844	33	35	
140	Sunday	04 August	152.4	2166	1838	3.71	4.79	1.37	0.10	57.1			23.3	168.3	3.2	3.1	600	1943	39	35	
141	Monday	05 August	142.2	2110	1810	3.74	4.82	1.31	0.09	55.4			23.4	156.1	3.4	2.4	607	1938	36	38	
53.17			155.74	2251.80	1910.60	3.86	4.69	1.36	0.09	53.26			23.02	164.08	3.28	2.79	573.43	1959.14	36.18	31.85	
142	Wednesday	07 August	142.0	2136	2190	3.88	4.80	1.31	0.04	51.9			21.7	162.0	3.4	2.8	579	1974	47	40	
143	Thursday	08 August	148.8	2058	2140	3.89	4.81	1.31	0.06	49.8			21.6	175.0	3.6	1.4	725	1995	40	36	
144	Friday	09 August	144.5	2124	2118	3.76	4.78	1.31	0.07	53.8			22.2	149.4	3.9	2.2	611	1973	55	45	
145	Saturday	10 August	154.7	2397	2036	3.70	4.85	1.33	0.04	54.0			22.3	164.5	2.6	2.4	603	1937	43	43	
146	Sunday	11 August	155.5	2318	1954	3.83	4.59	1.38	0.09	58.8			21.5	166.8	3.8	2.2	677	1999	30	43	
147	Monday	12 August	154.3	2204	1948	3.57	4.49	1.35	0.07	53.5			21.2	147.7	2.8	2.2	611	1891	55	41	
148	Tuesday	13 August	150.1	2258	1970	3.57	4.53	1.46	0.09	57.4			21.4	170.4	3.1	3.7	678	1806	43	39	
149	Wednesday	14 August	148.0	2296	1928	3.63	4.64	1.57	0.09	54.2			21.0	176.4	2.9	3.5	651	1929	41	35	
150	Thursday	15 August	138.9	2304	1977	3.63	4.64	1.49	0.08	55.0			21.5	163.3	2.8	1.9	659	1929	41	35	
151	Friday	16 August	139.8	2308	1938	3.75	4.92	1.53	0.09	60.7			21.4	173.0	3.5	2.4	568	1970	39	37	
152	Saturday	17 August	137.0	2198	1878	3.69	4.88	1.56	0.08	54.7			21.7	158.5	3.2	2.5	631	1821	41	33	
153	Sunday	18 August	131.1	2283	1972	3.70	4.80	1.41	0.09	45.9			20.0	146.8	2.4	2.0	616	1945	18	33	
154	Monday	19 August	136.7	2127	1792	3.73	4.10	1.41	0.08	51.4			21.3	158.9	3.1	2.5	591	1930	34	30	
53.13			145.06	2221.73	1969.54	3.71	4.75	1.40	0.08	53.33			21.78	165.36	2.83	2.57	679.64	1974.34	43.63	39.07	
155	Tuesday	20 August	125.8	2230	1894	3.74	4.63	1.53	0.00	64.7			21.7	160.3	3.2	3.7	741	1833	40	36	
156	Wednesday	21 August	132.3	2268	1904	3.81	4.83	1.45	0.06	62.0			21.2	177.8	3.4	3.1	611	1813	49	37	
157	Thursday	22 August	133.2	2202	1904	3.63	4.80	1.40	0.00	59.2			20.5	181.0	2.8	0.3	672	1872	36	38	
158	Friday	23 August	129.5	2318	1858	3.69	4.71	1.49	0.09	56.0			22.3	171.5	2.3	2.2	716	1915	30	37	
159	Saturday	24 August	136.2	2388	2028	3.75	4.86	1.58	0.09	53.3			22.7	188.9	2.7	2.0	649	1933	32	34	
160	Sunday	25 August	137.4	2402	2058	3.60	4.74	1.39	0.09	54.5			23.8	181.3	3.2	2.9	631	1866	34	28	
161	Monday	26 August	138.5	2454	2086	3.80	4.98	1.41	0.09	50.4			24.6	179.2	2.7	1.4	787	1920	52	37	
162	Tuesday	27 August	141.3	2408	2042	3.75	4.65	1.33	0.04	57.5			24.0	154.0	2.4	0.7	673	1954	41	30	
163	Wednesday	28 August	143.4	2092	1787	3.71	4.82	1.30	0.08	57.8			23.6	143.6	1.8	0.6	727	1912	34	28	
164	Thursday	29 August	138.6	2578	2164	3.77	4.77	1.29	0.07	57.9			21.8	132.4	2.9	2.0	633	1819	24	22	
165	Friday	30 August	148.8	2422	2116	3.78	4.81	1.29	0.07	57.8			21.7	158.8	3.1	0.8	645	1773	30	28	
53.14			138.80	2344.18	1998.91	3.77	4.69	1.39	0.08	61.01	ERR		21.65	168.09	2.94	1.72	699.97	1972.14	36.10	28.66	
167	Saturday	31 August	172.1	1978	1708	3.52	4.77	1.37	0.09	38.6			21.2	158.8	3.8	3.4	618	1946	40	35	
168	Sunday	01 September	149.4	2347	1847	3.58	4.81	1.32	0.07	35.6			21.3	138.8	2.2	0.8	575	1811	55	43	
169	Monday	02 September	145.2	2410	2007	3.52	4.56	1.34	0.07	38.6			21.2	132.0	3.3	0.6	579	1913	41	33	
170	Tuesday	03 September	147.1	2112	1882	3.55	4.62	1.36	0.07	37.4			20.4	145.8	3.2	1.1	575	1893	35	31	
171	Wednesday	04 September	145.4	2338	1884	3.58	4.75	1.32	0.08	36.4			21.3	182.4	3.1	2.2	563	1991	31	24	
172	Thursday	05 September	146.0	2278	1866	3.48	4.75	1.37	0.06	36.5			21.4	158.2	2.6	1.9	660	1886	35	29	
173	Friday	06 September	145.6	2288	1908	3.58	4.78	1.42	0.08	38.6			21.1	152.6	3.1	1.7	643	1928	33	31	
174	Saturday	07 September	142.0	2184	2004	3.40	4.57	1.30	0.07	38.7			21.2	144.8	2.4	0.7	622	1806	33	31	
175	Sunday	08 September	148.8	2418	2056	3.41	4.59	1.27	0.07	39.2											

Day No	1996	TSS		pH	COD/DO		TSS		TSS		TSS		TSS		TSS		TSS		TSS	
		mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
371	Sunday	22 March	138.05	2337.00	1817.00	7.65	7.82	1.34	0.07	44.34	2.10	63.74	130.70	3.22	2.10	63.74	1422.04	47.78	39.54	
372	Monday	23 March	139.05	2144.00	1678.00			1.35	0.07	43.82		39.64	113.40	2.66	2.24	43.18	2259.96	44.70	28.50	
373	Tuesday	24 March																		
374	Wednesday	25 March	134.77	2228.00	1719.00	7.31	7.55	1.36	0.07	44.57	59.58	121.60	2.50	2.58	63.18	2402.43	34.81	34.81		
375	Thursday	26 March	138.05	2016.00	1412.00	7.30	7.52	1.36	0.05	43.36	56.84	137.20	2.17	0.11	53.18	2301.78	44.78	40.77		
376	Friday	27 March	179.03	2480.00	1884.00	7.68	7.68	1.35	0.07	43.40	58.38	128.80	2.38	1.10	62.03	2424.64	46.73	40.12		
377	Saturday	28 March	130.72	2143.00	1650.00	7.97	7.91	1.34	0.06	44.74	63.14	128.00	2.24	2.10	57.05	2216.74	34.61	34.61		
378	Sunday	29 March	179.47	2736.00	1861.00	7.97	7.93	1.31	0.07	43.68	55.96	131.10	1.51	1.40	60.73	2301.78	42.78	38.68		
379	Monday	31 March	139.05	2724.00	1758.00	7.47	7.64	1.31	0.07	43.18	65.96	142.80	2.66	2.52	68.94	2608.04	38.96	30.78		
380	Tuesday	01 April	121.04	2396.00	1688.00	7.71	7.92	1.38	0.04		58.38	128.80	2.66	1.64	68.85	2400.64	38.96	34.68		
381	Wednesday	02 April	125.84	2278.00	1751.82	8.33	7.13	1.35	0.08	43.48	ERR	60.67	133.73	2.42	1.93	67.50	2368.60	40.91	35.36	
382	Thursday	03 April																		
383	Friday	04 April																		
384	Saturday	05 April																		
385	Sunday	06 April																		
386	Monday	07 April																		
387	Tuesday	08 April																		
388	Wednesday	09 April	128.84	2332.00	1830.00	7.72	7.73	1.32	0.08	70.84	88.34	144.20	3.36	0.70	77.78	2441.86	61.56	45.14		
389	Thursday	10 April	122.16	2128.00	1608.00			1.35	0.08	66.04	64.14	125.80	3.36	2.34	64.42	2257.70	62.61	28.88		
390	Friday	11 April	113.34	2280.00	1840.00	7.49	7.59	1.27	0.07	66.09	80.04	129.50	2.73	2.57	68.07	2303.16	51.10	28.57		
391	Saturday	12 April	116.40	1978.00	1602.00	7.80	7.75	1.34	0.07	63.78	77.94	107.80	2.10	1.66	67.85	2144.20	51.10	30.04		
392	Sunday	13 April	134.60	2014.00	1848.00			1.34	0.06	61.60	76.07	105.20	2.18	2.10	76.07	2207.57	57.25	40.66		
393	Monday	14 April	179.99	2154.00	1732.00	7.58	7.59	1.42	0.07	57.40	78.77	114.30	2.03	1.98	65.17	2173.74	55.10	51.10		
394	Tuesday	15 April	141.03	1884.00	1608.00	7.44	7.51	1.36	0.08	64.83	80.27	117.60	2.10	1.82	634.03	2006.44	44.57	38.79		
395	Wednesday	16 April	140.68	1706.00	1352.00	7.60	7.73	1.45	0.07	62.44	83.16	123.80	2.45	2.16	703.14	1900.32	49.08	28.82		
396	Thursday	17 April	133.17	1652.00	1284.00						80.22	86.00	1.96	1.96	672.81	1865.76	40.56	29.79		
397	Friday	18 April																		
398	Saturday	19 April																		
399	Sunday	20 April																		
400	Monday	21 April	130.89	1910.00	1592.00	7.70	7.73	1.31	0.07	67.20	89.32	107.10	2.17	2.10	845.05	2088.84	44.82	36.50		
401	Tuesday	22 April																		
402	Wednesday	23 April	129.38	2010.60	1615.20	7.61	7.70	1.33	0.07	64.82	81.62	114.30	2.48	1.96	749.63	2177.62	51.90	37.16		
403	Thursday	24 April																		
404	Friday	25 April																		
405	Saturday	26 April																		
406	Sunday	27 April																		
407	Monday	28 April	153.36	1758.00	1472.00	7.55	7.64	1.38	0.07	40.32	48.72	105.00	2.31	1.68	547.38	1907.16	46.67	46.67		
408	Tuesday	29 April	153.36	1758.00	1472.00	7.40	7.53	1.36	0.08	39.90	56.47	109.70	1.98	1.54	677.38	1835.30	44.35	44.35		
409	Wednesday	30 April	153.36	1758.00	1472.00	7.44	7.51	1.36	0.08	41.77	54.93	109.30	2.45	1.16	586.51	1695.04	52.42	36.29		
410	Thursday	01 May	153.36	1758.00	1472.00	7.53	7.64	1.27	0.07	47.31	60.36	103.90	2.45	1.16	664.80	1874.88	46.37	30.24		
411	Friday	02 May																		
412	Saturday	03 May	151.52	1914.00	1532.00	7.88	7.82	1.34	0.06	30.98	87.78	131.80	2.66	2.34	685.28	2058.32	66.48	43.34		
413	Sunday	04 May	150.17	1798.00	1354.00			1.44	0.07	44.57	82.44	101.30	1.82	1.62	518.10	1935.32	70.56	54.42		
414	Monday	05 May	148.73	1772.00	1358.00			1.49	0.07	41.03	87.16	108.10	1.89	1.82	705.80	1995.84	84.51	58.45		
415	Tuesday	06 May	151.62	1780.28	1419.43	7.51	7.65	1.30	0.08	43.68	ERR	107.30	2.22	1.68	617.17	1864.30	58.34	45.45		
416	Wednesday	07 May	143.38	1567.00	1208.00			1.37	0.08	74.48	36.34	73.40	1.75	1.88	572.54	1653.12	60.44	40.32		
417	Thursday	08 May																		
418	Friday	09 May	150.48	1487.00	1164.00	7.85	7.35				59.94	41.20	1.54	0.70	584.58	1573.88	36.79	36.79		
419	Saturday	10 May	128.74	1578.00	1264.00	7.88	7.62	1.43	0.06	79.14	101.50	78.40	1.40	0.70	572.32	1798.72	44.87	44.87		
420	Sunday	11 May	68.09	1278.00	1058.00			1.35	0.08	92.54	99.40	128.70	2.24	1.60	584.14	1430.60	55.16	38.84		
421	Monday	12 May	181.02	1802.00	1274.00			1.30	0.06	36.38	104.62	102.80	1.61	0.70	578.41	1737.40	40.88	26.82		
422	Tuesday	13 May	145.25	1790.00	1372.00			1.28	0.09	67.72	115.22	119.00	2.00	1.40	587.76	1757.84	49.06	46.86		
423	Wednesday	14 May	171.78	1830.00	1312.00			1.32	0.07	62.48	105.84	98.00	2.66	2.10	543.70	1737.40	44.87	36.79		
424	Thursday	15 May	146.38	1827.00	1386.00	7.66	7.51	1.35	0.07	62.70	ERR	102.10	82.10	1.88	1.71	573.35	1607.68	47.68	36.17	
425	Friday	16 May	146.89	1648.00	1108.00			1.29	0.06	54.76	73.74	88.60	1.61	1.62	637.73	1788.72	44.97	35.79		
426	Saturday	17 May	154.18	1946.00	1416.00			1.34	0.07	48.18	64.40	114.10	2.04	2.06	682.70	2003.12	34.75	26.37		
427	Sunday	18 May	161.29	2108.00	1656.00			1.41	0.07	49.70	87.08	108.50	2.24	0.70	715.40	2237.36	51.10	51.10		
428	Monday	19 May	146.92	2108.00	1670.00			1.40	0.07	49.58	66.04	118.30	1.82	0.28	638.61	2237.96	57.25	42.70		
429	Tuesday	20 May	144.08	2042.00	1888.00			1.36	0.07	51.52	87.48	111.30	1.60	0.14	703.14	2202.16	53.14	48.08		
430	Wednesday	21 May	148.27	2478.00	1802.00			1.44	0.08	49.84	65.10	118.70	1.05	0.70	736.48	2204.80	51.60	46.82		
431	Thursday	22 May																		
432	Friday	23 May	157.18	2354.00	1914.00			1.32	0.07	54.24	66.92	127.40	1.82	0.56	673.20	2529.60	51.00	42.84		
433	Saturday	24 May	158.15	2282.00	1810.00			1.38	0.08	49.00	67.74	132.20	2.17	0.42	781.78	2488.80	68.80	36.72		
434	Sunday	25 May	153.99	2078.00	1626.00			1.39	0.06	42.70	62.72	98.00	1.96	0.96	597.58	2264.40	46.92	42.84		
435	Monday	26 May	149.90	2068.00	1622.00			1.42	0.06	4										

Only Feet on Control System

Day No	1988	Allistics (mgd HOJ)				Allistics (mgd HOJ)				Phosphorus (mgd PO ₄ P)					
		Aerobic	Anoxic	Anoxic	Fitted Effluent	Aerobic	Anoxic	Aerobic	Fitted Effluent	Influent	Aerobic	Anoxic	Aerobic	Unfitted Effluent	Fitted Effluent
1	Monday 18 March														
2	Tuesday 19 March														
3	Wednesday 20 March														
4	Thursday 21 March														
5	Friday 22 March														
6	Saturday 23 March														
7	Sunday 24 March														
8	Monday 25 March														
9	Tuesday 26 March														
10	Wednesday 27 March														
11	Thursday 28 March														
12	Friday 29 March														
13	Saturday 30 March														
14	Sunday 31 March														
15	Monday 01 April														
16	Tuesday 02 April														
17	Wednesday 03 April														
18	Thursday 04 April														
19	Friday 05 April														
20	Saturday 06 April														
21	Sunday 07 April														
22	Monday 08 April														
23	Tuesday 09 April														
24	Wednesday 10 April														
25	Thursday 11 April														
26	Friday 12 April														
27	Saturday 13 April														
28	Sunday 14 April														
29	Monday 15 April														
30	Tuesday 16 April														
31	Wednesday 17 April														
32	Thursday 18 April														
33	Friday 19 April														
34	Saturday 20 April														
35	Sunday 21 April														
36	Monday 22 April														
37	Tuesday 23 April														
38	Wednesday 24 April														
39	Thursday 25 April														
40	Friday 26 April														
41	Saturday 27 April														
42	Sunday 28 April	0.05	0.07	0.31	0.31	0.10	0.50	1.52	8.44						
43	Monday 29 April	0.04	0.05	0.31	0.64	0.11	0.45	2.70	8.43						
44	Tuesday 30 April	0.05	0.07	0.33	0.65	0.80	0.07	4.27	7.94						
45	Wednesday 01 May	0.05	0.05	0.32	0.19	0.45	0.04	4.74	8.81						
46	Thursday 02 May	0.01	0.05	0.72	0.46	0.03	0.03	3.33	8.78						
47	Friday 03 May	0.07	0.17	0.41	0.44	0.05	0.01	0.00	4.02	13.7	8.0	2.9	3.7	2.6	
48	Saturday 04 May	0.15	0.07	1.64	4.18	0.33	0.02	1.75	1.56						
49	Sunday 05 May	0.06	0.19	1.99	1.77	0.00	0.18	3.40	1.50	13.0	18.1	12.3	4.4	2.7	2.7
50	Monday 06 May	0.08	0.08	1.53	1.29	0.00	0.00	3.48	4.18	20.2	15.4		1.7	1.7	1.0
51	Tuesday 07 May	0.07	0.11	1.16	1.20	0.00	0.00	3.86	4.93	12.1	18.8	8.8	2.1	1.7	2.1
52	Wednesday 08 May	0.07	0.08	1.08	1.20	0.17	0.13	3.47	8.08	15.10	16.51	9.04	2.77	2.34	2.00
53	Thursday 09 May	0.05	0.09	0.92	0.92	0.00	0.00	2.69	2.69	17.6	15.5	5.5	2.7	2.7	2.1
54	Friday 10 May	0.06	0.09	0.95	0.95	0.00	0.00	2.59	8.21	10.7	25.8	12.8	3.1	2.7	2.1
55	Saturday 11 May	0.08	0.09	0.41	0.84	0.00	0.00	0.15	0.15	10.5	26.1	13.3	2.1	2.7	2.1
56	Sunday 12 May	0.06	0.06	0.33	0.91	0.00	0.00	0.00	0.00	14.50	10.1	9.43	1.3	1.3	1.0
57	Monday 13 May	0.05	0.05	0.79	0.90	0.01	0.10	7.34	9.24	13.7	19.3	9.3	2.7	2.7	2.7
58	Tuesday 14 May	0.07	0.06	0.58	0.44	0.04	0.04	7.63	9.22	13.0	16.0	9.3	3.3	3.0	3.0
59	Wednesday 15 May	0.05	0.06	0.28	0.36	0.18	0.05	9.07	10.24	13.0	20.3	9.7	3.7	3.7	3.3
60	Thursday 16 May	0.00	0.09	0.41	0.74	0.01	0.07	7.02	8.33	13.7	16.3	10.0	3.0	3.0	3.0
61	Friday 17 May	0.03	0.04	0.77	0.74	0.01	0.02	7.06	5.86	13.3	20.0	9.7	3.3	3.0	3.0
62	Saturday 18 May	0.02	0.03	0.46	0.24	0.01	0.05	7.74	9.10	14.0	21.0	10.7	3.7	4.0	4.0
63	Sunday 19 May	0.07	0.07	0.37	0.16	0.00	0.04	8.61	8.52	13.7	20.0	10.3	3.7	4.0	4.0
64	Monday 20 May	0.03	0.03	0.77	0.21	0.03	0.08	8.51	9.24	14.0	20.3	10.7	4.0	4.3	4.0
65	Tuesday 21 May	0.07	0.07	0.13	0.11	0.01	0.05	7.75	8.12	12.7	20.0	10.3	4.0	4.3	4.0
66	Wednesday 22 May	0.04	0.04	0.38	0.38	0.03	0.25	7.76	9.21	13.44	19.93	10.00	3.46	3.78	3.48
67	Thursday 23 May	0.02	0.11	0.29	0.24	0.03	0.07	13.11	10.26	13.0	19.7	9.7	4.7	4.7	4.3
68	Friday 24 May	0.02	0.20	0.77	0.00	0.04	0.65	12.22	18.06	14.9	18.3	10.0	4.7	3.7	5.3
69	Saturday 25 May	0.03	0.09	0.11	0.13	0.03	0.05	8.35	11.58	17.5	21.8	12.2	7.1	6.6	7.4
70	Sunday 26 May	0.03	0.04	0.34	0.21	0.18	0.08	10.29	12.50	17.6	23.0	12.8	7.1	8.4	7.1
71	Monday 27 May	0.11	0.22	0.23	0.21	0.47	0.90	11.86	13.41	12.6	22.0	11.8	6.4	8.1	7.1
72	Tuesday 28 May	0.04	0.18	0.34	0.18	0.07	0.87	13.85	14.35	17.6	24.3	12.2	7.4	8.8	7.1
73	Wednesday 29 May	0.03	0.03	0.60	0.36	0.07	0.09	10.20	13.25	17.9	21.3	14.4	9.6	9.1	7.8
74	Thursday 30 May	0.04	0.10	0.28	0.31	0.08	0.37	13.10	13.87	13.7	19.0	9.7	3.3	3.7	5.7
75	Friday 31 May	0.03	0.10	0.28	0.13	0.04	0.19	9.51	13.84	14.0	20.7	11.1	4.7	5.0	5.0
76	Saturday 01 June	0.04	0.10	0.24	0.13	0.07	0.73	13.10	13.26	13.7	19.0	9.7	3.7	5.0	5.0
77	Sunday 02 June	0.04	0.10	0.21	0.13	0.05	0.64	12.25	14.18	13.7	20.9	10.3	5.0	5.3	5.0
78	Monday 03 June	0.04	0.11	0.29	0.20	0.17	0.14	11.63	13.38	15.84	20.80	11.29	5.17	6.74	6.74
79	Tuesday 04 June	0.02	0.05	0.08	0.04	0.01	0.14	7.57	10.80	13.0	18.7	10.3	3.0	3.3	5.0
80	Wednesday 05 June	0.02	0.02	0.05	0.00	0.02	0.03	5.90	7.07	13.0	18.0	10.0	5.0	5.3	5.0
81	Thursday 06 June	0.02	0.04	0.10	0.15	0.01	0.03	7.42	7.50	14.8	18.7	10.3	5.4	5.8	5.1
82	Friday 07 June	0.03	0.03	0.10	0.20	0.07	0.09	6.30	7.25	13.0	19.4	10.3	5.1	5.8	5.1
83	Saturday 08 June	0.07	0.04	0.06	0.11	0.07	0.07	8.83	6.18	13.90	18.89	10.36	3.14	3.48	5.03
84	Sunday 09 June	0.04	0.05	0.12	0.22	0.01	0.03	8.67	7.10	18.4	21.8	11.9	5.8	5.8	5.1
85	Monday 10 June	0.03	0.04	0.14	0.14	0.14	0.02	8.51	7.84	19.1	24.3	13.9	7.5	7.8	7.5
86	Tuesday 11 June	0.03	0.05	0.14	0.12	0.04	0.04	6.72	7.98	18.7	22.8	14.3	8.5	8.5	8.5
87	Wednesday 12 June	0.03	0.05	0.12	0.12	0.19	0.02	7.13	6.18	18.7	25.2	14.8	9.7	10.2	9.9
88	Thursday 13 June	0.03	0.07	0.12	0.12	0.22	0.09	6.02	7.58	18.6	22.3	14.4	6.0	11.4	9.5
89	Friday 14 June	0.03	0.03	0.20	0.11	0.60	0.02	6.80	7.47	19.4	22.8	14.4	8.8	11.4	9.6
90	Saturday 15 June	0.03	0.05	0.18	0.11	0.02	0.04	4.77	7.81	20.9	23.8	14.0	9.5	10.4	10.1
91	Sunday 16 June	0.03	0.03	0.10	0.10	0.38	0.08	8.64	8.06	20.0	24.3	14.4	9.1	11.1	9.1
92	Monday 17 June	0.08	0.08	0.15	0.11	0.07	0.08	8.84	8.38	19.9	23.5	15.0	8.8	11.4	10.8
93	Tuesday 18 June	0.07	0.25	0.10	0.14	0.31	0.04	4.46	6.53	20.1	25.7	15.0	9.7	11.6	10.8
94	Wednesday 19 June	0.04	0.05	0.14	0.13	0.14	0.03	6.86	7.33	18.54	23.72	14.71	8.52	10.74	9.26
95	Thursday 20 June	0.01	0.18	0.04	0.10	0.09	0.34	8.11	9.33	17.8	19.3	11.2	7.3	11.1	10.8
96	Friday 21 June	0.03	0.04	0.14	0.08	0.04	0.10	8.44	9.29	18.3	20.8	12.3	6.6	9.2	9.2
97	Saturday 22 June	0.02	0.19	0.13	0.18	0.04	0.39	9.24	10.56	18.8	24.1	12.2	7.6	8.2	8.2
98	Sunday 23 June	0.03	0.00	0.13	0.11	0.04	0.00	9.10	10.84	17.1	20.8	17.3	3.9	8.3	8.7
99	Monday 24 June	0.08	0.17	0.43	0.35	0.59	0.17	4.74	9.81	17.7	15.6	9.2	3.7	5.0	8.1
100	Tuesday 25 June	0.08	0.37	0.90	0.00	0.00	0.21	6.92	0.00	12.3	13.3	8.5	5.7		
101	Wednesday 26 June	0.07	0.64	0.33	0.35	0.04	0.19	7.68	9.71	12.6	13.0	3.3	3.4		
102	Thursday 27 June	0.06	0.23	0.35	0.37	0.78	0.38	7.18	9.07	11.6	14.6	3.7	3.7	5.9	5.9
103	Friday 28 June	0.05	0.13	0.32	0.36	0.00	0.11	6.52	9.42	12.0	14.4	9.0	5.4	8.4	9.9

Day No	1999	NH4-N (mg/L N51.4)				Nitrate (mg/L NO3-N)				Phosphorus (mg/L P5)				
		Anaerobic	Anaerobic	Aerobic	Filtered Effluent	Anaerobic	Anaerobic	Aerobic	Filtered Effluent	Water	Anaerobic	Anaerobic	Aerobic	Filtered Effluent
118	Saturday 13 July	0.09	0.73	1.17	0.33	0.01	0.06	8.25	11.00	22.7	30.7	17.0	32.7	75.3
119	Sunday 14 July	0.24	1.55	1.87	1.28	0.25	0.00	12.05	14.80	25.1	38.0	18.3	44.3	102.7
120	Monday 15 July	0.26	1.88	2.14	0.81	0.75	0.00	12.49	18.17	15.0	26.7	10.3	44.7	102.7
121	Tuesday 16 July	0.10	1.36	1.34	1.12	0.00	0.00	11.73	16.25	73.7	25.7	16.0	44.0	102.7
122	Wednesday 17 July	0.17	0.90	0.27	0.20	0.52	0.00	11.74	14.56	24.0	26.6	17.8	43.3	102.7
123	Thursday 18 July	0.04	0.73	0.87	0.70	1.00	0.30	9.29	14.19	24.3	25.8	18.8	43.8	102.7
124	Friday 19 July	0.09	0.58	0.43	0.13	0.51	0.68	10.14	12.19	27.3	25.8	18.8	43.3	102.7
125	Saturday 20 July	0.11	0.52	0.17	0.77	0.70	0.55	8.74	13.71	24.0	27.0	17.1	43.7	102.7
126	Sunday 21 July	0.05	0.48	0.43	0.22	0.18	1.40	10.56	12.04	23.8	27.3	18.1	43.4	102.7
127	Monday 22 July	0.01	0.93	1.45	0.81	0.21	1.72	10.46	13.15	22.0	22.0	14.1	43.3	102.7
128	Tuesday 23 July	0.06	0.87	0.77	0.39	0.17	1.71	10.99	14.10	24.3	24.1	17.4	43.8	102.7
129	Wednesday 24 July	0.03	0.70	0.73	0.78	0.09	1.65	10.14	13.74	24.1	22.7	18.8	44.3	102.7
130	Thursday 25 July	0.03	0.32	0.38	0.20	0.09	0.71	8.18	11.90	23.4	24.5	17.5	44.7	102.7
131	Friday 26 July	0.06	0.11	0.38	0.15	0.36	1.18	9.63	11.82	21.0	25.1	18.8	43.8	102.7
55-11		0.08	0.31	0.50	0.39	0.33	0.81	10.61	13.67	23.7	25.26	17.24	43.78	102.69
132	Saturday 27 July	0.03	0.19	0.15	0.17	0.16	1.33	10.28	13.99	21.7	23.0	18.1	42.6	102.7
133	Sunday 28 July	0.04	0.10	0.44	0.17	0.13	1.17	11.23	13.33	21.7	23.0	18.1	42.6	102.7
134	Monday 29 July	0.05	0.18	0.57	0.33	0.11	7.38	13.21	15.48	21.7	22.4	15.4	42.7	102.7
135	Tuesday 30 July	0.07	0.30	0.57	0.31	0.10	1.76	12.03	15.84	21.3	21.8	14.5	42.5	102.7
136	Wednesday 31 July	0.07	0.23	0.38	0.23	0.08	1.63	11.56	14.48	22.7	24.0	18.7	42.6	102.7
137	Thursday 01 August	0.07	0.37	0.73	0.23	0.14	0.67	11.60	14.36	22.7	24.0	18.8	42.3	102.7
138	Friday 02 August	0.04	0.31	0.47	0.23	0.09	0.66	11.12	15.08	21.3	23.3	18.2	43.3	102.7
139	Saturday 03 August	0.04	0.35	0.31	0.27	0.07	1.04	10.92	13.50	21.3	23.0	18.2	42.8	102.7
140	Sunday 04 August	0.04	0.48	0.49	0.25	0.06	0.33	11.69	14.08	23.4	23.7	18.2	44.5	102.7
141	Monday 05 August	0.04	0.43	0.40	0.27	0.05	0.00	8.78	13.52	22.7	22.7	16.6	43.7	102.7
142	Tuesday 06 August													
55-11		0.05	0.30	0.39	0.24	0.10	1.20	11.31	14.38	22.02	23.28	16.04	42.78	102.68
143	Wednesday 07 August	0.07	0.38	0.13	0.13	0.01	0.00	13.74	13.66	23.0	24.7	15.9	43.5	102.7
144	Thursday 08 August	0.02	0.15	0.32	0.13	0.07	0.00	10.28	12.23	22.9	23.5	18.7	42.7	102.7
145	Friday 09 August	0.04	0.09	0.17	0.14	0.01	0.00	10.87	13.33	22.2	24.5	14.7	43.1	102.7
146	Saturday 10 August	0.05	0.08	0.16	0.16	0.20	0.00	11.00	13.48	23.2	25.2	17.0	43.1	102.7
147	Sunday 11 August	0.08	0.08	0.16	0.14	0.44	0.00	11.33	13.55	22.6	25.6	16.3	42.4	102.7
148	Monday 12 August	0.03	0.15	0.35	0.13	0.55	0.00	11.60	13.63	23.3	23.5	17.0	42.7	102.7
149	Tuesday 13 August	0.05	0.17	0.18	0.12	0.00	0.00	10.86	13.35	22.5	25.5	16.3	43.1	102.7
150	Wednesday 14 August	0.04	0.14	0.56	0.34	0.04	0.77	8.25	17.06	22.1	25.4	17.4	42.4	102.7
151	Thursday 15 August	0.05	0.12	0.42	0.34	0.08	0.17	8.83	12.61	22.1	25.1	17.1	41.7	102.7
152	Friday 16 August	0.06	0.79	0.47	0.30	0.01	0.51	11.12	12.51	22.8	23.4	16.7	42.4	102.7
153	Saturday 17 August	0.04	0.83	0.66	0.40	0.01	1.58	12.06	14.88	22.4	24.8	18.1	43.7	102.7
154	Sunday 18 August	0.05	0.48	0.42	0.46	0.64	0.37	9.63	13.91	22.4	26.4	20.4	43.4	102.7
155	Monday 19 August	0.04	0.36	0.61	0.25	0.03	0.71	10.41	13.29	22.3	25.4	17.2	43.7	102.7
55-11		0.05	0.31	0.37	0.23	0.17	0.78	10.93	13.65	22.80	25.17	17.70	42.92	102.71
156	Tuesday 20 August	0.11	0.40	0.31	0.19	0.10	0.88	12.70	12.33	24.3	25.2	18.1	41.2	102.7
157	Wednesday 21 August	0.06	0.48	0.26	0.20	0.12	2.52	15.93	16.54	23.8	25.5	14.8	42.8	102.7
158	Thursday 22 August	0.07	0.51	0.28	0.23	0.20	2.68	17.04	19.65	23.8	24.8	16.8	42.0	102.7
159	Friday 23 August	0.07	0.32	0.21	0.28	0.12	2.42	16.10	19.60	23.1	24.8	16.4	42.2	102.7
160	Saturday 24 August	0.08	0.54	0.26	0.38	0.13	2.18	14.29	17.71	23.1	25.2	17.1	43.3	102.7
161	Sunday 25 August	0.08	0.87	0.55	0.36	0.13	2.22	16.77	18.83	23.3	26.6	18.9	44.3	102.7
162	Monday 26 August	0.08	0.85	0.31	0.21	0.12	0.00	15.53	19.12	26.6	28.9	19.2	44.3	102.7
163	Tuesday 27 August	0.08	0.80	0.25	0.22	0.20	0.00	14.35	14.64	25.8	26.8	18.9	43.0	102.7
164	Wednesday 28 August	0.09	1.05	1.03	0.47	0.14	0.00	12.54	15.73	25.8	25.1	17.1	45.4	102.7
165	Thursday 29 August	0.08	0.99	0.19	0.22	0.15	0.00	13.60	15.71	25.3	25.9	18.2	42.9	102.7
166	Friday 30 August	0.04	0.86	0.44	0.25	0.17	0.00	12.99	16.13	24.6	25.5	18.2	44.3	102.7
55-14		0.07	0.70	0.38	0.28	0.15	1.18	12.83	16.98	24.88	25.68	17.60	43.31	102.60
167	Saturday 31 August													
168	Sunday 01 September													
169	Monday 02 September	0.10	0.14	0.14	0.28	0.05	0.00	8.86	7.48	24.1	24.8	18.2	43.6	102.7
170	Tuesday 03 September	0.03	0.08	0.17	0.11	0.00	0.00	8.84	7.95	24.8	25.1	17.1	44.9	102.7
171	Wednesday 04 September	0.04	0.08	0.17	0.11	0.03	0.00	7.13	6.48	25.5	24.6	17.2	44.9	102.7
172	Thursday 05 September	0.04	0.66	0.12	0.10	0.05	0.00	8.83	7.80	23.5	25.1	17.0	41.8	102.7
173	Friday 06 September	0.03	0.11	0.14	0.11	0.08	0.00	7.01	6.05	23.5	25.1	17.0	43.2	102.7
174	Saturday 07 September	0.02	0.11	0.12	0.11	0.03	0.45	7.03	6.05	24.1	25.5	17.5	41.9	102.7
175	Sunday 08 September	0.04	0.08	0.11	0.11	0.04	0.00	7.14	6.46	24.1	25.6	17.5	41.6	102.7
176	Monday 09 September	0.03	0.14	0.24	0.36	0.11	0.20	5.89	8.43	24.4	25.7	18.7	43.0	102.7
177	Tuesday 10 September	0.05	0.11	0.48	0.08	0.01	0.00	8.78	7.14	25.8	26.8	17.2	43.4	102.7
55-14		0.05	0.10	0.19	0.18	0.08	0.11	8.72	7.95	25.94	25.11	17.73	42.29	102.60
178	Wednesday 11 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
179	Thursday 12 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
180	Friday 13 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
181	Saturday 14 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
182	Sunday 15 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
183	Monday 16 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
184	Tuesday 17 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
185	Wednesday 18 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
186	Thursday 19 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
187	Friday 20 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
188	Saturday 21 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
189	Sunday 22 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
190	Monday 23 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
191	Tuesday 24 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
192	Wednesday 25 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
193	Thursday 26 September	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
194	Friday 27 September	ERR	ERR											

Day No.	1998	Nitrate (mg N/100 L)				Nitrite (mg N/100 L)				Phosphorous (mg P/100 L)				
		Ammoniac	Amoxic	Aerobic	Filtered Effluent	Ammoniac	Amoxic	Aerobic	Filtered Effluent	Ammoniac	Amoxic	Aerobic	Filtered Effluent	
371	Sunday 23 March	0.07	0.10	0.42	0.26	0.13	0.01	8.40	9.81	21.04	17.71	20.19	6.53	6.53
372	Monday 24 March	0.04	0.05	0.30	0.22	0.13	0.13	9.72	10.43	20.48	38.01	19.80	8.53	8.53
373	Tuesday 25 March	0.04	0.05	0.42	0.26	0.17	0.16	8.81	10.25	21.08	36.22	20.19	6.53	6.53
374	Wednesday 26 March	0.04	0.05	0.42	0.26	0.17	0.16	8.81	10.25	21.08	36.22	20.19	6.53	6.53
375	Thursday 27 March	0.04	0.05	0.42	0.26	0.17	0.16	8.81	10.25	21.08	36.22	20.19	6.53	6.53
376	Friday 28 March	0.07	0.13	0.35	0.12	0.14	0.09	6.81	10.33	21.33	36.52	19.30	7.13	8.02
377	Saturday 29 March	0.05	0.04	0.21	0.15	0.06	0.07	7.66	10.11	22.17	35.84	19.09	8.01	10.17
378	Sunday 30 March	0.07	0.33	0.68	0.13	0.05	0.28	7.73	8.52	20.83	34.40	21.56	7.10	10.18
379	Monday 31 March	0.07	0.21	0.11	0.11	0.04	0.13	7.43	8.17	20.63	35.41	21.56	8.55	8.55
380	Tuesday 01 April	0.03	0.08	0.06	0.12	0.04	0.10	1.87	8.79	23.40	34.49	23.09	10.47	11.09
SS 74		0.03	0.09	0.30	0.20	0.10	0.23	8.24	8.70	21.38	37.59	20.90	7.78	8.11
381	Wednesday 03 April													
382	Thursday 04 April													
383	Friday 05 April													
384	Saturday 06 April													
385	Sunday 07 April													
386	Monday 08 April													
387	Tuesday 09 April													
388	Wednesday 10 April	0.13	0.48	0.60	0.43	0.17	1.50	10.18	20.73	22.73	38.47	20.00	11.11	7.82
389	Thursday 11 April	0.05	0.47	0.89	0.58	0.08	0.44	13.21	19.82	22.54	40.01	20.84	7.07	10.48
390	Friday 12 April	0.04	0.18	0.58	0.81	0.04	0.06	13.89	17.00	21.91	37.15	20.98	8.89	10.48
391	Saturday 13 April	0.07	0.35	1.72	0.54	0.05	0.23	13.25	13.88	21.77	33.34	20.22	8.89	10.16
392	Sunday 14 April	0.07	0.10	1.07	0.89	0.02	0.10	14.25	18.82	22.73	32.66	19.69	8.89	10.16
393	Monday 15 April	0.04	0.13	0.81	0.15	0.02	0.21	9.78	12.09	21.34	33.30	17.78	8.14	8.14
394	Tuesday 16 April	0.04	0.20	1.35	0.61	0.06	0.19	11.44	11.73	21.99	38.47	21.02	10.02	7.78
395	Wednesday 18 April	0.08	0.72	1.13	0.55	0.01	0.20	10.74	13.06	21.90	32.33	17.78	8.08	7.78
396	Thursday 19 April	0.07	0.24	0.90	0.49	0.09	0.63	10.39	13.82	22.51	34.92	20.05	11.60	8.41
397	Friday 20 April													
398	Saturday 21 April													
399	Sunday 22 April													
400	Monday 23 April	0.10	0.82	0.81	1.05	0.30	1.20	12.40	18.15	23.31	32.70	17.18	8.50	7.43
401	Tuesday 24 April													
SS 75		0.07	0.32	0.96	0.64	0.03	0.60	12.89	15.98	22.14	33.43	18.54	8.84	8.84
402	Wednesday 25 April													
403	Thursday 26 April													
404	Friday 27 April													
405	Saturday 28 April													
406	Sunday 29 April													
407	Monday 30 April	0.12	0.12	0.42	0.25	0.05	0.58	8.25	9.03	21.17	33.35	17.00	7.06	8.02
408	Tuesday 01 May	0.07	0.10	0.33	0.25	0.03	0.07	8.47	8.95	23.73	38.60	18.92	7.70	8.34
409	Wednesday 02 May	0.04	0.05	0.31	0.25	0.03	0.03	8.98	9.15	27.77	38.92	19.24	7.70	8.34
410	Thursday 03 May	0.06	0.06	0.33	0.25	0.04	0.05	8.18	9.03	23.41	35.92	20.21	8.34	8.96
411	Friday 04 May	0.05	0.28	0.54	0.84	0.06	0.07	8.98	9.96	25.34	37.32	19.88	7.70	8.02
412	Saturday 05 May	0.08	0.08	0.50	0.37	0.05	1.20	9.85	10.10	24.62	33.35	17.96	7.78	7.78
413	Sunday 06 May	0.07	0.83	1.17	0.99	0.09	0.06	8.72	11.53	25.05	44.15	22.89	9.36	9.08
414	Monday 07 May	0.06	0.18	0.37	0.30	0.05	0.24	7.89	9.77	23.65	38.22	18.57	7.43	8.35
SS 76		0.13	1.29	4.40	1.23	0.11	0.00	18.07	13.61	21.79	38.38	20.94	11.60	10.33
415	Tuesday 08 May													
416	Wednesday 09 May													
417	Thursday 10 May	0.20	1.89	5.08	3.72	0.38	0.00	21.30	24.43	22.73	37.25	21.92	14.72	16.60
418	Friday 11 May	0.00	0.07	3.67	4.72	0.41	9.50	74.99	28.87	22.73	31.87	21.40	15.86	18.76
419	Saturday 12 May	0.00	0.08	3.40	2.67	0.34	12.89	77.34	28.63	21.92	33.19	22.48	17.22	18.28
420	Sunday 13 May	0.00	0.07	1.35	1.34	0.85	18.74	30.60	30.89	22.54	32.98	18.73	12.84	13.15
421	Monday 14 May	0.07	0.02	1.36	1.30	0.82	13.32	28.50	26.64	22.81	32.85	20.94	13.36	13.99
422	Tuesday 15 May	0.11	0.02	1.76	1.38	0.32	17.04	77.48	29.14	23.12	30.42	21.80	14.60	14.30
SS 77		0.01	0.50	3.01	2.59	0.44	9.21	25.46	25.35	22.31	32.51	21.51	14.11	14.60
423	Wednesday 16 May	0.11	0.01	0.37	0.30	0.15	2.57	18.14	17.52	23.73	29.81	19.18	13.27	14.30
424	Thursday 17 May	0.00	0.00	0.13	0.04	0.05	0.35	10.08	15.14	24.03	30.72	22.21	13.59	13.99
425	Friday 18 May	0.03	0.07	0.11	0.08	0.05	0.10	9.84	11.04	25.52	22.64	15.21	16.73	16.41
426	Saturday 19 May	0.03	0.03	0.13	0.08	0.05	0.03	9.57	11.51	25.29	33.77	20.99	10.65	11.56
427	Sunday 20 May	0.03	0.03	0.10	0.07	0.12	0.11	7.28	10.66	22.77	32.42	20.38	10.19	11.42
428	Monday 21 May	0.04	0.02	0.05	0.01	0.13	0.08	8.32	11.13	24.08	32.13	18.43	11.73	11.47
429	Tuesday 22 May	0.06	0.03	0.05	0.03	0.09	0.19	8.94	11.14	23.48	33.41	18.22	9.18	9.10
430	Wednesday 23 May													
431	Thursday 24 May	0.07	0.04	0.10	0.18	0.03	0.11	9.43	10.36	24.08	36.43	19.78	7.41	8.95
432	Friday 25 May	0.04	0.05	0.13	0.02	0.02	0.07	9.17	10.66	24.08	37.36	20.69	8.34	8.64
433	Saturday 26 May													
434	Sunday 27 May	0.01	0.04	0.23	0.10	0.10	0.18	4.46	10.73	23.16	38.21	23.46	11.11	10.19
435	Monday 28 May	0.02	0.03	0.18	0.16	0.21	0.10	8.82	9.43	22.94	35.88	21.34	8.24	10.51
436	Tuesday 29 May	0.02	0.02	0.18	0.06	0.13	0.53	8.79	9.85	22.88	38.17	20.07	9.24	8.37
437	Wednesday 30 May	0.02	0.04	0.36	0.11	0.07	0.13	9.53	9.92	22.57	40.05	21.34	9.24	7.43
438	Thursday 31 May	0.03	0.05	0.23	0.15	0.06	0.59	9.93	10.13	23.89	40.14	21.88	8.28	8.00
439	Friday 01 June													
440	Saturday 02 June													
441	Sunday 03 June													
442	Monday 04 June	0.10	0.17	0.48	0.33	0.17	0.53	9.19	9.70	23.89	35.88	17.52	8.05	5.42
443	Tuesday 05 June	0.02	0.05	0.98	0.23	0.08	0.08	8.87	9.92	23.89	38.32	18.48	7.33	5.42
444	Wednesday 06 June	0.05	0.20	0.40	0.21	0.29	1.18	16.45	17.45	22.36	33.62	14.15	6.14	7.26
445	Thursday 07 June	0.05	0.34	0.50	0.22	0.18	1.53	11.87	13.44	26.30	37.97	18.10	8.14	7.20
SS 78		0.04	0.08	0.96	0.72	0.11	0.28	9.43	11.95	24.13	35.42	20.35	8.66	9.30
446	Friday 08 June	0.06	0.07	0.28	0.17	0.09	0.08	8.81	11.48	27.53	32.26	21.60	10.33	9.08
447	Saturday 09 June	0.05	0.06	0.27	0.40	0.05	0.10	10.43	10.09	27.87	43.52	23.68	12.52	11.90
448	Sunday 10 June													
449	Monday 11 June													
450	Tuesday 12 June	0.10	0.06	0.37	0.27	0.08	0.13	16.22	10.53	17.87	43.32	13.48	12.32	10.33
451	Wednesday 13 June	0.03	0.04	0.42	0.19	0.06	0.47	10.66	10.41					

Day Mo	1990	Phosphorus MB					Nitrogen MB					CO2 MB				M	% BA
		Aerobic mgP/ft ³ est.	Anoxic mgP/ft ³ est.	Aerobic mgP/ft ³ ind.	Sediment mgP/ft ³ ind.	Removal mgP/ft ³ ind.	N denit	N in Vssal	TKN in Eff	NO3 in Eff	MB mgO/d	MOC mgO/d	MOD mgO/d	CO2 in VV	CO2 in Eff		
245	Sunday	17															
246	Monday	18															
247	Tuesday	19															
248	Wednesday	20															
249	Thursday	21															
250	Friday	22															
251	Saturday	23															
252	Sunday	24															
253	Monday	25															
254	Tuesday	26															
255	Wednesday	27															
256	Thursday	28															
257	Friday	29															
258	Saturday	30															
259	Sunday	01															
260	Monday	02															
261	Tuesday	03															
262	Wednesday	04															
263	Thursday	05															
264	Friday	06															
265	Saturday	07															
266	Sunday	08															
267	Monday	09															
268	Tuesday	10															
269	Wednesday	11															
270	Thursday	12															
271	Friday	13															
272	Saturday	14															
273	Sunday	15															
274	Monday	16															
275	Tuesday	17															
276	Wednesday	18															
277	Thursday	19															
278	Friday	20															
279	Saturday	21															
280	Sunday	22															
281	Monday	23															
282	Tuesday	24															
283	Wednesday	25															
284	Thursday	26															
285	Friday	27															
286	Saturday	28															
287	Sunday	29															
288	Monday	30															
289	Tuesday	31															
290	Wednesday	01															
291	Thursday	02															
292	Friday	03															
293	Saturday	04															
294	Sunday	05															
295	Monday	06															
296	Tuesday	07															
297	Wednesday	08															
298	Thursday	09															
299	Friday	10															
300	Saturday	11															
301	Sunday	12															
302	Monday	13															
303	Tuesday	14															
304	Wednesday	15															
305	Thursday	16															
306	Friday	17															
307	Saturday	18															
308	Sunday	19															
309	Monday	20															
310	Tuesday	21															
311	Wednesday	22															
312	Thursday	23															
313	Friday	24															
314	Saturday	25															
315	Sunday	26															
316	Monday	27															
317	Tuesday	28															
318	Wednesday	29															
319	Thursday	30															
320	Friday	31															
321	Saturday	01															
322	Sunday	02															
323	Monday	03															
324	Tuesday	04															
325	Wednesday	05															
326	Thursday	06															
327	Friday	07															
328	Saturday	08															
329	Sunday	09															
330	Monday	10															
331	Tuesday	11															
332	Wednesday	12															
333	Thursday	13															
334	Friday	14															
335	Saturday	15															
336	Sunday	16															
337	Monday	17															
338	Tuesday	18															
339	Wednesday	19															
340	Thursday	20															
341	Friday	21															
342	Saturday	22															
343	Sunday	23															
344	Monday	24															
345	Tuesday	25															
346	Wednesday	26															
347	Thursday	27															
348	Friday	28															
349	Saturday	29															
350	Sunday	30															
351	Monday	31															
352	Tuesday	01															
353	Wednesday	02															
354	Thursday	03															
355	Friday	04															
356	Saturday	05															
357	Sunday	06															
358	Monday	07															

Day No	1998	Phosphorus MB					Nitrogen MB					CDD MB					%	h ₂ O	
		Ambio mgPA ml	Ambio mgPA ml	Ambio mgPA ml	Surber mgPA ml	Removal mgPA ml	N total mgPA ml	N in Water mgPA ml	N in Sediment mgPA ml	N in Fish mgPA ml	N in Egg mgPA ml	W/B mgPA ml	MOC mgPA ml	UOD mgPA ml	CDD in Egg mgPA ml	CDD in Egg mgPA ml			
371	Sunday	23	33.55	7.42	-35.87	-1.13	-15.74	338.53	260.40	84.40	203.50	64.64	4220.75	1543.07	484.00	453.12	50.41	0.19	
372	Monday	24	33.43	1.56	-33.43	0.00	-14.75	362.90	226.80	132.70	212.88	60.70	3880.16	1087.10	4810.97	205.84	80.92	0.19	
373	Tuesday	25																	
374	Wednesday	26	30.85	0.95	-33.82	2.97	-13.86	583.34	243.80	51.80	210.87	80.24	462.01	1616.64	4694.96	692.24	92.99	0.19	
375	Thursday	27	32.38	1.19	-48.70	0.59	-14.53	535.31	274.40	42.40	210.87	112.09	4767.53	1645.30	4773.32	695.84	106.09	0.20	
376	Friday	28	32.64	4.93	-44.34	1.23	-15.40	474.44	177.26	47.80	200.49	64.64	5147.90	1356.56	4609.38	814.10	92.32	0.19	
377	Saturday	29	30.79	1.31	-48.64	1.23	-14.10	481.41	252.00	44.80	205.59	78.70	4921.89	1495.45	4434.18	691.24	84.74	0.18	
378	Sunday	30	27.41	12.53	-33.43	3.10	-11.70	450.13	242.20	32.70	193.10	82.16	5150.87	1261.37	4773.57	455.12	99.03	0.16	
379	Monday	31	28.84	8.91	-48.64	0.00	-11.70	475.80	240.80	38.20	193.10	82.16	4730.76	1360.22	4601.68	607.68	84.55	0.15	
380	Tuesday	01	27.48	14.21	-30.50	0.00	-13.53	408.18	286.80	33.20	178.12	70.27	4467.88	1138.83	5212.08	772.78	64.05	0.09	
381	Wednesday	02	32.83	4.84	-32.30	0.68	-13.87	515.48	268.51	48.45	187.91	84.33	4683.30	1374.28	4733.20	816.17	86.80	0.18	
382	Thursday	03																	
383	Friday	04																	
384	Saturday	05																	
385	Sunday	06																	
386	Monday	07																	
387	Tuesday	08	34.81	4.87	-35.56	-7.82	-15.24	935.61	288.40	87.20	413.49	90.49	2816.50	2879.85	4680.79	1231.20	73.16	0.14	
388	Wednesday	09	38.03	-2.54	-32.07	2.54	-15.24	970.98	271.80	87.20	413.49	101.84	2827.14	2770.93	4514.40	1272.74	87.37	0.18	
389	Thursday	10	31.43	7.22	-48.70	2.54	-12.07	927.13	248.00	54.60	368.12	106.48	3539.70	2652.73	4869.38	1022.56	88.96	0.18	
390	Friday	11	25.06	6.86	-43.72	1.77	-12.38	666.77	115.60	42.00	373.13	93.04	4008.96	2483.25	4392.40	1022.00	80.56	0.16	
391	Saturday	12	23.40	3.18	-43.18	1.37	-13.34	706.00	210.00	47.60	336.18	98.98	4083.33	2501.18	4415.04	1144.64	80.31	0.13	
392	Sunday	13	27.48	7.88	-46.56	-0.03	-13.84	634.83	200.60	46.80	387.70	75.87	5505.17	1515.03	4548.49	1102.76	102.03	0.15	
393	Monday	14	30.93	0.28	-43.87	-5.67	-15.57	670.44	235.20	42.00	248.71	74.43	4810.15	1917.46	4128.68	899.36	69.87	0.21	
394	Tuesday	15	24.90	0.32	-38.80	-1.29	-14.87	873.78	187.80	43.00	373.33	71.11	4520.57	1628.77	3881.84	981.12	79.86	0.16	
395	Wednesday	16	27.48	-1.94	-22.33	-7.78	-14.53	652.30	173.80	39.20	286.30	71.77	4548.78	1955.58	3731.52	811.20	49.93	0.16	
396	Thursday	17																	
397	Friday	18																	
398	Saturday	19																	
399	Sunday	20																	
400	Monday	21	24.83	-0.05	-43.84	1.30	-15.87												
401	Tuesday	22																	
402	Wednesday	23	29.21	0.51	-42.70	-1.42	-14.40	604.38	730.84	49.83	320.66	87.33	4055.06	2300.53	4374.56	1054.17	81.72	0.18	
403	Thursday	24																	
404	Friday	25																	
405	Saturday	26																	
406	Sunday	27																	
407	Monday	28	28.54	-3.85	-39.77	1.28	-13.79	397.08	210.00	48.20	185.56	86.09	3740.54	1135.85	3934.32	973.44	89.34	0.18	
408	Tuesday	29	78.54	0.32	-44.80	0.54	-18.04	442.89	214.40	39.70	183.06	78.28	3730.60	1298.09	3870.72	887.04	72.00	0.26	
409	Wednesday	30	29.83	0.64	-48.18	0.64	-15.07	474.20	218.80	49.00	188.04	64.83	3778.94	1356.22	3790.08	1048.32	67.73	0.17	
410	Thursday	01	28.22	3.53	-47.47	0.84	-15.87	318.87	207.20	49.00	185.56	80.06	3849.61	1468.82	3749.78	927.36	83.91	0.20	
411	Friday	02																	
412	Saturday	03	29.83	0.84	-48.33	0.84	-17.32	568.13	243.80	33.70	212.86	80.86	4864.65	1876.32	4112.64	1209.60	89.16	0.19	
413	Sunday	04	24.70	0.84	-42.33	0.00	-17.00	610.16	208.00	44.80	193.84	77.99	4548.84	2011.64	4411.20	112.32	90.12	0.18	
414	Monday	05	38.45	2.82	-37.81	-1.88	-17.77	537.40	100.00	37.50	297.49	81.87	4142.42	1536.36	4090.24	77.62	62.68	0.16	
415	Tuesday	06	29.67	0.63	-48.72	0.26	-15.93	456.65	214.60	44.40	100.27	81.31	4142.64	1920.42	3908.61	1106.74	52.41	0.16	
416	Wednesday	07	78.49	-0.84	-36.22	-1.13	-14.90	1010.17	136.80	35.00	296.87	88.75	3102.13	2466.08	3306.24	1205.60	91.78	0.15	
417	Thursday	08																	
418	Friday	09	20.35	0.84	-36.81	1.68	-7.51	1579.28	162.40	30.80	603.33	118.34	382.80	4317.73	3147.78	735.84	68.78	0.23	
419	Saturday	10	19.41	-3.82	-23.80	1.88	-5.32	1011.31	198.80	28.00	431.85	96.05	3521.96	2892.30	3587.44	899.36	77.85	0.24	
420	Sunday	11	20.94	0.34	-35.06	-1.68	-5.64	807.82	176.40	44.80	613.84	82.59	2517.16	2210.38	2861.60	1103.78	77.82	0.24	
421	Monday	12	22.86	-3.32	-37.55	0.00	-10.02	573.40	205.80	32.20	336.81	67.78	4069.81	1640.14	3474.80	817.63	68.77	0.25	
422	Tuesday	13	21.90	-1.52	-30.42	0.41	-9.43	730.30	238.00	46.60	600.77	69.94	4441.48	2088.86	3315.08	981.12	63.04	0.21	
423	Wednesday	14	15.87	7.91	-35.20	7.83	-9.13	415.17	198.00	53.20	610.49	79.12	4430.35	2231.36	3474.80	899.36	107.59	0.21	
424	Thursday	15	71.40	-0.17	-26.60	0.26	-4.42	332.50	164.60	17.80	370.63	85.66	2787.18	2808.96	3339.76	648.52	85.74	0.22	
425	Friday	16	10.73	-3.04	-20.77	7.83	-10.03	1009.80	171.20	38.40	558.49	133.34	2578.70	2088.96	1507.44	699.36	78.13	0.17	
426	Saturday	17	15.71	7.60	-37.85	-2.61	-10.85	864.10	228.20	58.60	304.44	26.05	3826.25	1941.10	4008.74	694.96	78.79	0.18	
427	Sunday	18	15.81	10.34	-37.72	-3.43	-8.43	811.37	217.80	44.80	722.15	81.87	4186.04	1748.51	4455.92	1022.00	83.82	0.26	
428	Monday	19	21.29	-4.56	-41.37	1.83	-13.89	625.11	235.80	36.40	277.29	62.53	4810.70	1784.96	4453.92	1144.64	90.63	0.19	
429	Tuesday	20	20.68	3.25	-40.75	1.85	-12.97	504.56	222.80	42.00	313.59	72.87	3530.84	1443.06	4868.18	1582.86	96.29	0.18	
430	Wednesday	21	22.54	4.17	-46.40	-1.23	-13.26	534.29	238.40	21.00	222.80	78.68	5371.89	1595.27	4569.60	1020.00	64.35	0.18	
431	Thursday	22	23.00	2.47	-44.46	-0.42	-14.98	565.96	282.80	35.00	222.80	83.81	5217.78	1618.82	5181.90	1101.60	83.48	0.17	
432	Friday	23	29.02	3.18	-49.40	2.47	-15.25	578.83	254.80	36.40	222.80	81.50	5682.48	1849.73	5059.20	1020.00	95.00	0.21	
433	Saturday	24	29.35	3.40	-48.40	0.00	-16.05	578.70	274.80	43.80	211.58	82.54	5040.87	1849.38	4877.60	816.00	69.01	0.18	
434	Sunday	25																	
435	Monday	26	31.60	8.18	-48.40	-3.09	-14.70	548.17	198.20	33.20	218.86								

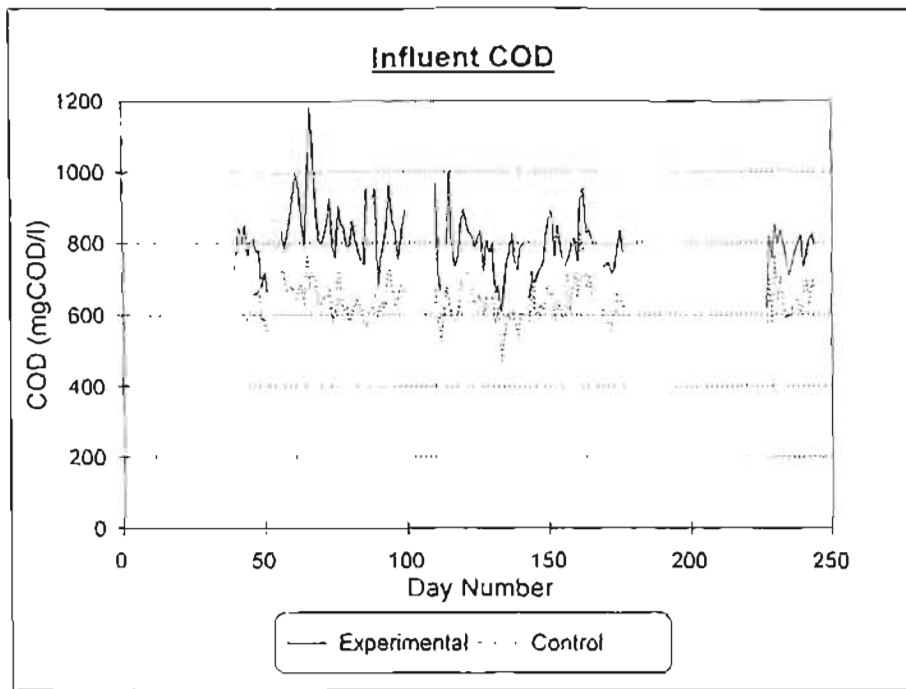


Figure A1: Daily unfiltered influent COD concentrations in EXP and CTL systems from day 1 to day 250.

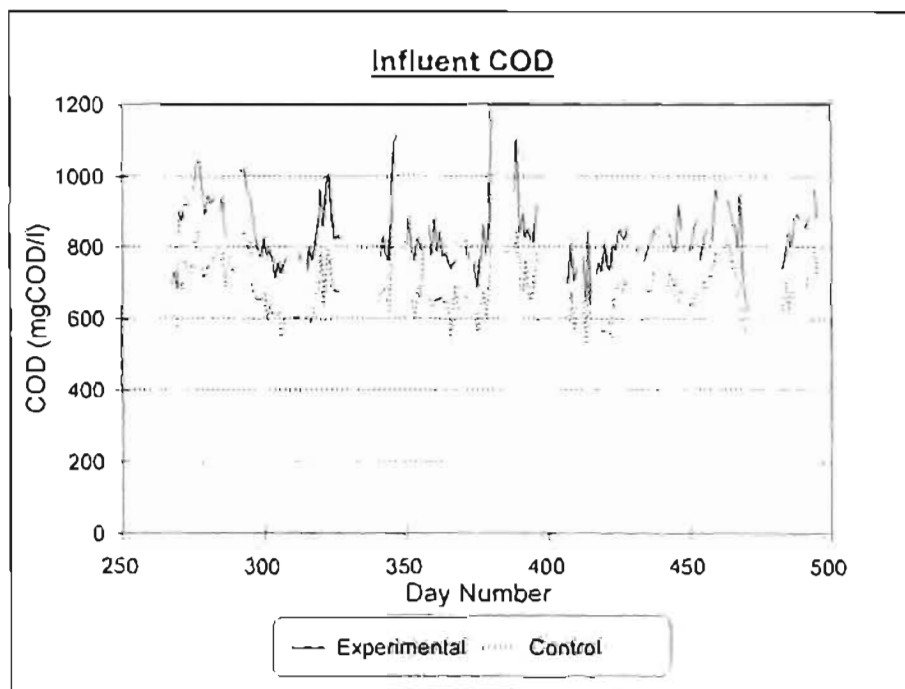


Figure A2: Daily unfiltered influent COD concentrations in EXP and CTL systems from day 251 to day 495.

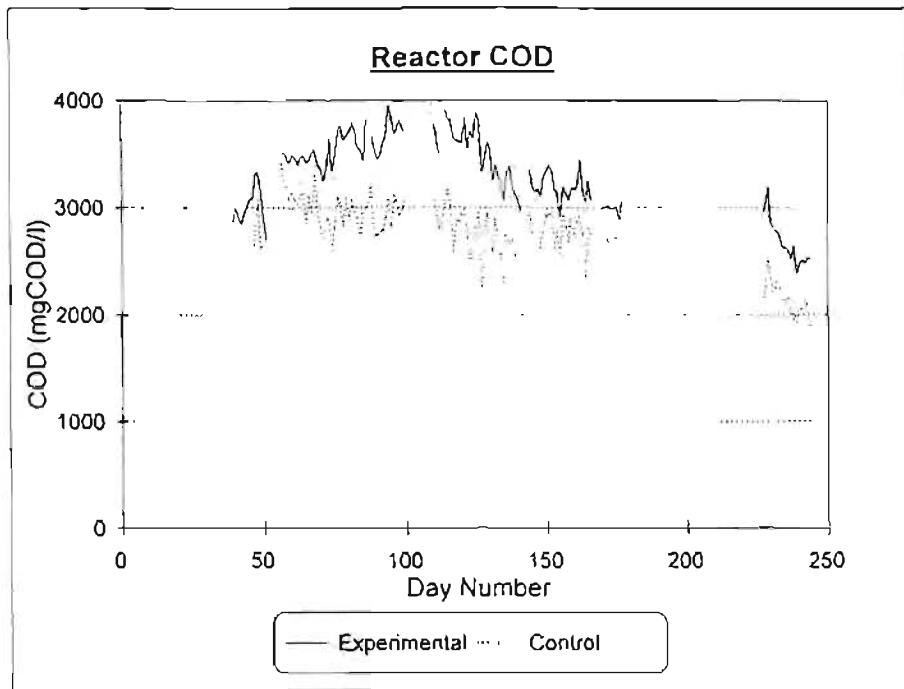


Figure A3: Daily aerobic reactor COD concentrations in EXP and CTL systems from day 1 to day 250.

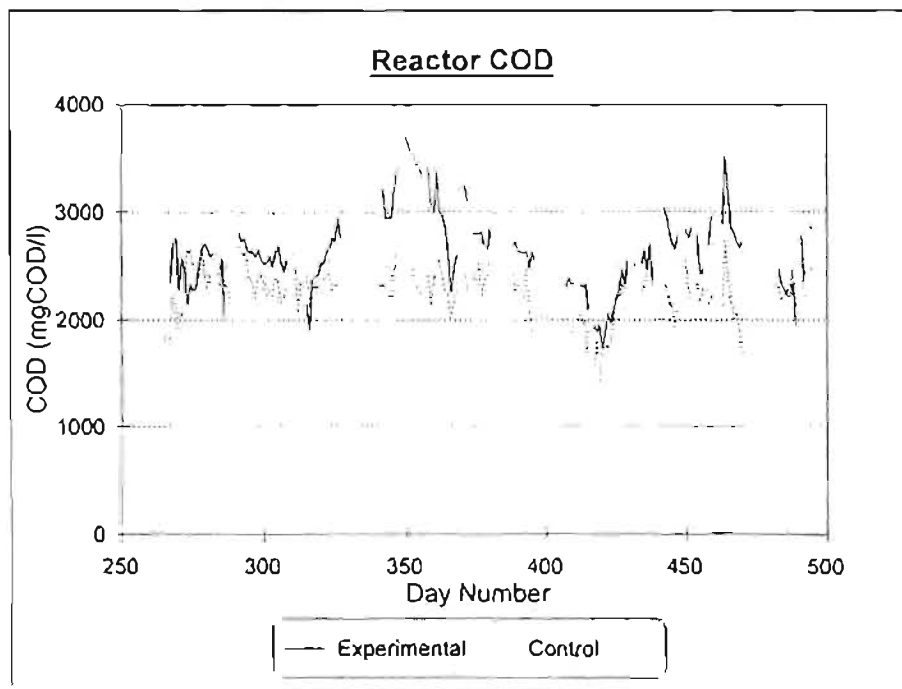


Figure A4: Daily aerobic reactor COD concentrations in EXP and CTL systems from day 251 to day 495.

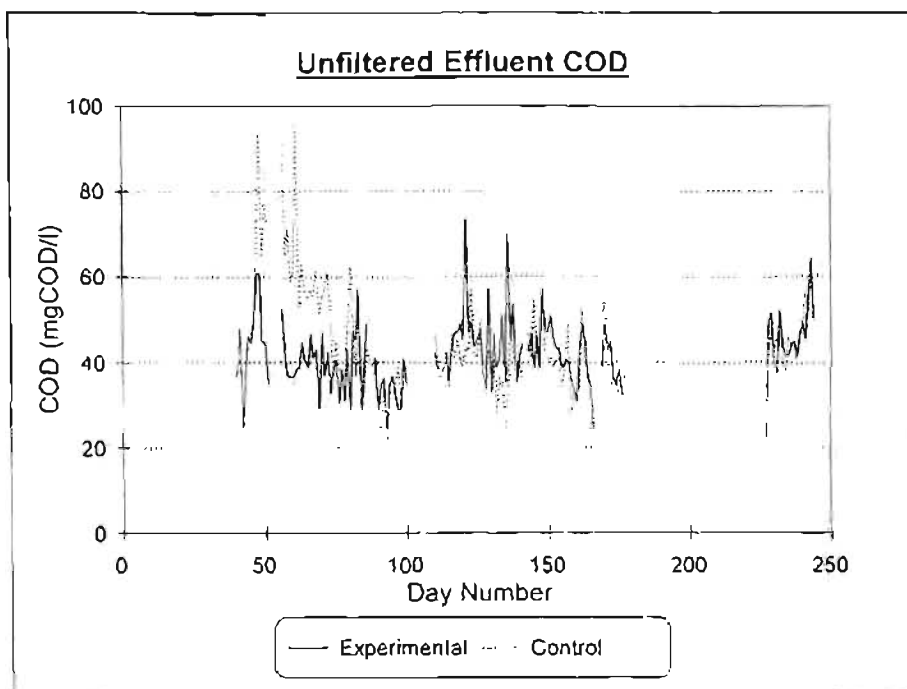


Figure A5: Daily unfiltered effluent COD concentrations in EXP and CTL system from day 1 to day 250.

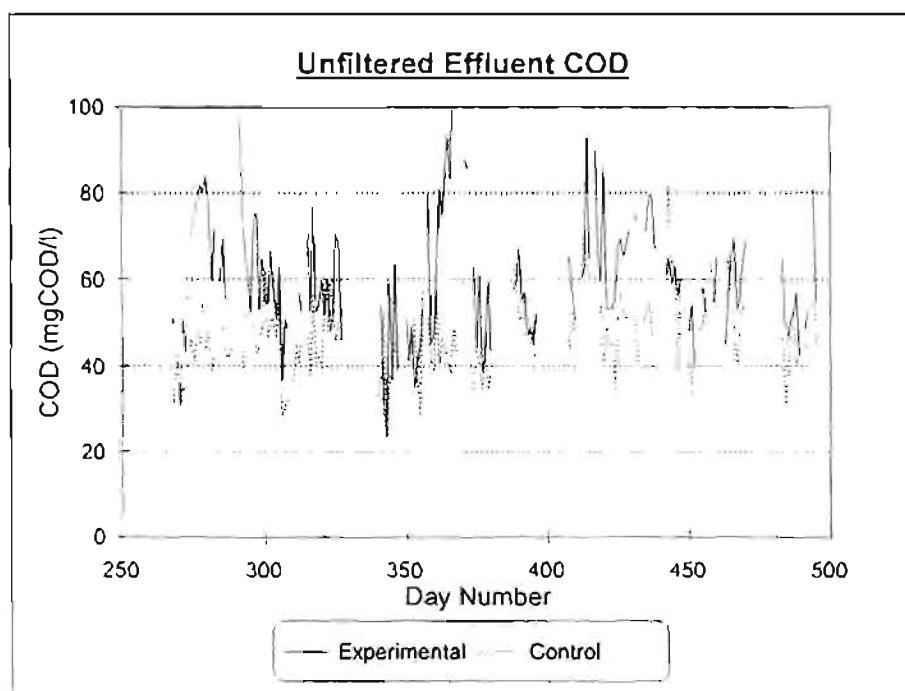


Figure A6: Daily unfiltered effluent COD concentrations in EXP and CTL system from day 251 to day 495.

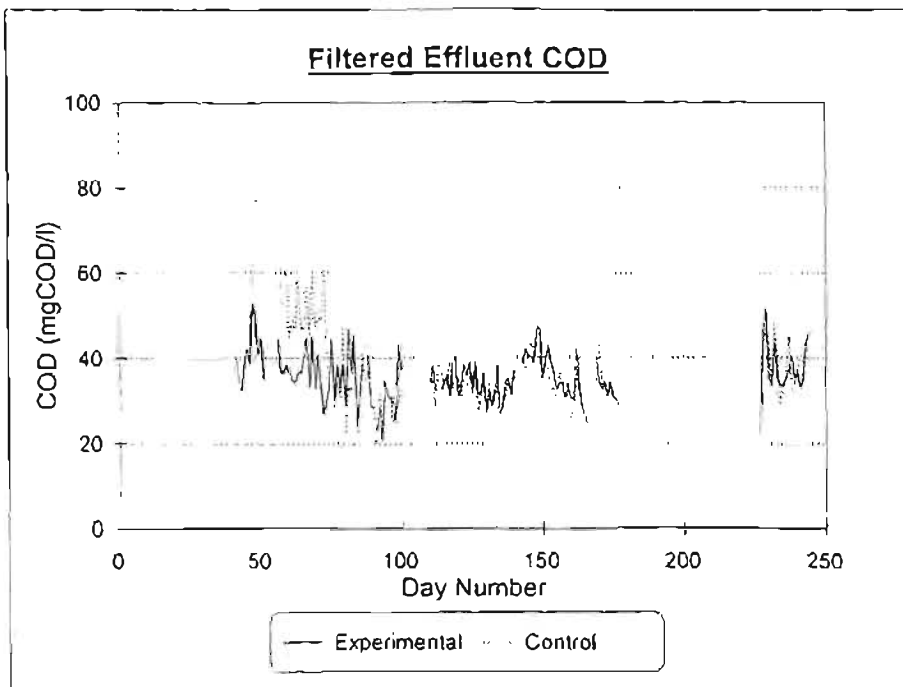


Figure A7: Daily filtered effluent COD concentrations in EXP and CTL systems from day 1 to day 250.

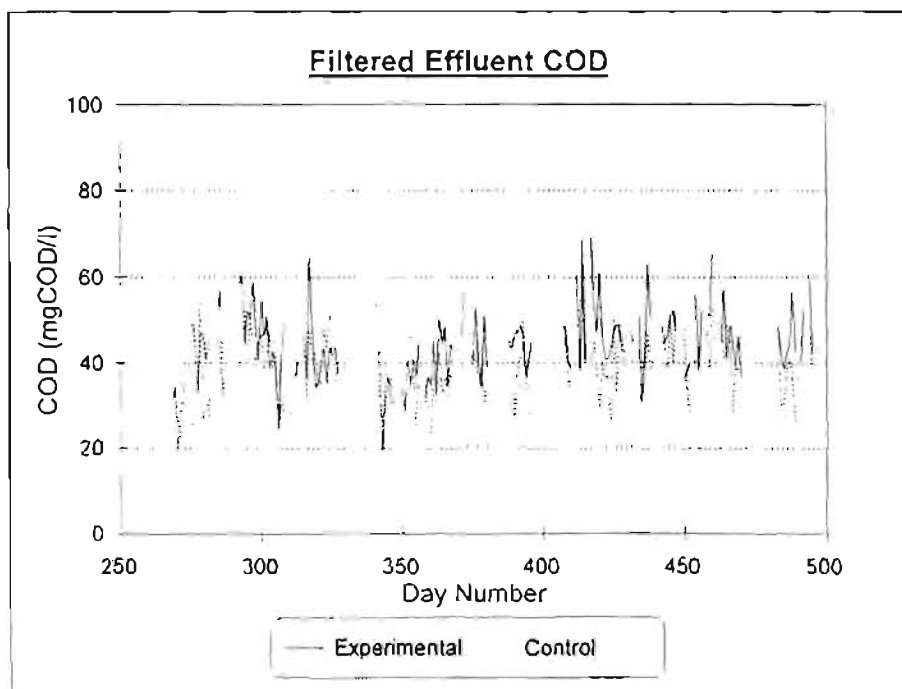


Figure A8: Daily filtered effluent COD concentrations in EXP and CTL systems from day 251 to day 495.

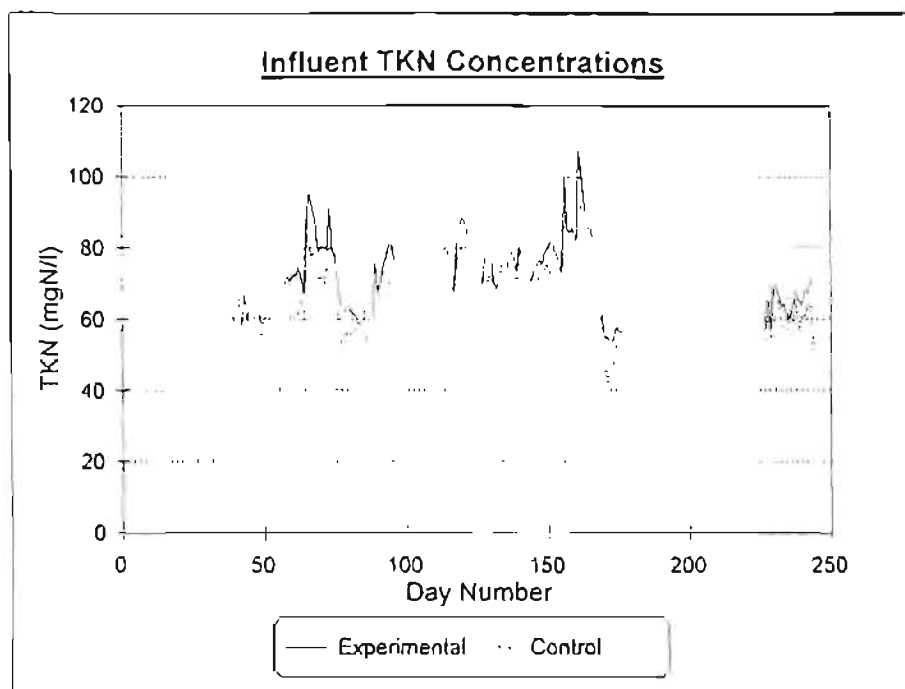


Figure A9: Daily unfiltered influent TKN concentrations in EXP and CTL systems from day 1 to day 250.

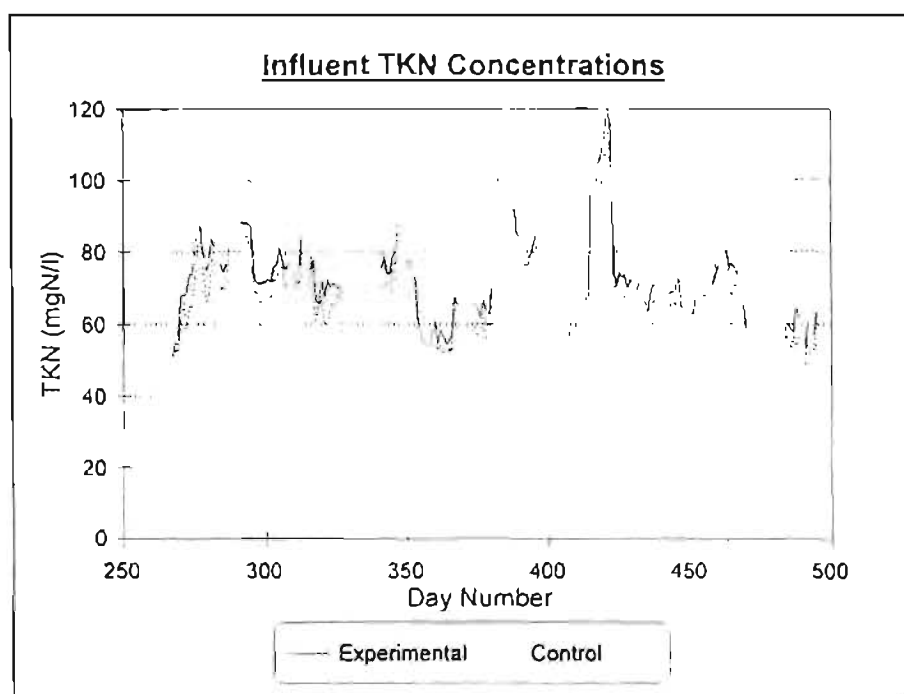


Figure A10: Daily unfiltered influent TKN concentrations in EXP and CTL systems from day 251 to day 495.

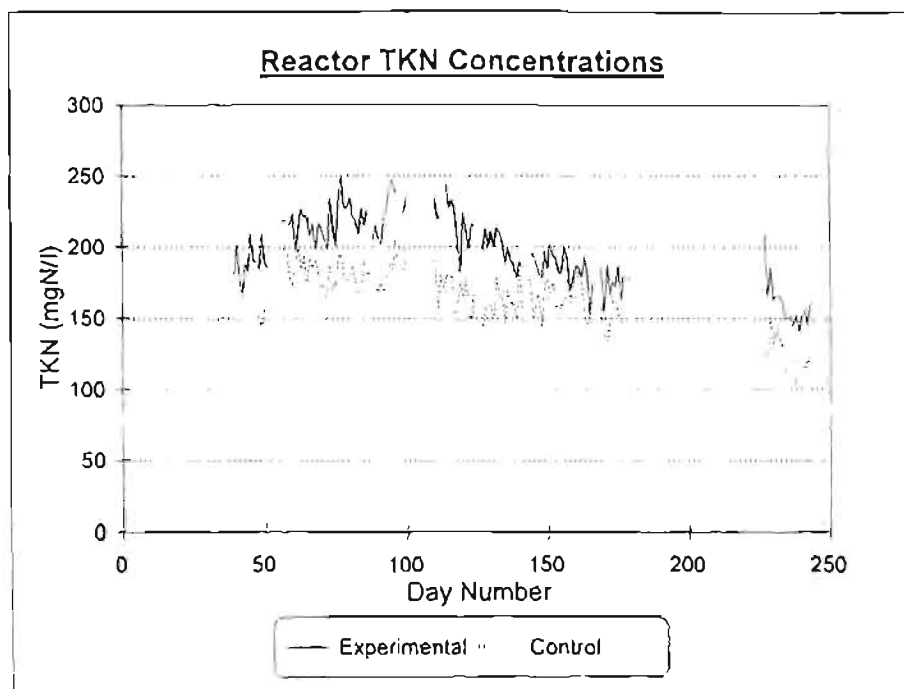


Figure A11: Daily aerobic reactor TKN concentrations in EXP and CTL systems from day 1 to day 250.

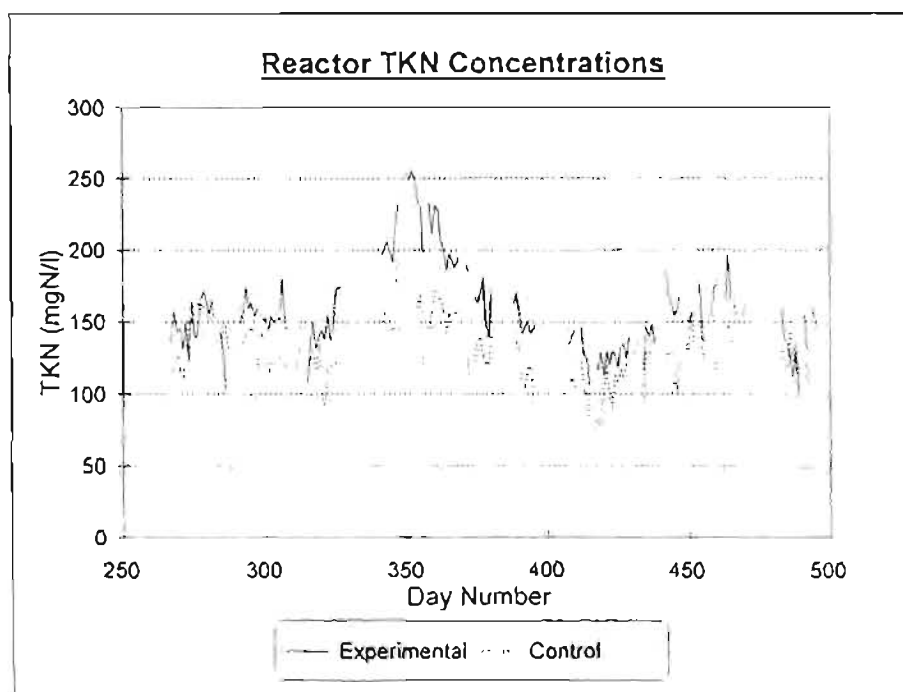


Figure A12: Daily aerobic reactor TKN concentrations in EXP and CTL systems from day 251 to day 495.

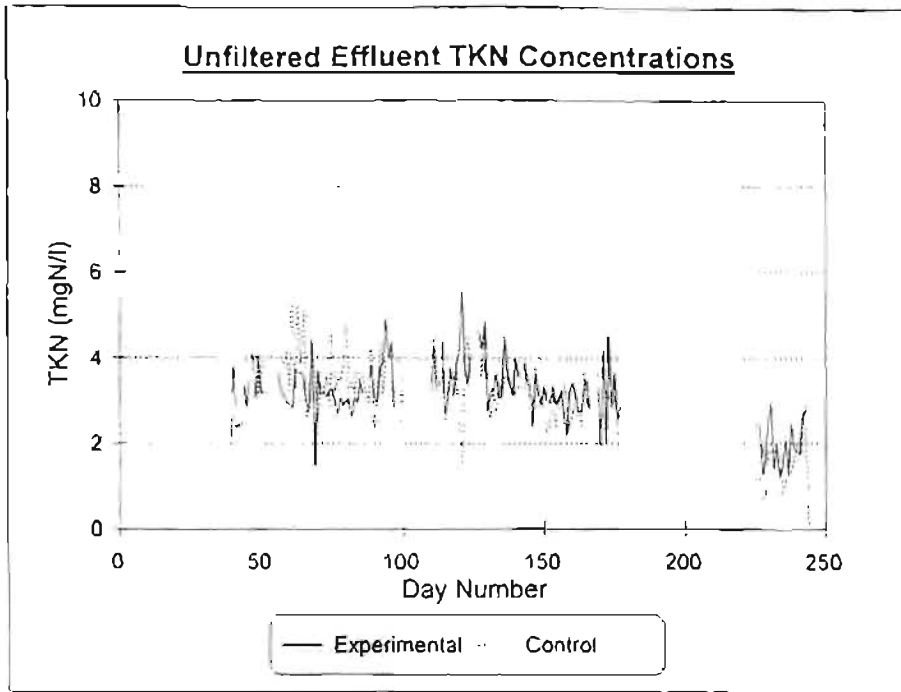


Figure A13: Daily unfiltered effluent TKN concentrations in EXP and CTL systems from day 1 to day 250.

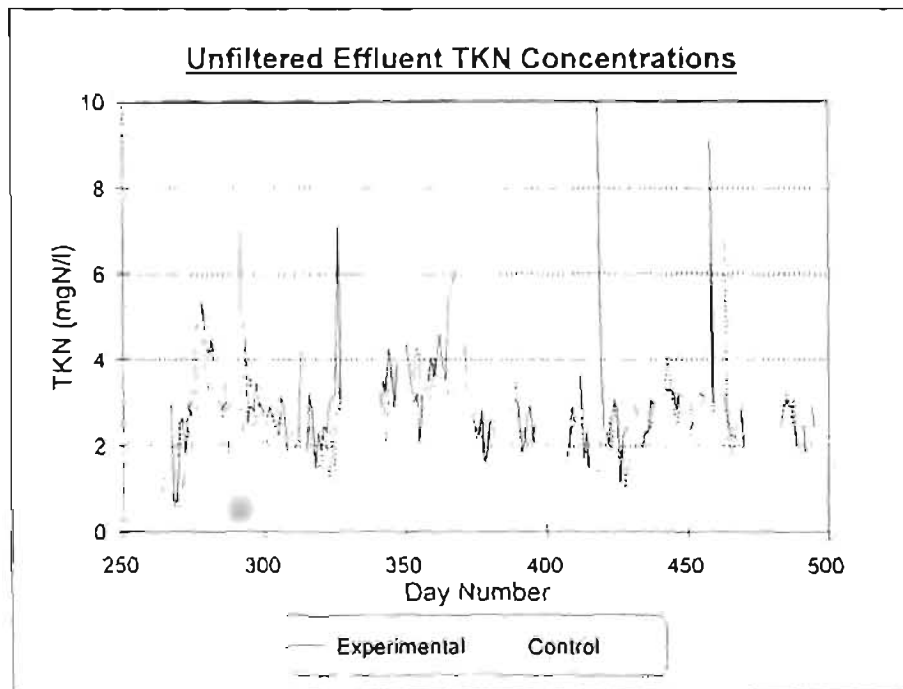


Figure A14: Daily unfiltered effluent TKN concentrations in EXP and CTL systems from day 251 to day 495.

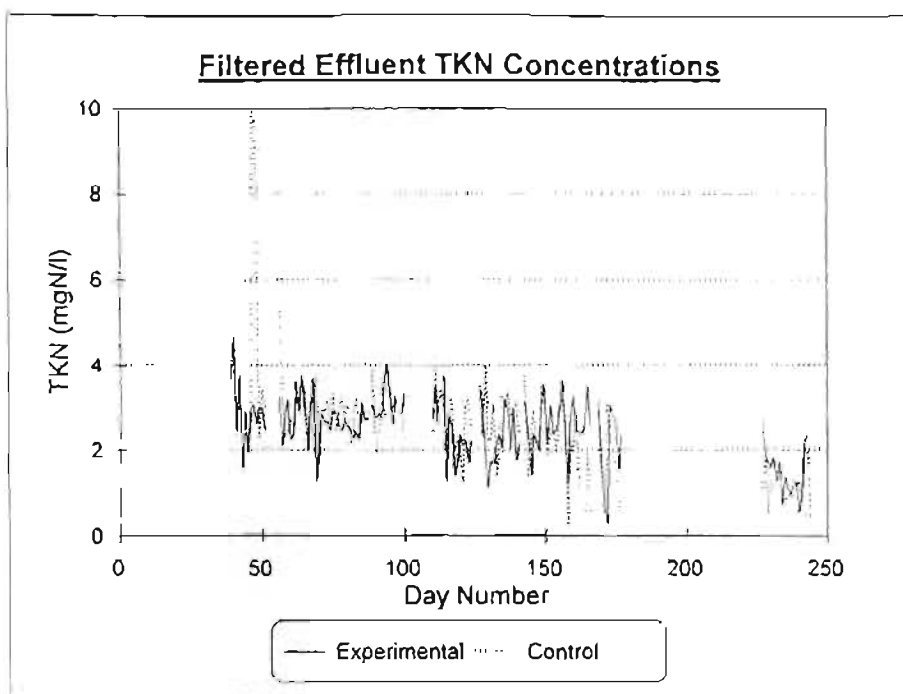


Figure A15: Daily filtered effluent TKN concentrations in EXP and CTL systems from day 1 to day 250.

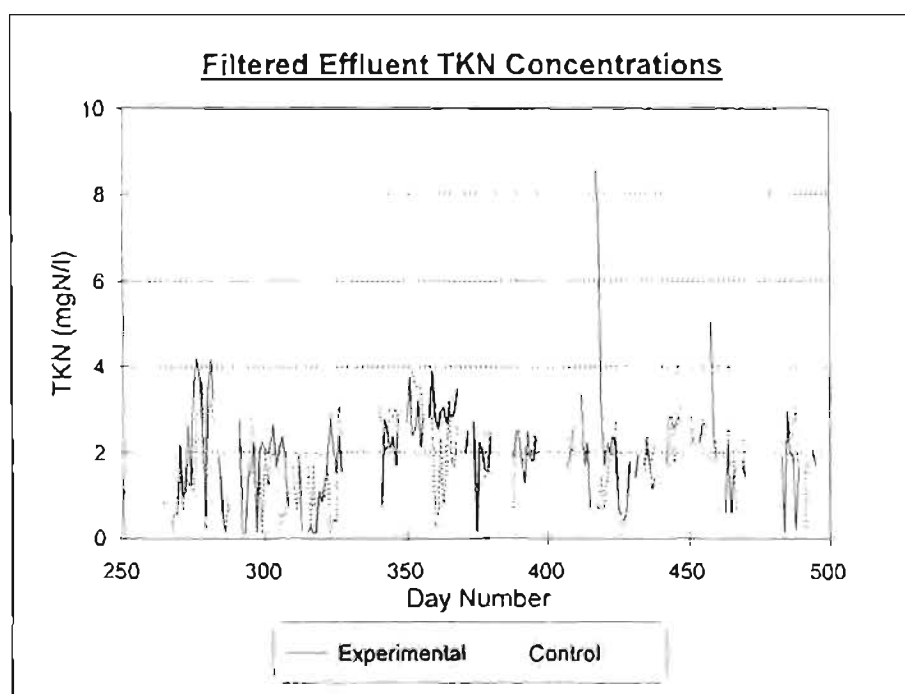


Figure A16: Daily filtered effluent TKN concentrations in EXP and CTL systems from day 251 to day 495.

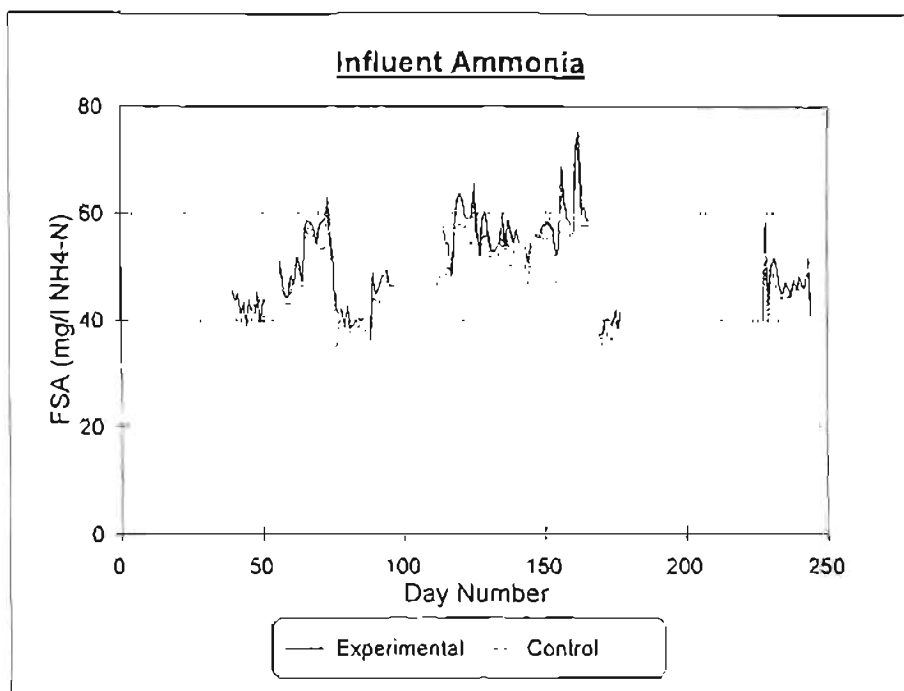


Figure A17: Daily influent Ammonia concentrations in EXP and CTL systems from day 1 to day 250

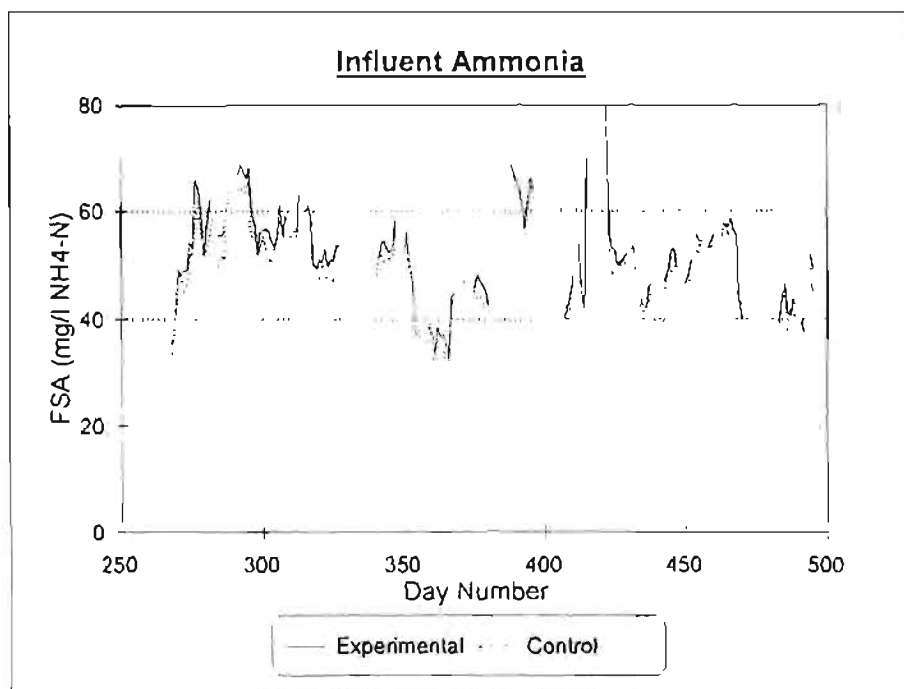


Figure A18: Daily influent Ammonia concentrations in EXP and CTL systems from day 251 to day 495.

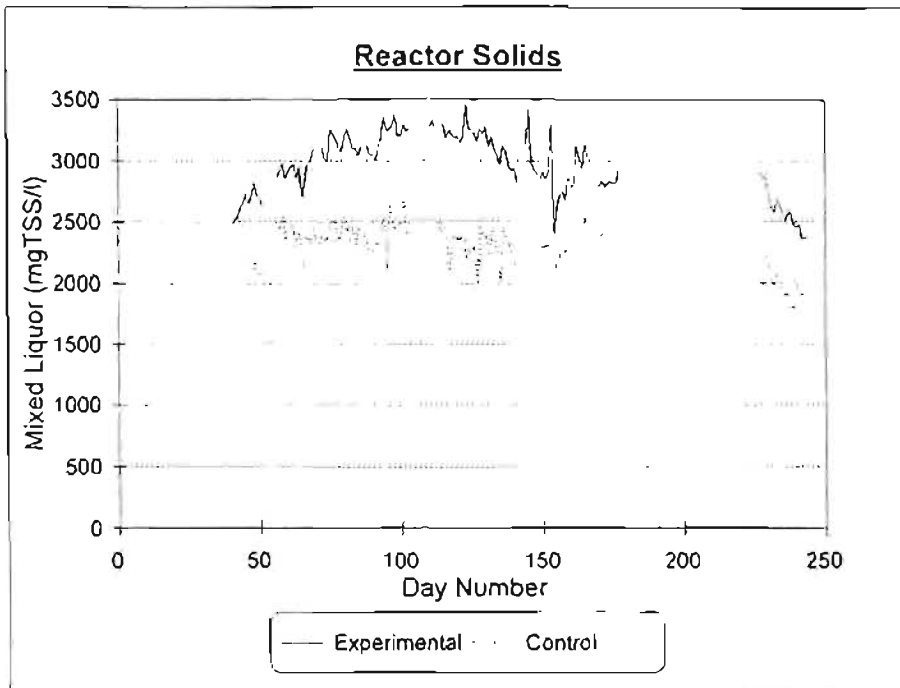


Figure A19: Daily aerobic reactor mixed liquor Total Suspended Solids concentrations in EXP and CTL systems from day 1 to day 250.

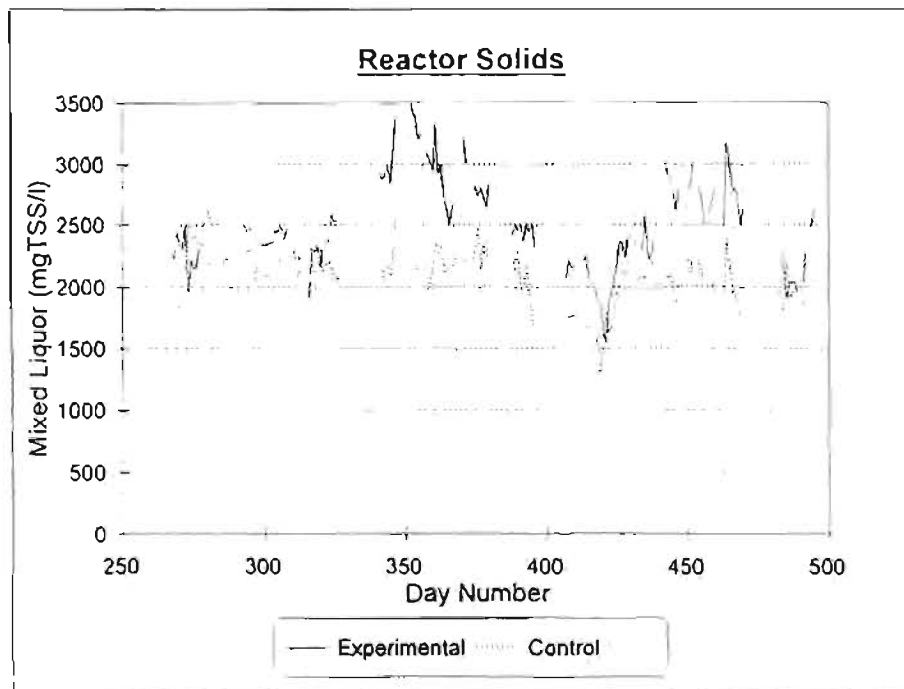


Figure A20: Daily aerobic reactor mixed liquor Total Suspended Solids concentrations in EXP and CTL systems from day 251 to day 495.

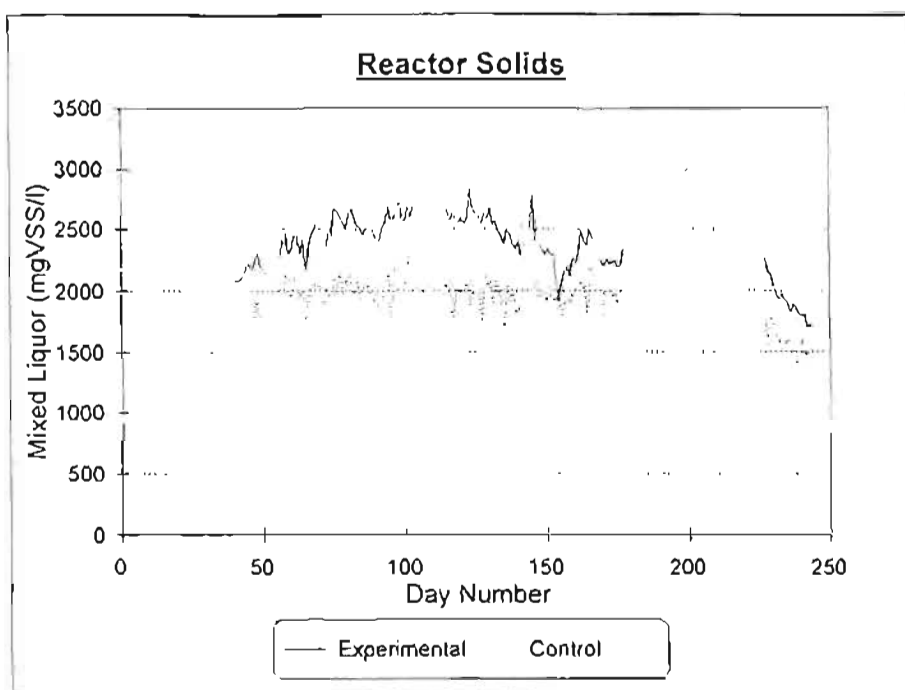


Figure A21: Daily aerobic reactor mixed liquor Volatile Suspended Solids concentrations in EXP and CTL systems from day 1 to day 250.

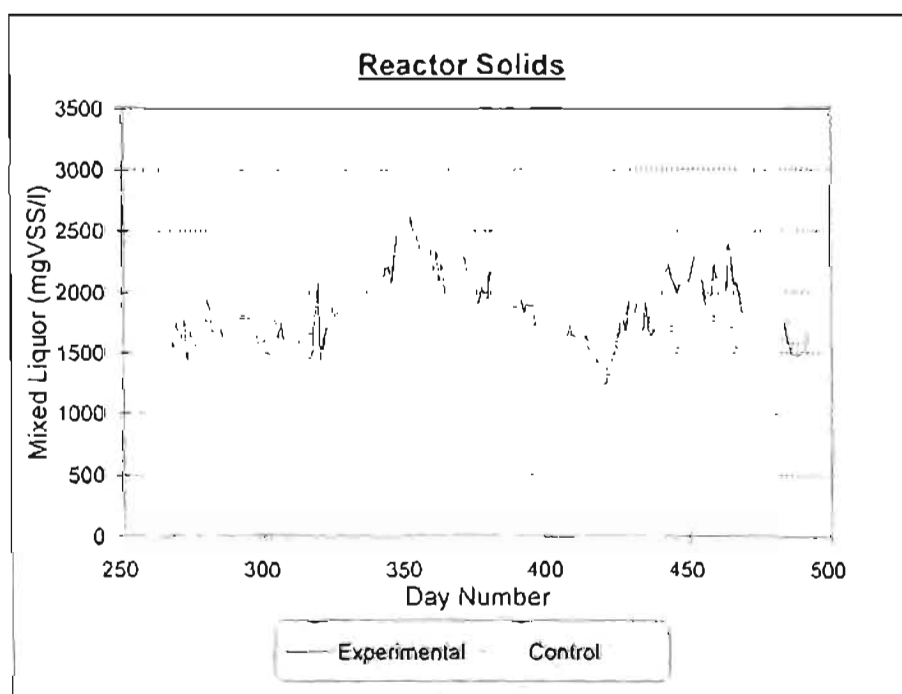


Figure A22: Daily aerobic reactor mixed liquor Volatile Suspended Solids concentrations in EXP and CTL systems from day 251 to day 495.

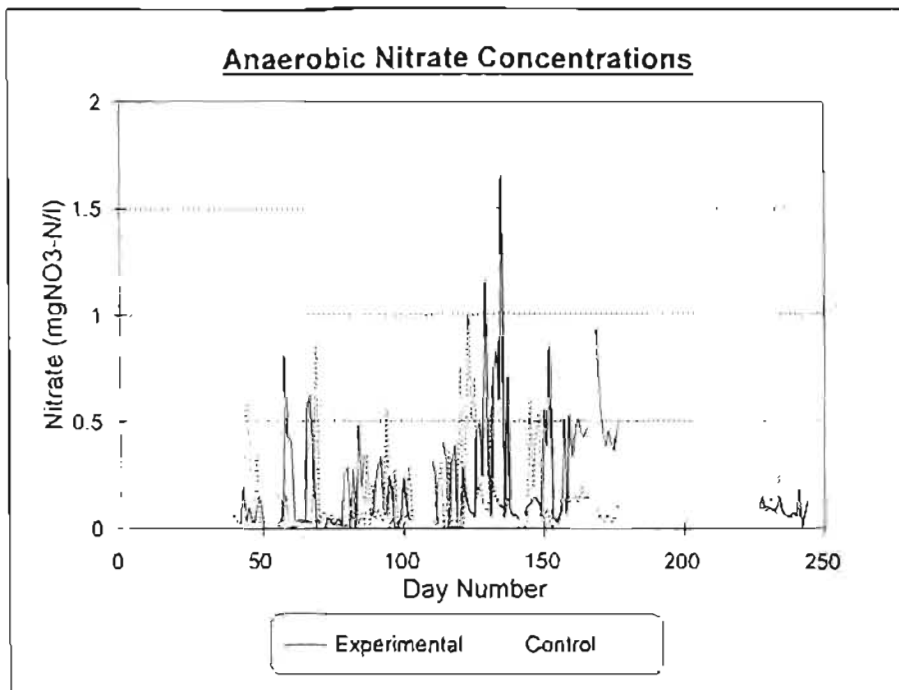


Figure A23: Daily anaerobic reactor Nitrate concentrations in EXP and CTL systems from day 1 to day 250.

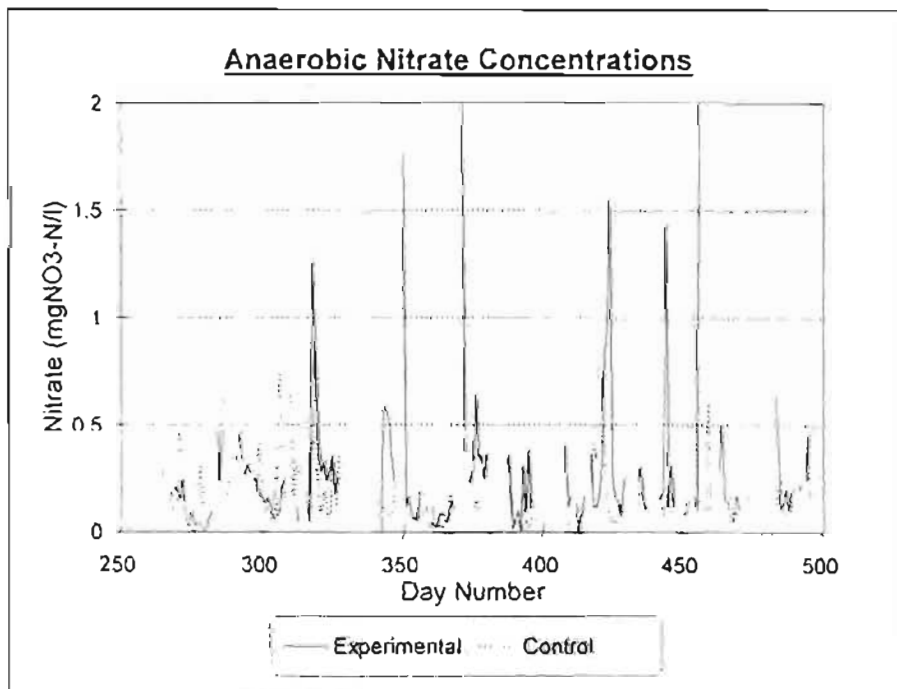


Figure A24: Daily anaerobic reactor Nitrate concentrations in EXP and CTL systems from day 251 to day 495.

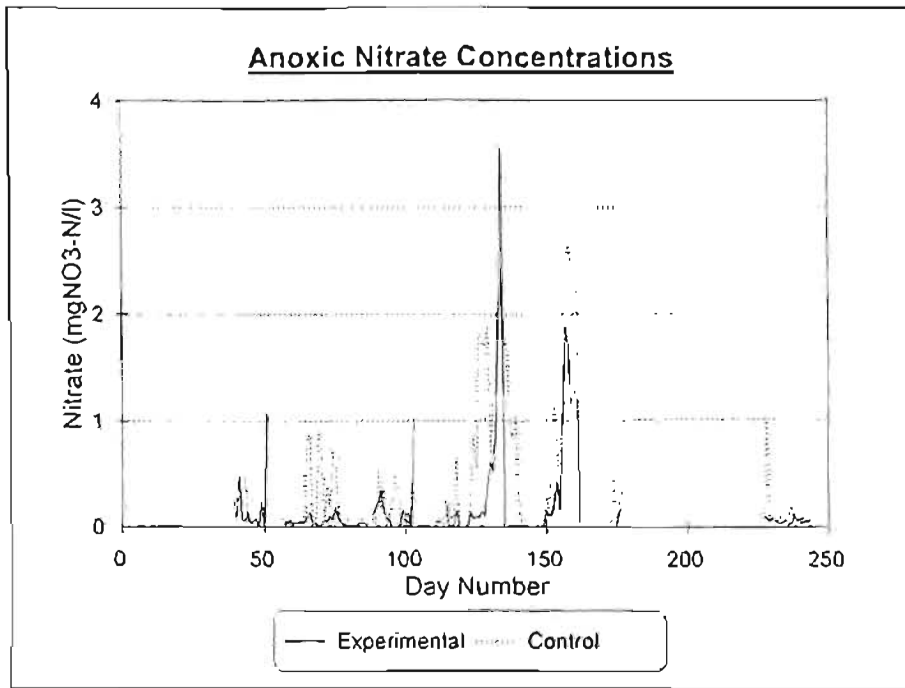


Figure A25: Daily anoxic reactor Nitrate concentrations in EXP and CTL systems from day 1 to day 250.

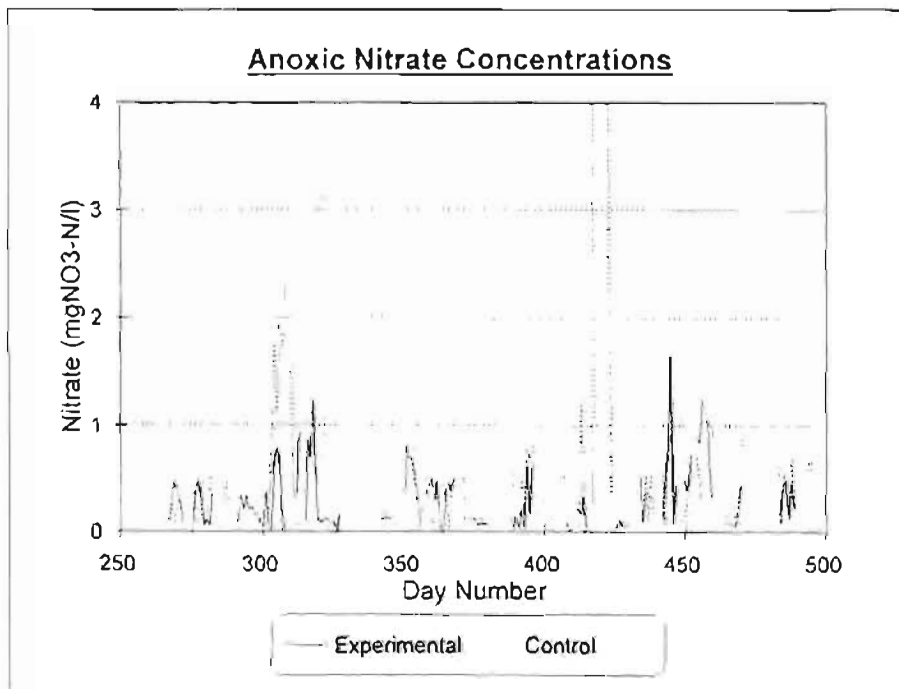


Figure A26: Daily anoxic reactor Nitrate concentrations in EXP and CTL systems from day 251 to day 495.

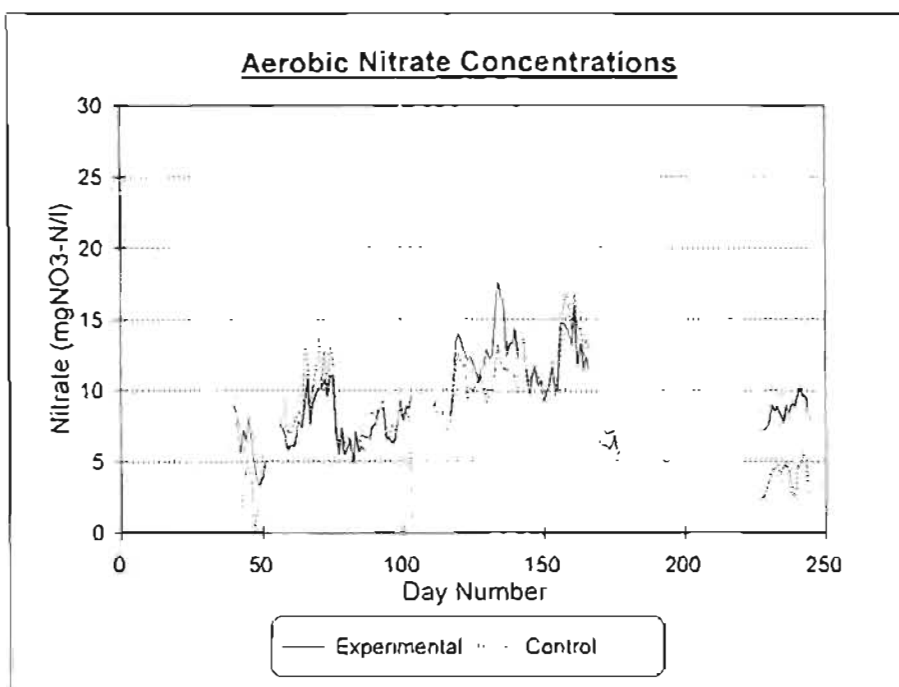


Figure A27: Daily aerobic reactor Nitrate concentrations in EXP and CTL systems from day 1 to day 250.

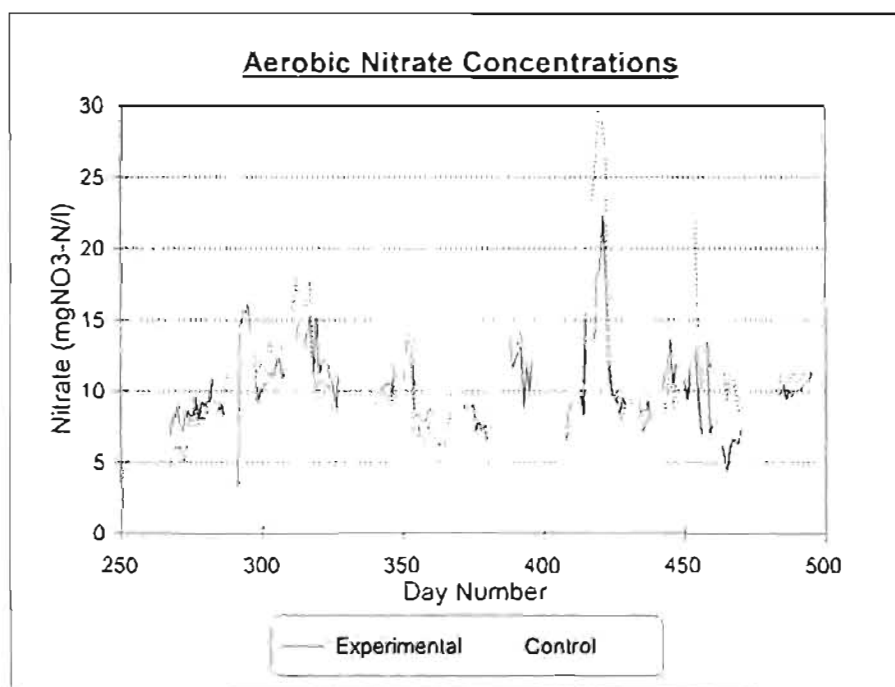


Figure A28: Daily aerobic reactor Nitrate concentrations in EXP and CTL systems from day 251 to day 495.

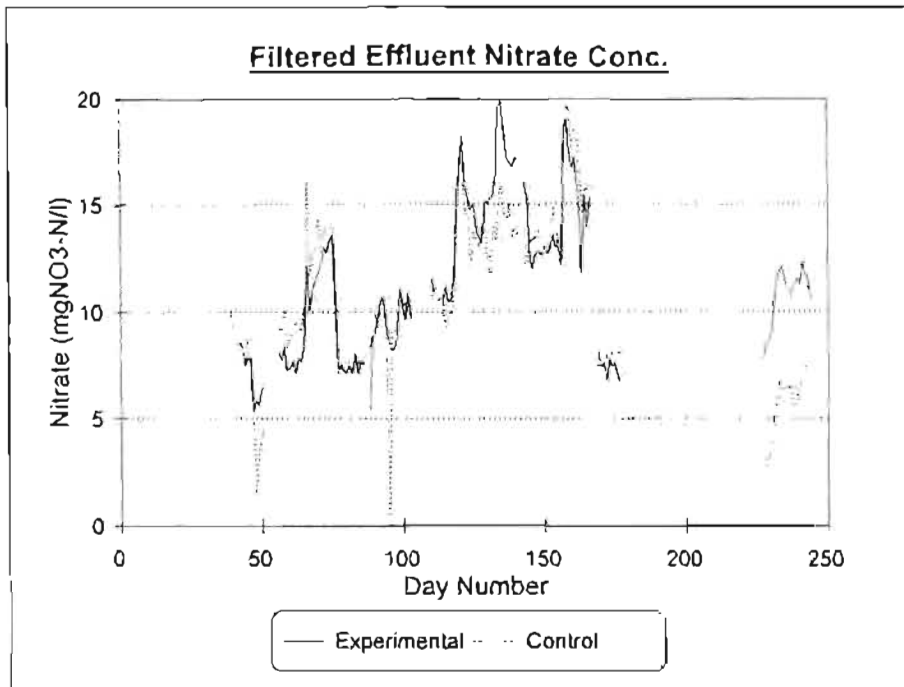


Figure A29: Daily effluent Nitrate concentrations in EXP and CTL systems from day 1 to day 250.

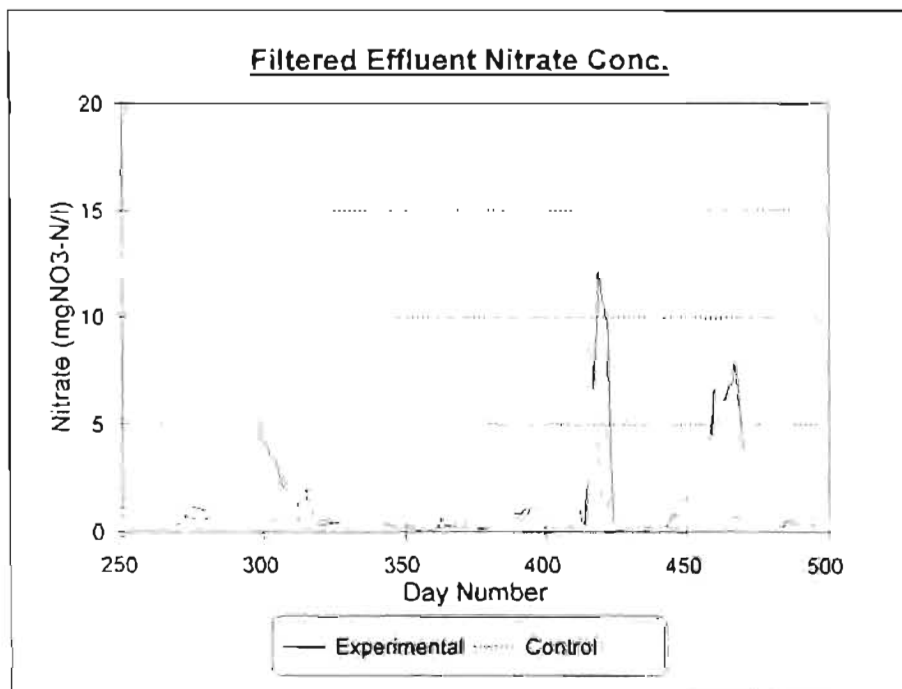


Figure A30: Daily effluent Nitrate concentrations in EXP and CTL systems from day 251 to day 495.

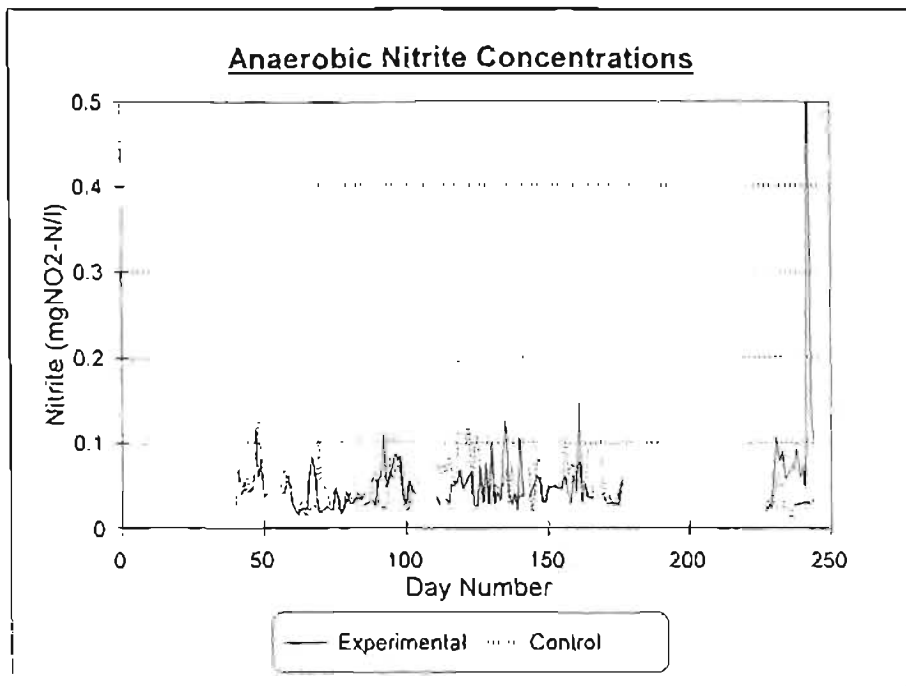


Figure A31: Daily anaerobic reactor Nitrite concentrations in EXP and CTL systems from day 1 to day 250.

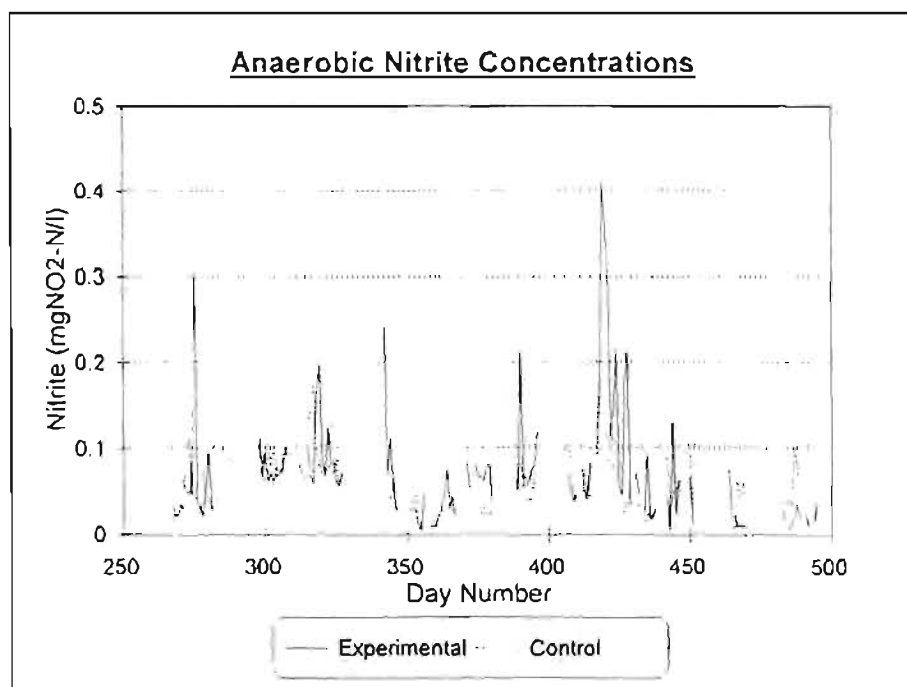


Figure A32: Daily anaerobic reactor Nitrite concentrations in EXP and CTL systems from day 251 to day 495.

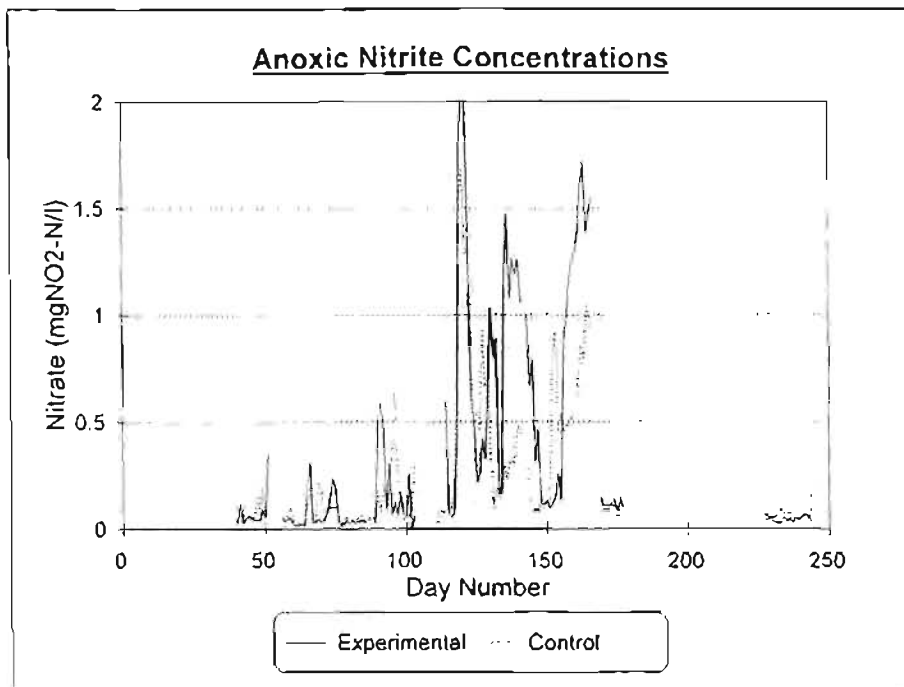


Figure A33: Daily anoxic reactor Nitrite concentrations in EXP and CTL systems from day 1 to day 250.

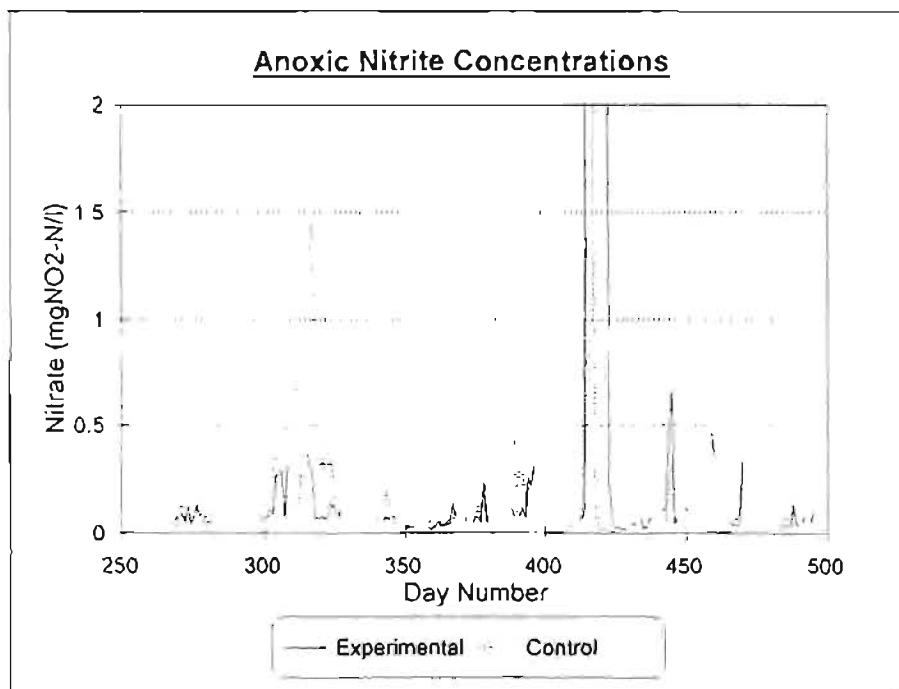


Figure A34: Daily anoxic reactor Nitrite concentrations in EXP and CTL systems from day 251 to day 495.

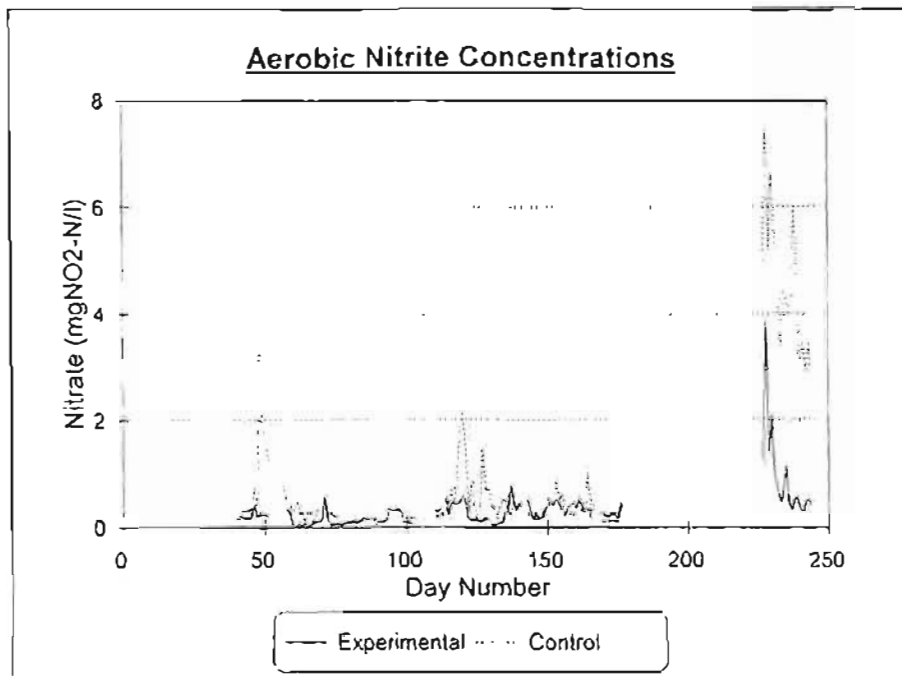


Figure A35: Daily aerobic reactor Nitrite concentrations in EXP and CTL systems from day 1 to day 250.

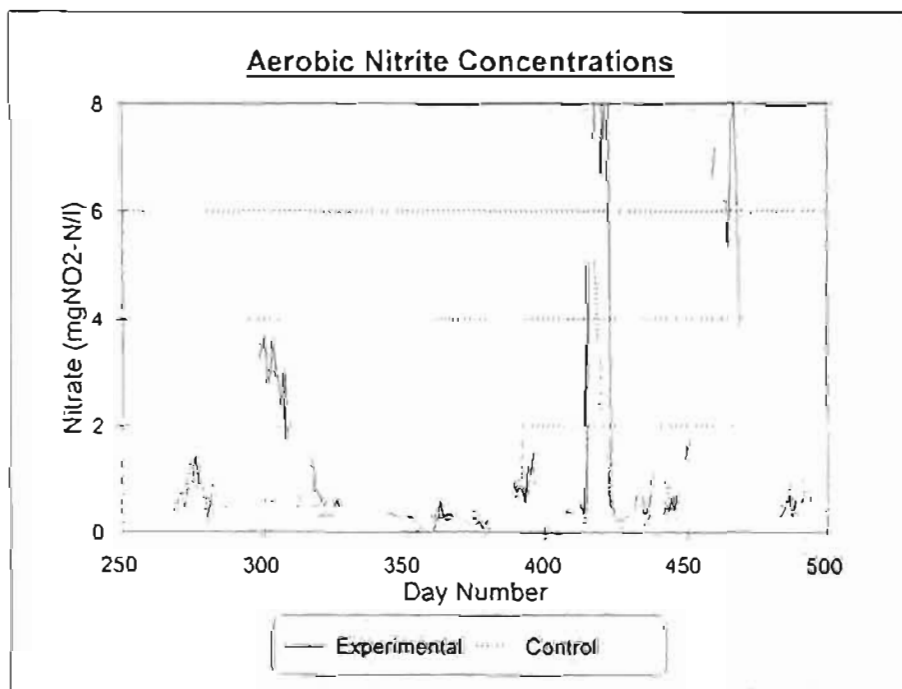


Figure A36: Daily aerobic reactor Nitrite concentrations in EXP and CTL systems from day 251 to day 495.

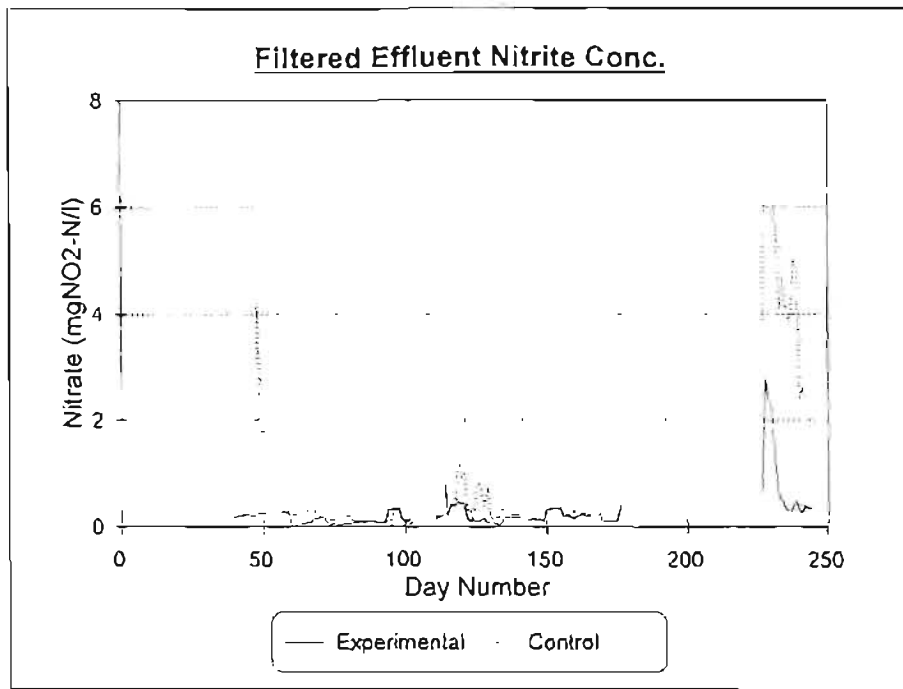


Figure A37: Daily effluent Nitrite concentrations in EXP and CTL systems from day 1 to day 250.

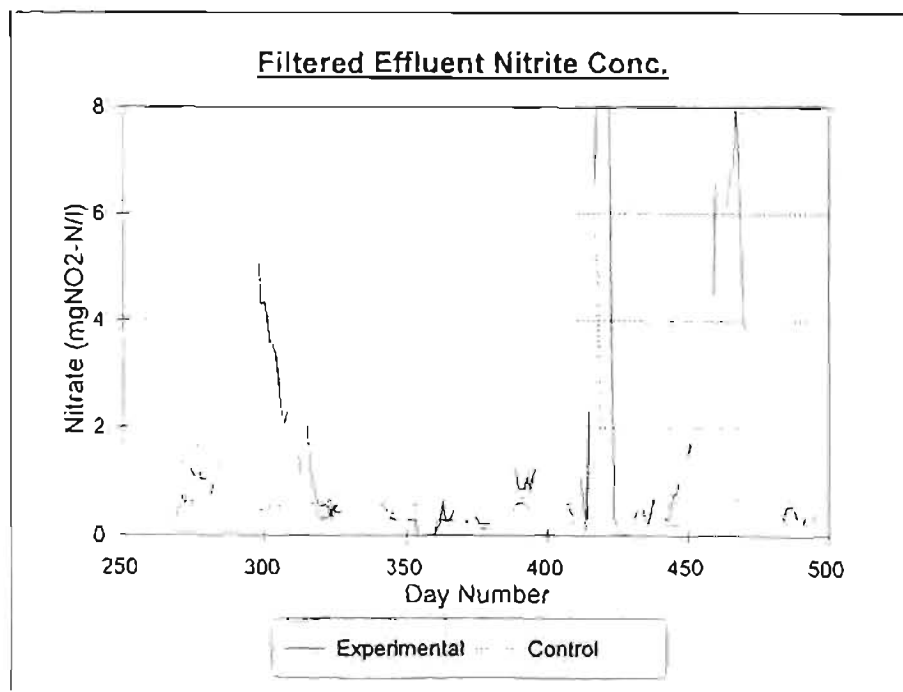


Figure A38: Daily effluent Nitrite concentrations in EXP and CTL systems from day 251 to day 495.

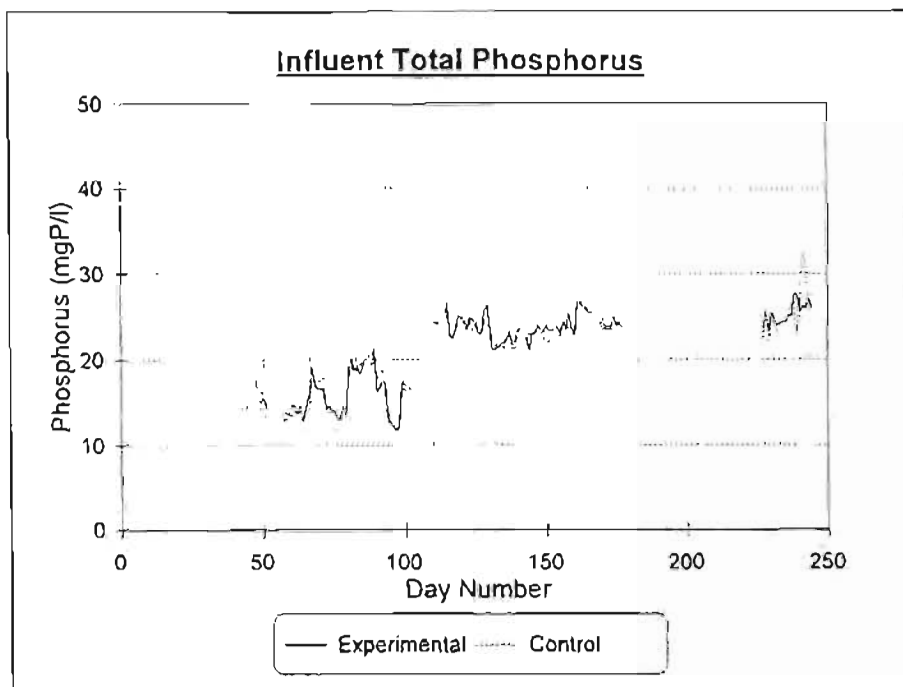


Figure A39: Daily unfiltered influent Total P concentrations in EXP and CTL systems from day 1 to day 250.

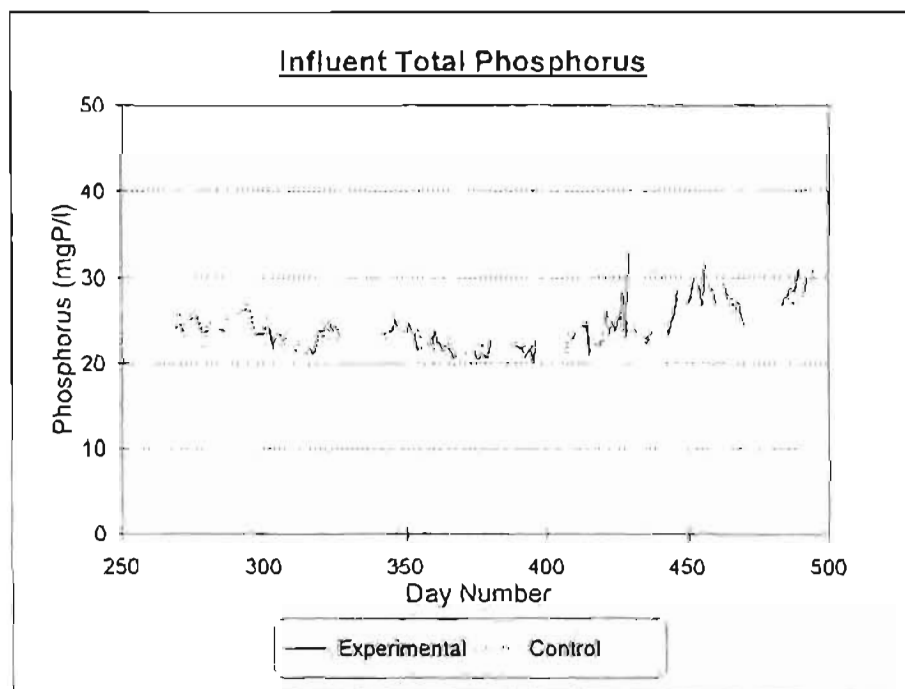


Figure A40: Daily unfiltered influent Total P concentrations in EXP and CTL systems from day 251 to day 495.

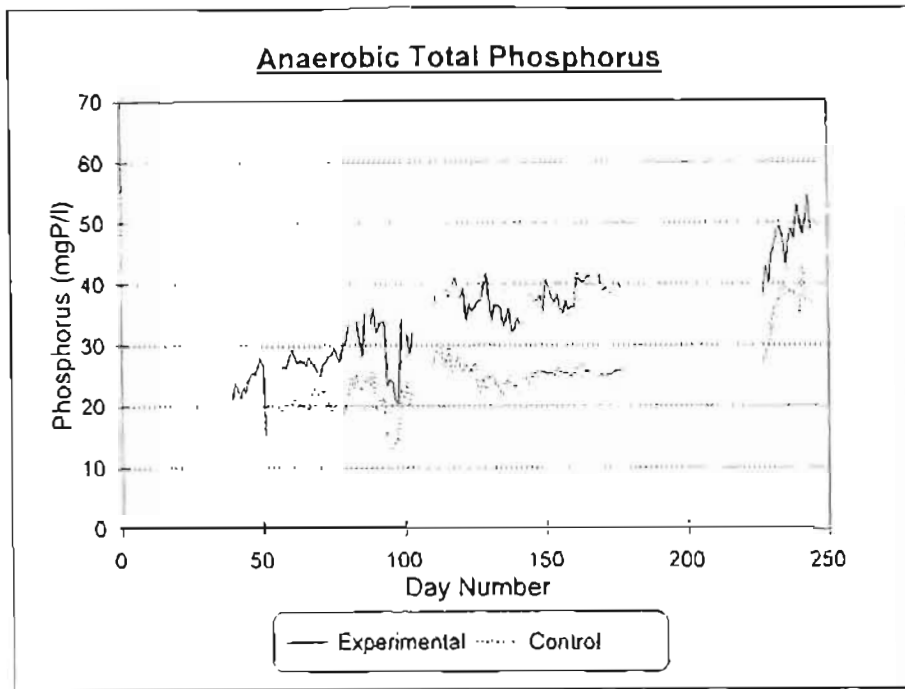


Figure A41: Daily anaerobic reactor filtered Total P concentrations in EXP and CTL systems from day 1 to day 250.

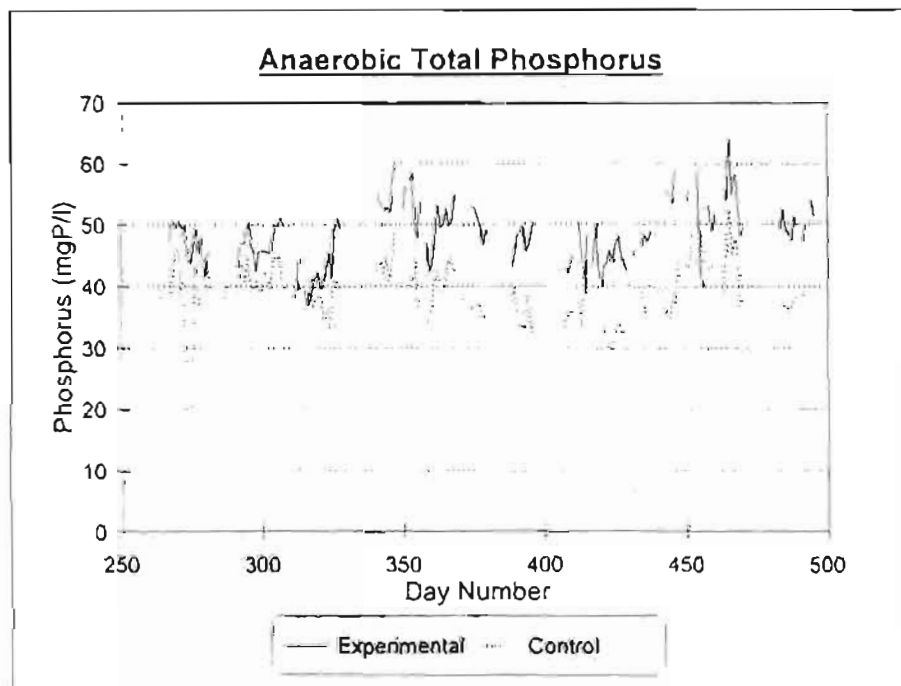


Figure A42: Daily anaerobic reactor filtered Total P concentrations in EXP and CTL systems from day 251 to day 495.

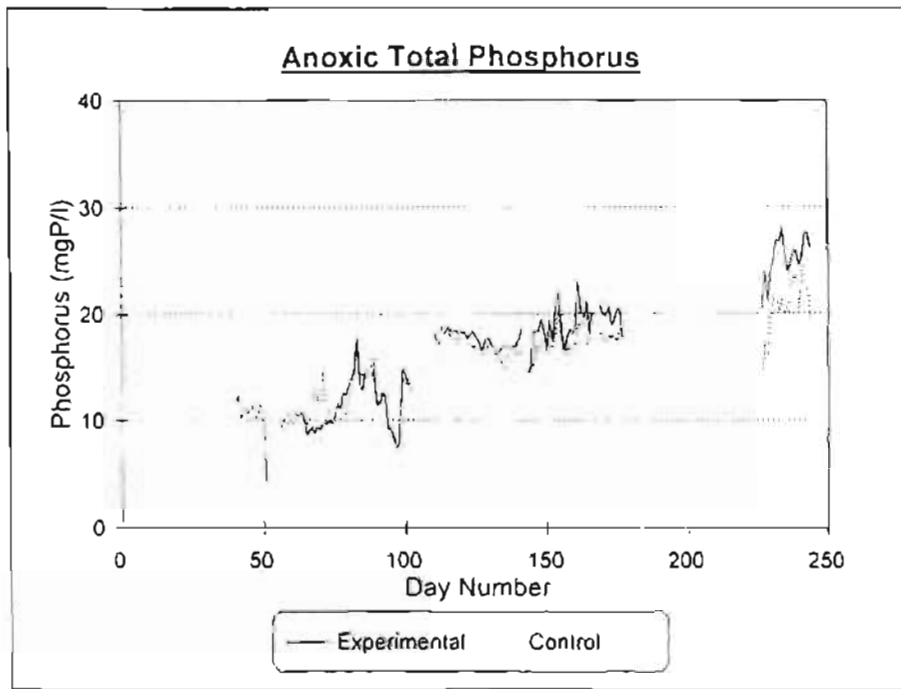


Figure A43: Daily anoxic reactor filtered Total P concentrations in EXP and CTL systems from day 1 to day 250.

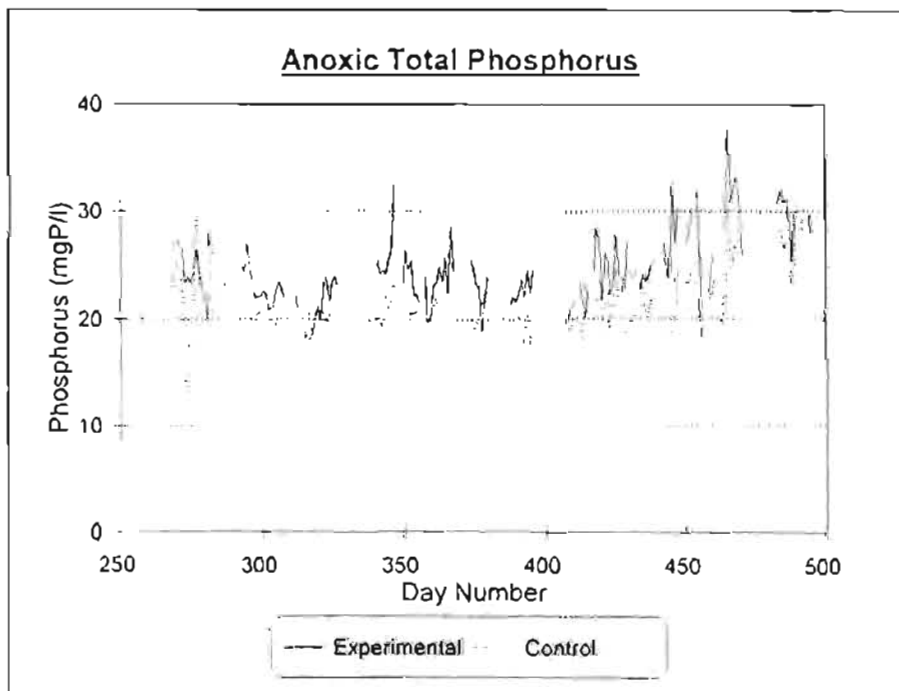


Figure A44: Daily anoxic reactor filtered Total P concentrations in EXP and CTL systems from day 251 to day 495.

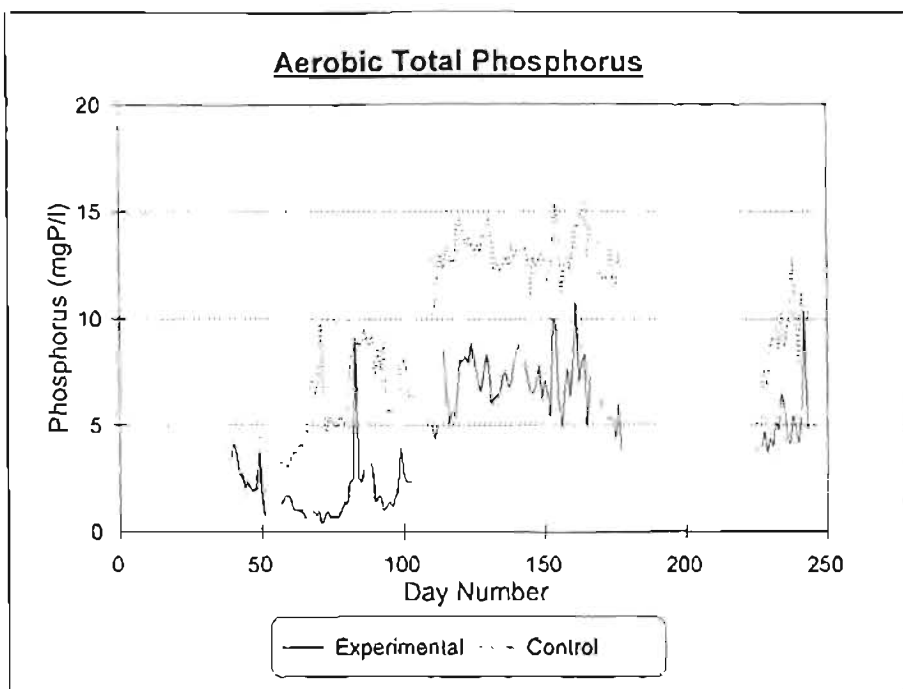


Figure A45: Daily aerobic reactor filtered Total P concentrations in EXP and CTL systems from day 1 to day 250.

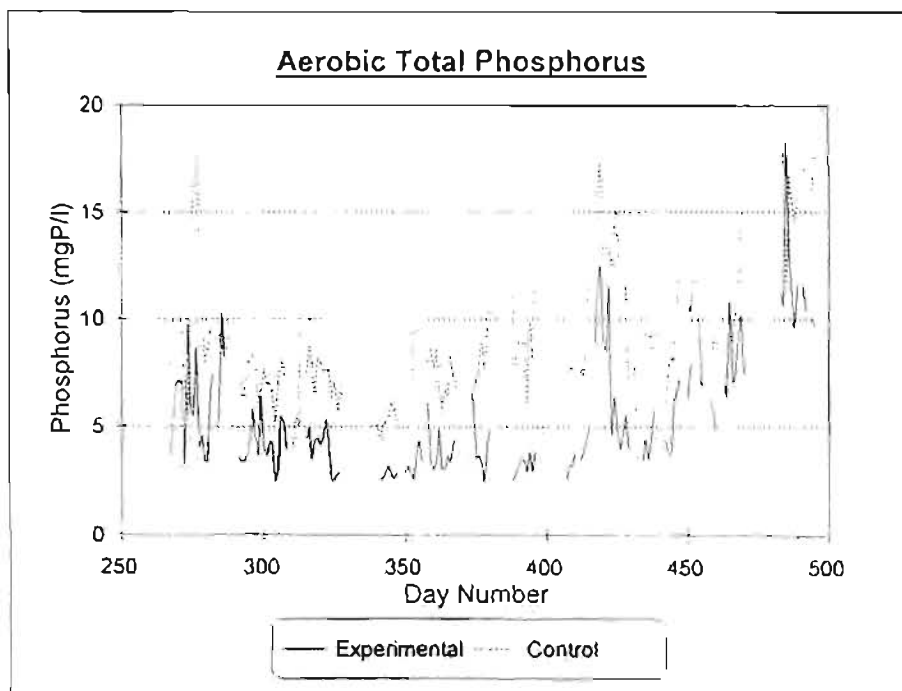


Figure A46: Daily aerobic reactor filtered Total P concentrations in EXP and CTL systems from day 251 to day 495.

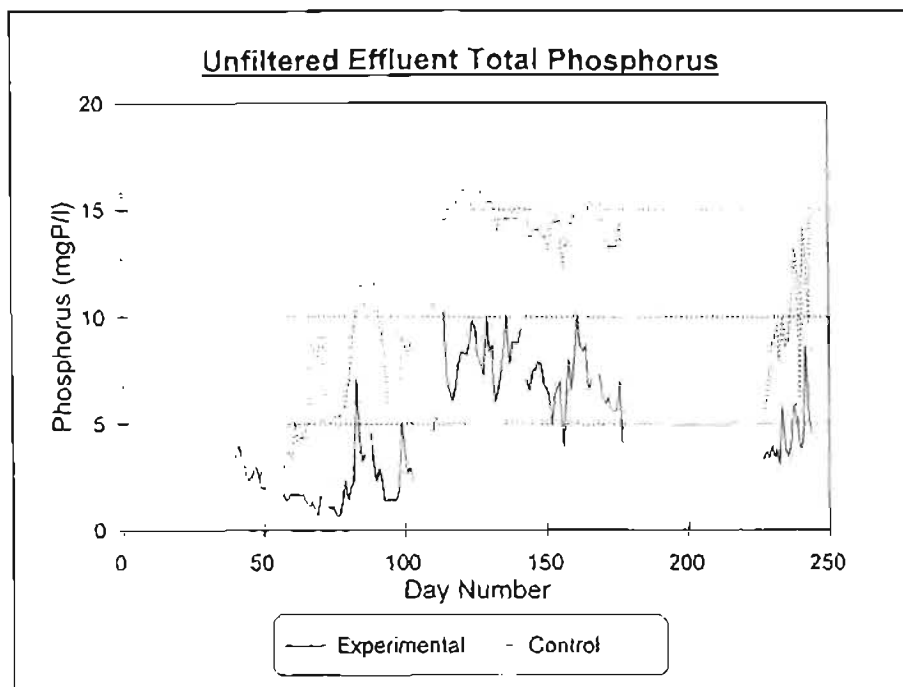


Figure A47: Daily unfiltered effluent Total P concentrations in EXP and CTL systems from day 1 to day 250.

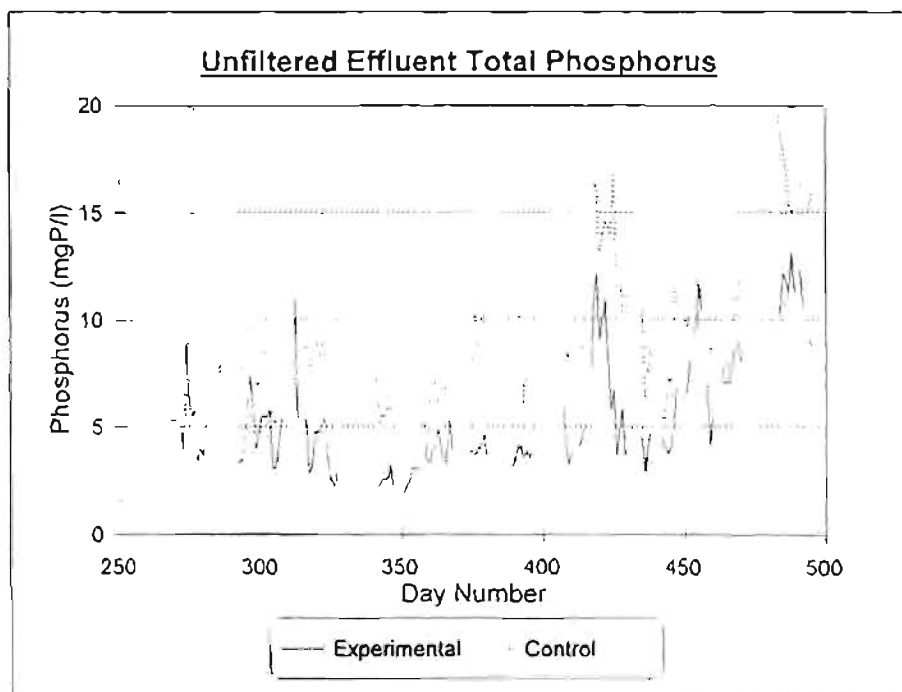


Figure A48: Daily unfiltered effluent Total P concentrations in EXP and CTL systems from day 251 to day 495.

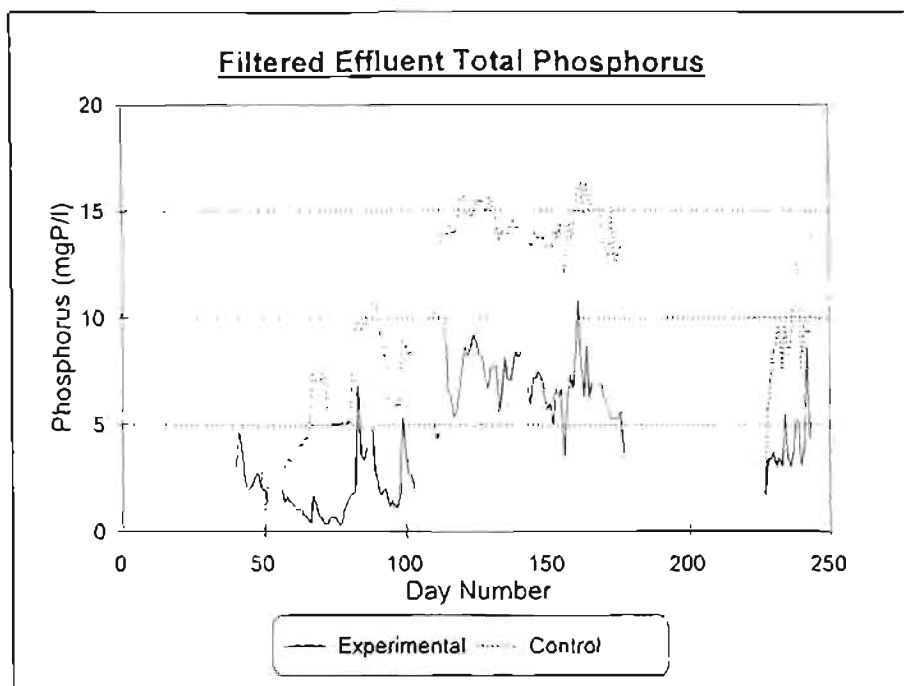


Figure A49: Daily filtered effluent Total P concentrations in EXP and CTL systems from day 1 to day 250.

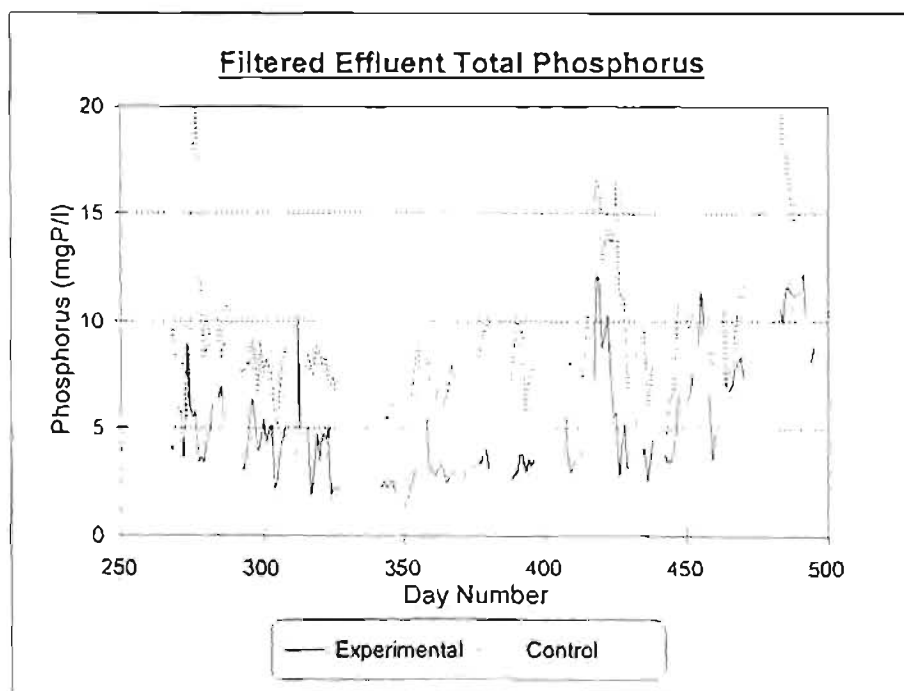


Figure A50: Daily filtered effluent Total P concentrations in EXP and CTL systems from day 251 to day 495.

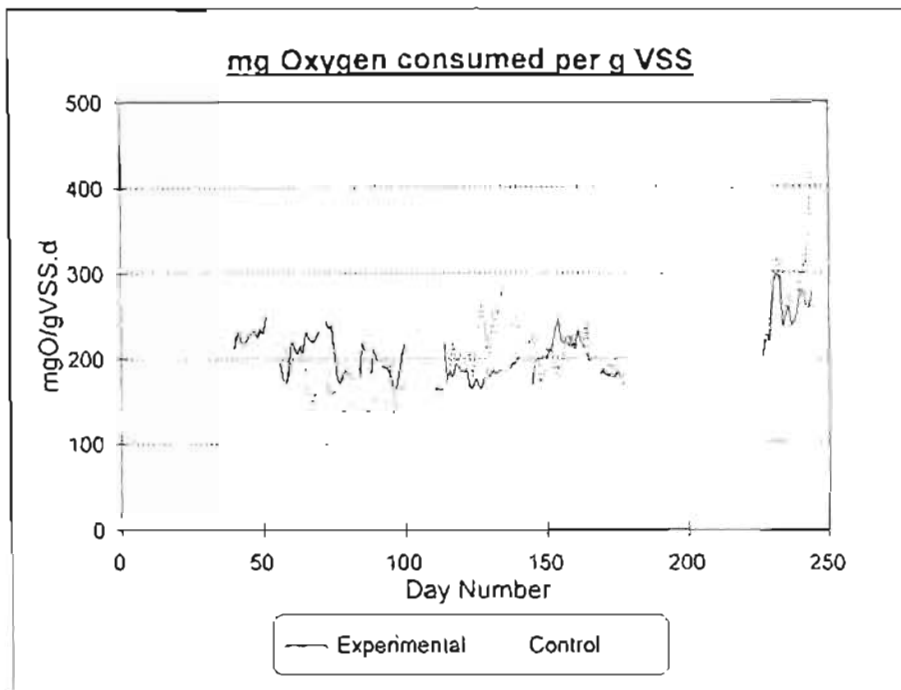


Figure A51: Daily mass of oxygen (mg) utilized per gram Volatile Suspended Solids in EXP and CTL systems from day 1 to day 250 (Measured aerobic reactor OUR/VSS concentration).

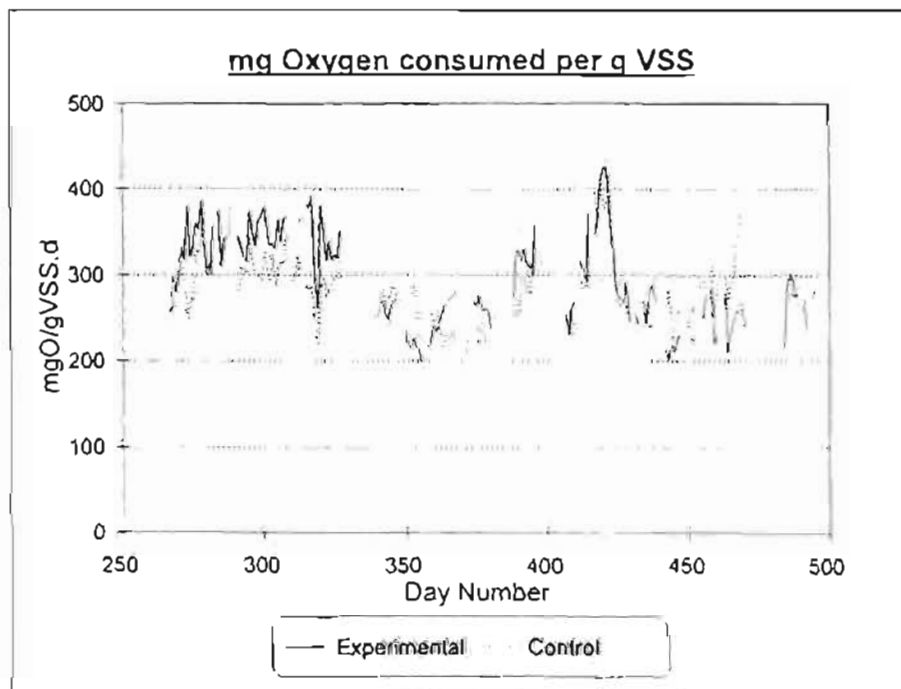


Figure A52: Daily mass of oxygen (mg) utilized per gram Volatile Suspended Solids in EXP and CTL systems from day 251 to day 495 (Measured aerobic reactor OUR/VSS concentration).

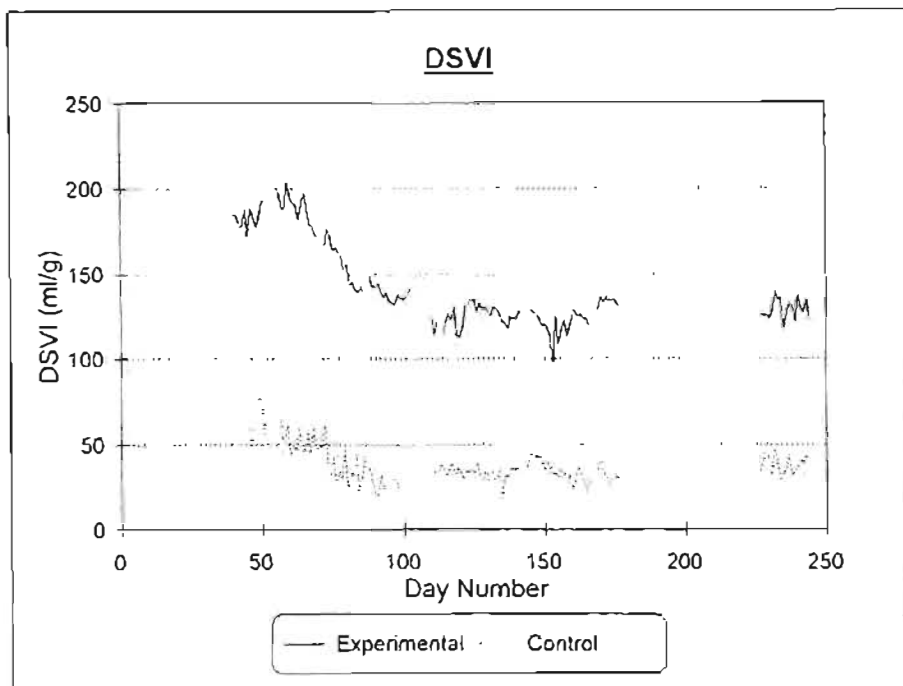


Figure A53: Daily aerobic reactor Diluted Sludge Volume Index in EXP and CTL systems from day 1 to day 250.

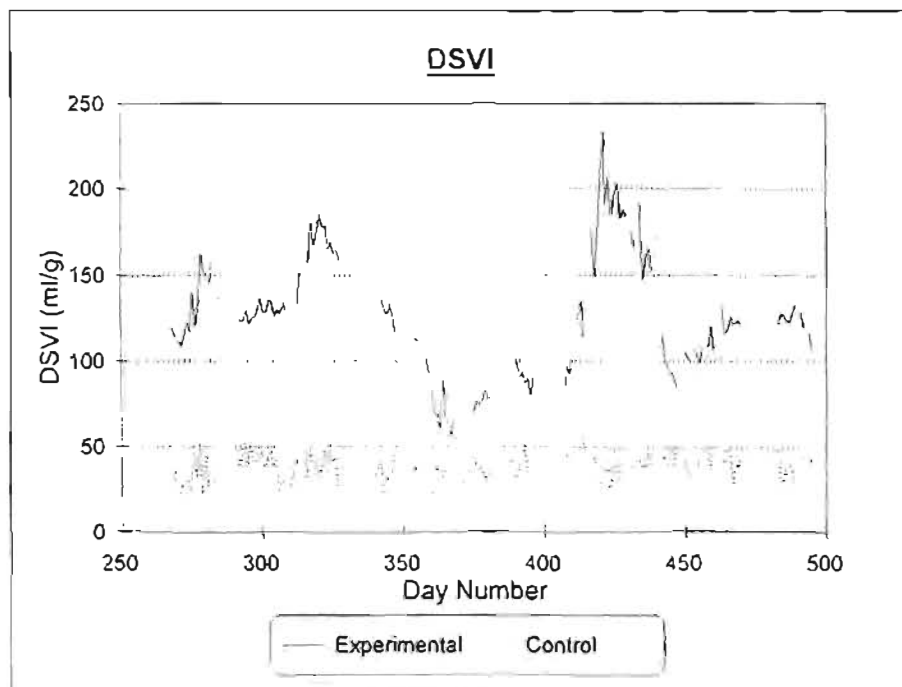


Figure A54: Daily aerobic reactor Diluted Sludge Volume Index in EXP and CTL systems from day 251 to day 495.

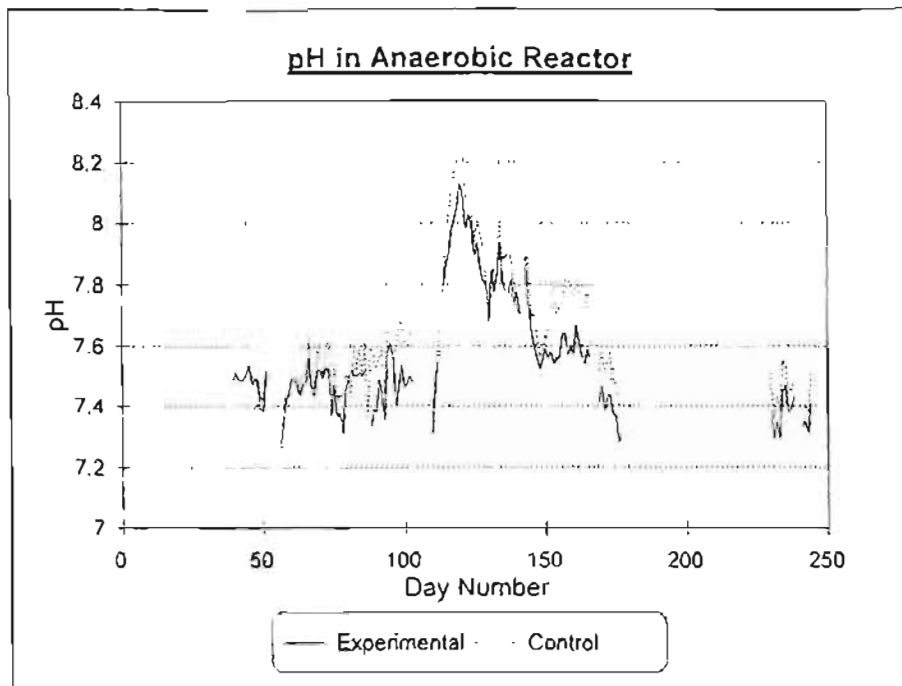


Figure A55: Daily anaerobic pH measurements in the EXP and CTL systems from day 1 to day 250.

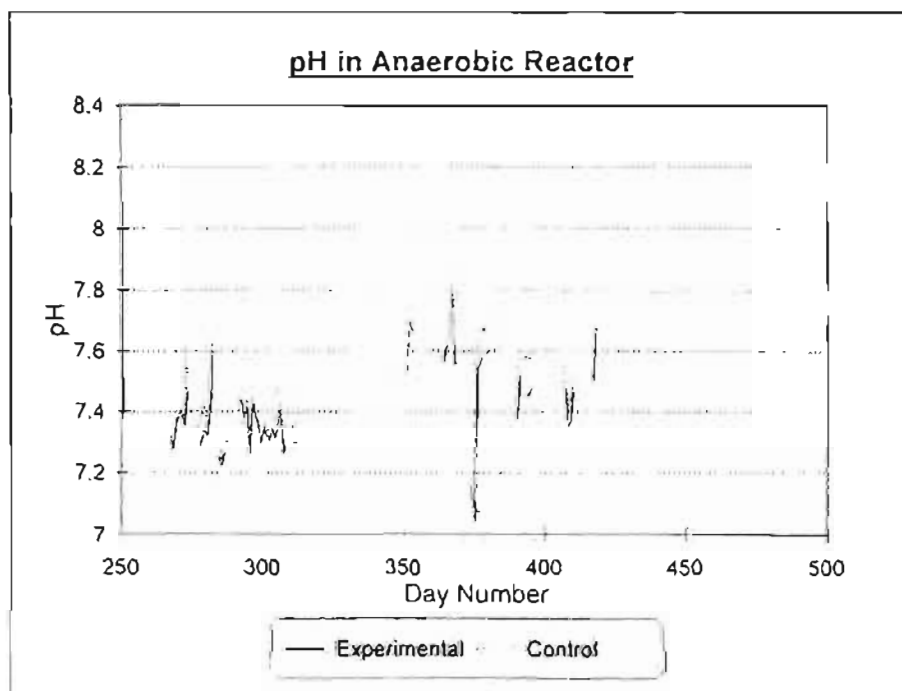


Figure A56: Daily anaerobic pH measurements in the EXP and CTL systems from day 251 to day 495.

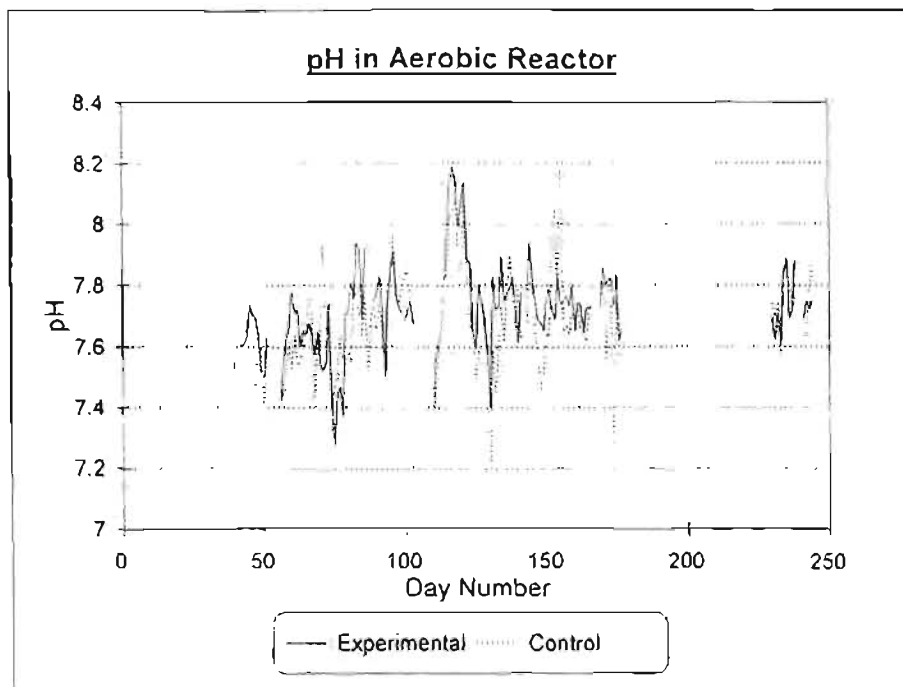


Figure A57: Daily anaerobic pH measurements in the EXP and CTL systems from day 1 to day 250.

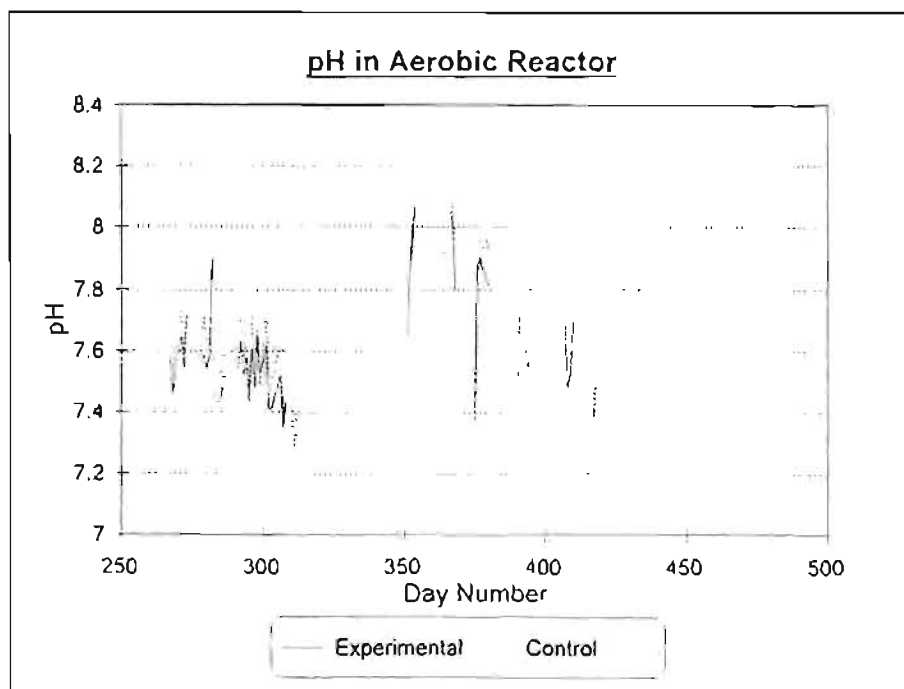


Figure A58: Daily anaerobic pH measurements in the EXP and CTL systems from day 251 to day 495.

APPENDIX B

- Nitrogen Mass Balance
- COD Mass Balance

APPENDIX B

NITROGEN AND COD MASS BALANCES

In order to test the accuracy of the measured system response data, nitrogen and COD mass balances were performed on the system. These are discussed in detail and illustrated by an example using the data of steady state period 23 of the EXP system (see Table B1 and B2 below).

1. NITROGEN MASS BALANCE

The daily mass of nitrogen that enters the laboratory system in the form of the influent TKN should be accounted for as follows:

- i) Nitrogen that is denitrified.
- ii) Nitrogen in the waste sludge.
- iii) Nitrogen in the effluent i.e. TKN plus nitrate and nitrite.

1.1 Mass of Nitrate Denitrified

In the UCT system configuration (see Figure 3.1) the mass of nitrogen denitrified is calculated by carrying out a nitrate and nitrite mass balance around the anaerobic and anoxic reactors. If significant amounts of nitrite were generated it would have been necessary to split the nitrate and nitrite in order to produce an accurate calculation particularly for the COD mass balance. As there were no large amounts of nitrite produced during this investigation, the nitrate and nitrite can be added together and is indicated by the symbol NO_x .

The mass of nitrate and nitrite denitrified in the anaerobic and anoxic zones is calculated in the following way:

Mass of NO_x denitrified in the anaerobic reactor:

$$M\text{NO}_{x\text{d anaer}} = (r).Q.(NO_2+NO_3)_{\text{anox}} - (1+r).Q.(NO_2+NO_3)_{\text{anaer}}$$

and in the anoxic reactor:

$$M\text{NO}_{x\text{d anox}} = (1+r).Q.(NO_2+NO_3)_{\text{anaer}} + (a).Q.(NO_2+NO_3)_{\text{acr}} + (s).Q.(NO_2+NO_3)_{\text{eff}} - (1+r+a+s).Q.(NO_2+NO_3)_{\text{anox}} \quad (\text{mgNO}_x\text{-N/d})$$

where:

MNO_{xd}	=	mass of nitrate and nitrite denitrified in the anaerobic or anoxic reactor respectively per day ($mgNO_x-N/d$)
anaer	=	indicates NO_x concentration in anaerobic reactor
aer	=	indicates NO_x concentration in aerobic reactor
anox	=	indicates NO_x concentration in anoxic reactor
eff	=	indicates NO_x concentration in the effluent
Q	=	daily influent flow (l/d)
a, r, s	=	recycle ratios equal to 1,2 and 1 respectively

Substituting the appropriate average values for steady state 23 of the EXP system, you get:

$$\begin{aligned} MNO_{xd \text{ anaer}} &= (1).20.(0.03+0.31) - (1+1).20.(0.03+0.07) \\ &= 2.8 \quad mgNO_x-N/d \end{aligned}$$

$$\begin{aligned} MNO_{xd \text{ anox}} &= (1+1).20.(0.03+0.07) + (2).20.(0.21+7.74) + (1).20.(0.16+8.48) \\ &\quad - (1+1+2+1).20.(0.03+0.31) \\ &= 460.8 \quad mgNO_x-N/d \end{aligned}$$

Therefore, the total mass of nitrate and nitrite (NO_x) denitrified

$$\begin{aligned} MNO_{xd} &= MNO_{xd \text{ anaer}} + MNO_{xd \text{ anox}} \\ &= 2.8 + 460.8 \\ &\approx 463.6 \quad mgNO_x-N/d \end{aligned}$$

1.2 Nitrogen in Waste Sludge

The mass of N in the waste sludge is given by the product of the TKN/VSS ratio (f_n) and the mass of VSS wasted per day.

$$MX_n = f_n.MX_v$$

$$\text{where: } f_n = (212.8)/(2197.7) = 0.0968$$

Substituting the appropriate values gives

$$\begin{aligned} MX_n &= (0.0968).(2*2197.7) \\ &= 425.6 \quad mgN/d \end{aligned}$$

1.3 Mass of Nitrogen in the Effluent

The mass of N in the effluent is the product of the daily flow rate and the sum of the effluent

TKN, nitrate and nitrite concentrations:

$$\begin{aligned} MN_{\text{eff}} &= Q \cdot (N_{\text{te}} + \text{NO}_{2\text{eff}} + \text{NO}_{3\text{eff}}) \\ &= 20 \cdot (3.90 + 0.16 + 8.48) \\ &= 250.8 \quad \text{mgN/d} \end{aligned}$$

1.4 Nitrogen Mass Balance

The % N mass balance is then given by:

$$\% \text{ N Balance} = 100 \cdot (MNO_{\text{xd}} + MX_{\text{n}} + MN_{\text{eff}}) / MN_{\text{ti}}$$

where: MN_{ti} is the mass of TKN in the influent given by the product of the influent TKN concentration and the daily flow rate ($MN_{\text{ti}} = N_{\text{ti}} \cdot Q$)

Substituting the values calculated above:

$$\begin{aligned} \% \text{ N Balance} &= (100) \cdot (463.6 + 425.6 + 250.8) / (56.85 \cdot 20) \\ &= 100.3 \% \end{aligned}$$

2. **COD MASS BALANCE**

The daily mass of COD (MS_{ti}) that enters the system should be accounted by:

- i) The mass oxygen demand required per day for degradation of carbonaceous material in the aerobic reactor.
- ii) The equivalent mass oxygen demand per day by denitrification of nitrate and nitrite.
- iii) The COD mass in the waste sludge.
- iv) The COD mass in the effluent.

2.1 Carbonaceous Oxygen Demand

The total amount of oxygen utilized in the aerobic zone is made up of the nitrification oxygen demand and the carbonaceous oxygen demand. Since nitrification does not consume any of the influent COD, the oxygen demand due to nitrification must be subtracted from the total measured oxygen demand. Stoichiometrically, the oxygen requirements for nitrification of ammonia to nitrite (by *nitrosomonas*) and to nitrate (by both *nitrosomonas* and *nitrobacter*) is different with the former reaction being slightly less (i.e. 3.43 mgO/mgN and 4.57 mgO/mgN generated from ammonia). As already stated however, there was never an excessive nitrite build up in the systems which meant that the nitrite could be added to the nitrate and called NO_x . The calculation for the carbonaceous oxygen demand is as follows:

- (a) Provided that the nitrogen mass balance is acceptable, the mass of nitrogen generated in the system MS_{no} is found from the sum of the NO_x mass denitrified and the mass in the effluent i.e.

$$MS_{no} = MNO_{xd} + MNO_{x\text{ eff}}$$

$$\text{where: } MNO_{x\text{ eff}} = Q \cdot (NO_{2\text{ eff}} + NO_{3\text{ eff}})$$

Substituting the appropriate values for steady state period 23 of the EXP system:

$$= 463.6 + 20 \cdot (0.16 + 8.48)$$

$$= 636.4 \quad \text{mgN/d}$$

From the mass of nitrite generated, the nitrification oxygen demand (MO_n) is given by:

$$MO_n = 4.57 \cdot (MS_{no})$$

$$= 4.57 \cdot (636.4)$$

$$= 2908.3 \quad \text{mgO/d}$$

where: 4.57 is the mass of oxygen utilized per $\text{mgNH}_4\text{-N}$ nitrified.

From the measured OUR ($\text{mgO}/\ell/\text{h}$) the mass carbonaceous oxygen demand is given by:

$$MO_c = (\text{OUR}) \cdot V_a \cdot (24) - MO_n$$

where: V_a is the volume of the aerobic reactor (ℓ)

$$= (43.25) \cdot 10 \cdot (24) - 2908.3$$

$$= 7471.7 \quad \text{mgO/d}$$

- (b) The equivalent oxygen demand of denitrification MO_d is given by:

$$MO_d = 2.86 \cdot (MNO_{xd})$$

$$= 2.86 \cdot (463.6)$$

$$= 1325.9 \quad \text{mgO/d}$$

- (c) The COD of the wasted sludge mass is given by the COD/VSS ratio times the mass of VSS wasted per day i.e.

$$MS_{ws} = f_{cv} \cdot (MX_v)$$

$$\text{where: } f_{cv} = (3061.9)/(2197.7) = 1.393$$

$$MS_{ws} = (1.393) \cdot (2 \cdot 2197.7)$$

$$= 6122.8 \quad \text{mgCOD/d}$$

(d) The COD mass in the effluent MS_{te} is given by:

$$\begin{aligned}
 MS_{te} &= Q \cdot S_{te} \\
 &= (20) \cdot (65.81) \\
 &= 1316.2 \text{ mgCOD/d}
 \end{aligned}$$

The % COD mass balance is then given by:

$$\% \text{ COD Balance} = 100 \cdot (MO_c + MO_d + MS_{ws} + MS_{te}) / MS_{ti}$$

where: MS_{ti} is the total COD mass fed to the system.

Substituting the values calculated above:

$$\begin{aligned}
 \% \text{ COD Balance} &= 100 \cdot (7471.7 + 1325.9 + 6122.8 + 1316.2) / (20 \cdot 803.73) \\
 &= 101.0 \%
 \end{aligned}$$

EXPERIMENTAL SYSTEM

Steady State Period	COD Mass Balance					Nitrogen Mass Balance				
	MOc	MOd	COD in Waste	COD in Eff.	%	Denit	N in Waste	TKN in Eff.	NO3 in Eff.	%
1	6175.32	1739.22	6157.69	868.93	101.34	608.12	406.75	103.38	238.07	121.10
2	4781.33	1980.50	6369.66	831.41	100.29	692.48	399.16	65.64	256.90	84.09
3	5410.67	1674.41	6572.02	651.57	102.31	590.02	432.09	64.78	219.49	91.07
4	7334.22	1117.77	6013.37	879.02	100.57	390.83	377.78	62.57	153.85	78.83
5	6712.88	1261.00	6941.81	811.91	90.26	440.91	434.00	65.80	157.07	77.72
6	7351.75	1806.04	6904.62	792.87	94.38	631.48	424.34	62.62	239.35	80.09
7	6618.30	1191.05	7407.48	713.40	94.02	416.45	470.40	58.10	164.50	85.83
8	7245.18	1155.84	7303.07	837.80	97.92	404.14	438.67	63.31	149.23	84.04
9	6488.71	1418.28	7392.89	659.96	98.02	495.90	455.28	71.12	196.39	80.17
10	5750.29	1717.27	7460.53	822.74	98.76	600.44	460.80	71.00	225.29	92.47
11	4702.47	2061.21	7212.45	936.72	93.51	720.70	412.18	79.10	304.11	94.14
12	3992.14	2337.96	6407.96	912.67	93.33	817.47	389.76	70.42	354.23	107.94
13	5114.40	1938.47	6430.24	903.83	93.11	677.79	379.28	62.42	266.28	90.64
14	5280.30	2015.71	6343.83	751.55	87.78	704.79	362.60	59.82	319.88	81.07
15	5470.03	1180.89	5983.32	779.13	88.47	412.90	349.69	61.60	151.97	86.68
16	6158.30	1711.45	5495.94	855.05	92.05	598.41	324.48	37.80	229.27	93.19
17	5511.21	1792.83	5002.11	1053.57	85.26	647.05	306.95	44.80	241.38	91.93
18	6785.39	1423.52	4980.43	879.68	90.09	497.73	279.40	35.40	184.02	82.40
19	7795.68	1731.87	4894.52	1425.97	84.35	605.55	296.80	78.08	218.53	76.11
20	6369.58	2458.93	5048.16	1223.20	92.93	859.77	302.52	62.30	312.89	99.03
21	6719.86	2137.93	5281.39	1129.74	86.74	747.53	302.68	59.78	272.11	99.41
22	7145.43	2044.21	6591.40	877.70	97.20	714.76	446.09	71.40	263.87	96.82
23	7468.20	1327.56	6123.79	1316.13	101.21	464.18	425.60	78.05	172.79	100.35
24	7187.91	1534.78	5606.87	1357.64	97.86	536.64	344.65	65.42	206.73	88.20
25	6822.95	2280.29	5237.36	1090.22	87.22	797.30	303.02	51.18	310.56	87.19
26	5613.19	1588.81	4675.23	1291.34	88.60	555.53	271.80	48.20	209.57	84.83
27	2947.11	3347.67	3881.12	1346.48	79.01	1170.51	237.80	94.80	544.24	93.25
28	5414.66	1786.64	5024.84	1349.88	83.30	624.70	286.22	53.43	237.47	85.12
29	5987.60	1822.85	5401.52	1064.24	85.57	637.36	310.45	57.23	245.13	93.92
30	5572.26	2117.79	5817.55	1186.87	87.60	734.98	333.48	64.96	262.83	96.16
31	4624.43	1749.66	4858.06	1073.74	71.33	614.84	271.09	51.16	218.98	97.47
Average	6017.80	1788.79	5961.98	989.52	91.75	626.17	362.45	63.73	242.81	90.36
Averages above are from start to end of study.										
Average	5989.43	2016.43	5295.61	1192.27	88.21	704.84	319.62	63.16	271.43	93.48
Averages above are from SS 20 to SS 31.										

CONTROL SYSTEM

Steady State Period	COD Mass Balance					Nitrogen Mass Balance				
	MOc	MOd	COD in Waste	COD in Eff.	%	Denit	N in Waste	TKN in Eff.	NO3 in Eff.	%
1										
2										
3										
4										
5	4962.13	1460.49	6218.42	1311.02	106.13	511.75	380.49	85.09	191.72	93.86
6	1888.00	2009.36	5802.58	1067.32	81.77	702.57	357.13	70.25	271.62	93.90
7	2818.60	1239.69	6021.64	795.02	83.74	433.46	371.35	70.00	165.68	92.07
8	3045.75	1252.49	5905.71	852.46	90.36	437.93	358.26	70.84	161.10	91.28
9	3138.90	1348.94	5868.65	604.99	84.21	471.66	364.51	65.02	207.71	86.03
10	3776.98	1541.33	5897.40	815.86	99.33	566.79	356.83	67.20	219.53	88.19
11	4398.58	1767.75	5500.81	848.55	96.11	618.10	320.25	70.12	285.13	85.96
12	5351.58	1829.67	5191.07	723.61	115.41	639.75	328.16	65.52	291.90	93.43
13	3738.09	1956.04	5568.75	858.62	96.72	683.93	330.72	58.58	274.13	94.02
14	3551.85	2273.95	5544.28	722.06	86.84	795.09	332.18	58.80	345.22	91.79
15	4766.99	1212.40	5285.67	783.67	99.50	423.92	299.13	51.96	163.26	95.67
16	4925.51	1545.70	4369.69	867.18	92.56	540.46	253.94	28.86	206.21	85.41
17	6665.37	1412.12	4046.40	1069.66	99.28	493.75	222.32	36.68	201.13	79.33
18	5298.27	1144.44	3948.49	720.75	87.17	400.15	223.65	25.73	159.28	75.16
19	7471.27	1595.72	4918.99	909.54	98.66	557.95	304.77	63.22	207.57	78.83
20	4816.18	2311.95	4710.41	920.66	95.91	808.37	259.47	48.79	317.40	96.46
21	5120.33	1849.36	4675.26	989.65	90.03	646.63	236.60	40.32	247.85	90.91
22	5422.43	1781.77	4735.10	831.31	89.02	623.00	303.38	67.62	225.65	83.23
23	5351.45	1139.94	4619.57	869.65	91.65	398.58	310.92	65.45	152.35	86.75
24	4683.39	1474.26	4733.20	818.17	88.89	515.48	266.51	48.49	197.91	84.93
25	4055.66	2300.53	4374.96	1054.17	81.72	804.38	230.84	49.93	326.66	87.33
26	4142.64	1420.42	3908.61	1106.74	87.41	496.65	214.60	44.40	200.42	81.31
27	2787.16	2666.96	3339.76	949.52	85.24	932.50	184.60	37.80	570.65	85.08
28	4787.55	1706.57	4604.36	1064.28	87.03	596.70	241.50	48.92	241.53	86.39
29	5073.86	1787.05	4482.86	933.72	91.89	624.84	265.30	56.00	228.69	88.41
30	5723.06	1905.38	4297.15	1075.89	92.93	663.52	236.46	65.52	249.42	86.79
31	4613.47	1896.61	4722.24	918.33	88.37	659.35	258.11	50.40	233.11	108.08
Average	4532.41	1697.07	4936.74	906.76	92.14	594.34	289.33	55.98	242.33	88.54
Averages above are from start to end of study.										
Average	4926.80	1832.81	4470.96	957.05	89.90	640.61	254.85	52.84	261.48	88.04
Averages above are from SS 19 to SS 31.										

APPENDIX C

- Steady State Results

Experimental System

K = 0.06

Steady State Period	h _{us}	fcw	fs _{br}	INPUT M _{up}	Sup.	S _{us}	S _{br}	S _{sw}	S _{st}	INPUT S _{sw}	M _{SW} /Q	S _{sw}	M _{SW}	M _{St}	M _{Ag}	M _{Ag}	INPUT M _{Ag}	Delta P _g	M _{Ag}	M _{Ag}	Delta P _h	M _u	Delta P _h	Calculated Delta P	Measured Delta P	Calculated M _u	Measured M _u
1	0.076	1.54		0.00	55.67	877.03	0.00	-0.81		887.28			-14.60	13555.30	-47.01	-4.76	0.00	17940.84	8611.60	3.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.077	1.57		0.00	53.99	843.52	0.00	3.21		855.67			-51.00	12921.43	-164.04	-18.40	0.00	17101.90	8208.91	3.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.068	1.53		0.00	47.69	654.66	0.00	1.96		666.67			-26.49	13119.77	-65.15	-8.52	0.00	17364.40	8334.91	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.053	1.39		0.00	43.00	737.54	0.00	3.36		766.04			-38.52	14529.07	123.18	-12.32	0.00	19308.06	9268.35	4.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.043	1.46		0.00	37.21	537.42	0.00	-8.89		1108.18			-10.06	16758.55	-37.24	-3.20	0.00	22180.44	10644.01	4.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.041	1.41		0.00	36.67	654.19	0.00	-1.74		1146.08			28.19	17312.06	83.61	-5.38	0.00	22914.25	10984.64	3.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.041	1.43		0.00	35.16	814.52	0.00	-0.58		1078.68			-3.58	16799.94	-30.76	-3.08	0.00	21573.45	10355.26	4.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.042	1.44		0.00	35.74	806.50	0.00	-0.64		1068.26			-10.66	16110.76	-34.21	-3.43	0.00	21382.77	10254.13	4.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.036	1.43		0.00	29.63	795.26	0.00	-3.21		1056.80			-53.02	15656.26	-170.43	-17.04	0.00	21721.23	10138.19	4.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.042	1.41		0.00	34.17	778.39	0.00	-1.98		1032.27			-25.60	15540.30	-67.29	-8.23	0.00	20636.20	9706.33	4.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.043	1.38		0.00	34.83	786.01	0.00	-0.30		1076.22			-152.77	15474.05	-484.75	-48.42	0.00	20480.36	9830.57	4.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.045	1.32		0.00	33.06	702.86	0.00	-14.85		948.67			-228.21	14286.34	-736.62	-73.68	0.00	18908.39	9076.03	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.042	1.40		0.00	39.86	727.18	0.00	-3.70		1057.88			-60.47	14604.04	-194.37	-19.44	0.00	19328.87	9277.86	4.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.030	1.37		0.00	31.68	790.75	0.00	-18.08		1069.89			-288.77	16163.83	-960.31	-98.03	0.00	21213.89	10236.87	4.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.044	1.34		0.00	33.07	735.83	0.00	-1.20		883.88			21.31	14500.03	-68.78	-8.87	0.00	19370.83	9249.90	4.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.048	1.39		0.00	37.02	739.53	0.00	-0.84		893.63			-15.28	14759.84	-49.06	-4.91	0.00	18506.03	9485.25	4.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.049	1.44		0.00	36.70	747.11	0.00	-1.08		890.25			-17.60	14669.81	-56.57	-5.56	0.00	18799.74	9503.88	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.034	1.49		0.00	27.07	762.22	0.00	-2.51		1012.14			-41.13	15285.54	130.19	-13.22	0.00	20298.68	9710.81	4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.049	1.45		0.00	45.60	885.27	0.00	-1.84		1187.38			-31.05	17806.03	-95.82	-9.88	0.00	23739.53	11394.87	5.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.050	1.52	0.18	-4.388	-4.95	47.47	776.90	143.28	138.75	1347.81	861.58	13.87	2218.31	13321.85	1723.85	172.38	0.438	15.72	17631.59	8463.15	3.91	451.82	0.00	0.00	0.00	0.00	0.00
21	0.046	1.51	0.19	-4.323	-2.17	40.33	867.67	167.06	159.43	1478.72	976.74	11.77	2587.67	14759.67	1349.68	134.97	0.833	16.03	18934.80	9376.73	4.34	-2926.21	-0.44	0.00	0.00	0.00	0.00
22	0.038	1.41	0.10	-6.118	103.29	34.20	731.24	141.68	138.76	1878.72	823.21	18.79	2185.14	12439.68	702.36	70.23	0.638	16.12	14684.29	7902.66	3.66	14908.66	2.19	0.00	0.00	0.00	0.00
23	0.050	1.39	0.15	-6.183	106.37	40.07	657.29	122.49	119.49	1378.81	748.01	17.88	1842.49	11500.79	592.28	59.23	0.634	13.64	14860.24	7180.91	3.32	15297.54	2.28	0.00	0.00	0.00	0.00
24	0.055	1.37	0.20	-6.083	67.84	44.82	705.15	140.16	138.01	1811.81	780.65	17.88	2156.35	11947.48	6326.66	632.66	0.385	13.78	15812.84	7580.17	3.51	11906.39	1.48	0.00	0.00	0.00	0.00
25	0.047	1.39	0.15	-6.307	-6.27	44.12	894.69	136.41	131.87	111.81	1039.59	11.61	2172.95	15708.89	6984.49	698.45	0.808	14.34	20791.18	9879.77	4.62	-901.90	-0.14	0.00	0.00	0.00	0.00
26	0.066	1.41	0.15	-6.342	31.75	49.00	665.81	101.50	99.68	111.01	729.86	10.07	1554.52	11783.50	4996.68	499.67	0.836	15.95	15595.94	7486.05	3.46	4490.25	0.87	0.00	0.00	0.00	0.00
27	0.069	1.40	0.14	-6.394	3.02	51.02	688.37	93.75	52.88	856.82	838.81	12.58	817.29	12819.04	7526.79	752.79	0.788	10.36	11718.43	8226.45	3.80	-431.58	-0.06	0.00	0.00	0.00	0.00
28	0.057	1.39	0.20	-6.331	25.05	46.42	743.30	145.28	142.20	114.84	835.17	14.84	2246.21	12619.75	7219.95	722.06	0.481	16.61	18702.61	8017.25	3.71	3702.03	0.36	0.00	0.00	0.00	0.00
29	0.054	1.29	0.17	-6.081	68.09	45.18	724.57	121.11	114.68	134.54	836.72	12.58	1617.44	12675.68	5841.77	584.17	0.481	15.89	16774.25	8051.64	3.72	10222.16	1.58	0.00	0.00	0.00	0.00
30	0.056	1.41	0.18	-6.378	66.21	47.87	737.84	121.33	117.75	137.17	852.85	10.17	1866.17	12884.54	8004.07	800.40	0.512	15.48	17053.07	8165.48	3.79	9358.76	1.40	0.00	0.00	0.00	0.00
31	0.055	1.50	0.21	-6.343	-35.52	46.60	841.35	174.69	170.81	181.46	931.05	10.46	2757.97	14069.11	8864.91	886.49	0.512	15.31	18620.68	8838.02	4.13	-4745.98	-0.71	0.00	0.00	0.00	0.00
Average	0.054	1.412	0.177	0.040	33.103	44.742	752.855	133.689	126.951	127.993	867.835	12.993	2016.311	13038.38	6480.847	649.084	0.471	15.010	17256.68	8283.207	3.831	4852.41	0.728	19.569	-19.569	37332.1	37332.1
Averages are from SS 20 to SS 31																											
Average	0.052	1.418	0.164	0.045	36.850	43.689	767.938	140.878	137.705	133.954	871.729	13.954	2185.992	13172.70	7026.404	702.640	0.428	15.381	17434.58	8368.599	3.870	5417.025	0.813	20.084	-20.084	38949.1	38949.1
Averages are from SS 20 to SS 31 (excluding SS 26 & 27)																											

Control System

K = 0.06

Steady State Period	h _{us}	fcw	fs _{br}	INPUT M _{up}	Sup.	S _{us}	S _{br}	S _{sw}	S _{st}	INPUT S _{sw}	M _{SW} /Q	S _{sw}	M _{SW}	M _{St}	M _{Ag}	M _{Ag}	INPUT M _{Ag}	Delta P _g	M _{Ag}	M _{Ag}	Delta P _h	M _u	Delta P _h	Calculated Delta P	Measured Delta P	Calculated M _u	Measured M _u		
1																													
2																													
3																													
4	0.106	1.52		0.00	66.90	889.93	0.00	-1.80		742.27			-29.21	11267.83	-93.90	-4.38	0.00	14633.86	7120.27	3.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
5	0.091	1.57		0.00	64.40	819.97	0.00	-0.88		821.89			-13.51	12417.95	-43.43	-4.38	0.00	16428.07	7685.80	3.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
6	0.073	1.47		0.00	48.17	811.80	0.00	5.18		858.56			-8.60	13287.58	-80.77	-28.68	0.00	16386.66	7857.05	3.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
7	0.054	1.46		0.00	35.17	817.81	0.00	-0.58		818.86			-15.48	12371.68	-49.68	-4.87	0.00	16374.28	7859.85	3.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.053	1.47		0.00	32.79	880.31	0.00	-8.81		768.70			-12.58	11618.84	-40.47	-4.87	0.00	15317.87	7361.28	3.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.044	1.45		0.00	28.52	925.78	0.00	-3.87		832.98			-58.31	12521.99	-180.99	-18.99	0.00	16629.40	7988.61	3.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.057	1.43		0.00	34.72	873.33	0.00	-1.70		781.08			-28.35	11483.03	-84.66	-8.41	0.00	15211.36	7301.45	3.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.051	1.39		0.00	33.54	871.																							

APPENDIX D

- Anaerobic Batch Tests
 - Leachate/Sewage Mixture
 - Leachate Only (Kimaru *et al.*, 1996)

Anaerobic Batch Test
Number 01 on 10/04/97

	Start	End
	Exp. Sys.	Exp. Sys.
TSS	1250	1256
VSS	990	1036

Sample Number	Time	Experimental System				
		Nitrate	Nitrite	NOx	PO4	COD
1	0	0.22	0.11	0.33	11.94	67
2	10	0.03	0.02	0.05	13.23	63
3	20	0.01	0.02	0.03	15.48	47
4	30	0.00	0.02	0.02	17.42	55
5	40	0.01	0.02	0.03	17.74	51
6	50	0.09	0.02	0.11	18.39	51
7	60	0.01	0.02	0.03	19.03	55
8	75	-0.00	0.02	0.02	20.00	43
9	90	0.02	0.02	0.04	20.97	43
10	120	0.04	0.02	0.07	22.26	43
11	150	0.05	0.02	0.07	23.55	43
12	180	0.02	0.02	0.04	23.87	31
13	210	0.02	0.02	0.04	23.23	35
14	240	0.02	0.02	0.05	22.90	31
15	270	0.06	0.06	0.12	23.23	31
16	300	0.06	0.17	0.23	23.87	47
17	330	0.02	0.02	0.05	23.23	43
18	360	0.02	0.02	0.05	23.23	39

Phosphorus Rates

Best fit line:

	Time	Conc.	PO4 Rate
	min	mgPO4/l-P	mg/min
PO4	0	11.4	0.207
	90	30.0	

Rate A
mgPO4-P/mgAGVSS.d
0.8522

Best fit line:

	Time	Conc.	PO4 Rate
	min	mgPO4/l-P	mg/min
PO4	0	15.3	0.061
	240	30.0	

Rate B
mgPO4-P/mgAGVSS.d
0.2526

MXbg = 6984 mgVASS
Xbg = 349 mgVASS/l

PO4 Release

PO4 @ start =	11.4	mgPO4/l-P
PO4 @ end =	23.0	mgPO4/l-P
Difference =	11.6	mgPO4/l-P

COD Rates

Best fit line:

	Time	Conc.	COD Rate
	min	mgPO4/l-P	mg/min
COD	0	67.1	-0.412
	163	0.0	

PO4 Released / COD Utilized = 0.502 mgPO4/mgCOD

Anaerobic Batch Test
Number 02 on 17/04/97

	Start	End
	Exp. Sys.	Exp. Sys.
TSS	1174	1130
VSS	918	946

Sample Number	Time	Experimental System				
		Nitrate	Nitrite	NOx	PO4	COD
1	0	0.33	0.20	0.54	13.25	47
2	10	0.09	0.03	0.12	15.52	43
3	20	-0.01	0.02	0.01	17.13	39
4	30	0.03	0.03	0.05	19.07	39
5	40	0.08	0.04	0.12	20.04	34
6	50	0.01	0.02	0.04	21.33	34
7	60	0.01	0.02	0.03	21.01	26
8	75	0.08	0.03	0.11	21.33	39
9	90	0.09	0.05	0.14	21.98	34
10	120	-0.01	0.02	0.02	22.95	26
11	150	0.05	0.02	0.07	24.24	30
12	180	0.08	0.02	0.11	25.21	22
13	210	0.04	0.03	0.07	25.54	18
14	240	0.09	0.03	0.12	26.51	30
15	270	-0.01	0.02	0.02	26.51	18
16	300	0.03	0.03	0.05	26.18	22
17	330	0.09	0.04	0.13	27.15	18
18	360	0.23	0.08	0.32	26.51	18

Phosphorus Rates

Best fit line: Time Conc. PO4 Rate
 min mgPO4/l-P mg/min

PO4	0	13.3	0.184
	91	30.0	

Rate A
mgPO4-P/mgAGVSS.d
0.7567

Best fit line: Time Conc. PO4 Rate
 min mgPO4/l-P mg/min

PO4	0	17.4	0.064
	196	30.0	

Rate B
mgPO4-P/mgAGVSS.d
0.2651

MXbg = 6984 mgVASS
 Xbg = 349 mgVASS/l

PO4 Release

PO4 @ start = 13.3 mgPO4/l-P
 PO4 @ end = 26.5 mgPO4/l-P
 Difference = 13.2 mgPO4/l-P

COD Rates

Best fit line: Time Conc. COD Rate
 min mgPO4/l-P mg/min

COD	0	46.7	-0.354
	132	0.0	

PO4 Released / COD Utilized = 0.519 mgPO4/mgCOD

Anaerobic Batch Test (Using Acetate instead of Leachate)
Number 03 on 05/05/97

	Start	End
	Exp. Sys.	Exp. Sys.
TSS	1088	1028
VSS	826	872

Sample Number	Time	Experimental System				
		Nitrate	Nitrite	NOx	PO4	COD
1	0	0.27	0.11	0.54	12.51	41
2	10	0.02	0.02	0.12	16.04	37
3	20	0.09	0.02	0.01	20.85	33
4	30	0.01	0.02	0.05	24.37	29
5	40	0.01	0.02	0.12	27.58	25
6	50	-0.00	0.03	0.04	30.15	20
7	60	-0.00	0.02	0.03	33.03	16
8	75	-0.00	0.02	0.11	34.64	25
9	90	0.01	0.03	0.14	35.92	16
10	120	-0.00	0.03	0.02	35.92	12
11	150	-0.00	0.03	0.07	36.24	16
12	180	-0.00	0.03	0.11	36.88	16
13	210	-0.01	0.03	0.07	36.24	16
14	240	-0.01	0.03	0.12	36.24	25
15	270	-0.02	0.03	0.02	36.56	33
16	300	-0.01	0.03	0.05	36.56	25
17	330	0.01	0.04	0.13	36.56	16
18	360	0.03	0.05	0.32	36.88	29

Phosphorus Rates

Best fit line: Time Conc. PO4 Rate
 min mgPO4/l-P mg/min

PO4	0	12.9	0.386
	74	40.0	

Rate A
mgPO4-P/mgAGVSS.d
2.1108

Best fit line: Time Conc. PO4 Rate
 min mgPO4/l-P mg/min

PO4	0	17.6	0.252
	89	40.0	

Rate B
mgPO4-P/mgAGVSS.d
1.4507

MXbg = 4997 mgVASS
 Xbg = 250 mgVASS/l

PO4 Release

PO4 @ start = 12.9 mgPO4/l-P
 PO4 @ end = 36.7 mgPO4/l-P
 Difference = 23.8 mgPO4/l-P

COD Rates

Best fit line: Time Conc. COD Rate
 min mgPO4/l-P mg/min

COD	0	40.9	-0.413
	99	0.0	

PO4 Released / COD Utilized = 0.886 mgPO4/mgCOD

APPENDIX E

- Denitrification Batch Tests


Denitrification Batch Test
Number 1 on 14/02/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2506	1886	2422	1960
VSS	1858	1490	1820	1488

Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	4.32	0.36	15.84	ERR	2.12	1.75	13.31	ERR
2	10	3.48	0.55	15.53	---	1.24	0.52	10.14	---
3	20	2.36	0.86	16.16	---	0.89	0.71	11.41	---
4	30	2.65	1.06	16.16	---	0.25	0.86	10.77	---
5	40	0.98	1.27	15.84	---	-0.07	1.02	10.46	---
6	50	0.36	1.40	15.21	---	-0.63	1.09	10.46	---
7	60	0.20	1.56	15.53	---	-0.82	0.82	10.14	---
8	75	-0.01	1.29	14.89	ERR	---	0.30	10.46	ERR
9	90	0.52	0.59	15.21	---	---	---	10.46	---
10	120	-0.44	0.29	16.48	---	---	---	11.09	---
11	150	-0.17	---	17.43	ERR	---	---	12.36	ERR
12	210	---	---	19.01	ERR	---	---	12.68	ERR
13	270	---	---	21.86	ERR	---	---	14.26	ERR
14	330	---	---	22.50	ERR	---	---	15.53	ERR


Experimental System

Best fit line: Time Conc. NO3 Rate
min mgNO3/l-N mg/min

NO3  -0.076

NO3-3/5NO2 mg/min	K2' Rate mgNO3-N/mgAHVSS.d
-0.049	-0.0859


Best fit line: Time Conc. NO2 Rate
min mgNO2/l-N mg/min

NO2  0.045

MXbh 
523 mgVASS/l


Control System

Best fit line: Time Conc. NO3 Rate
min mgNO3/l-N mg/min

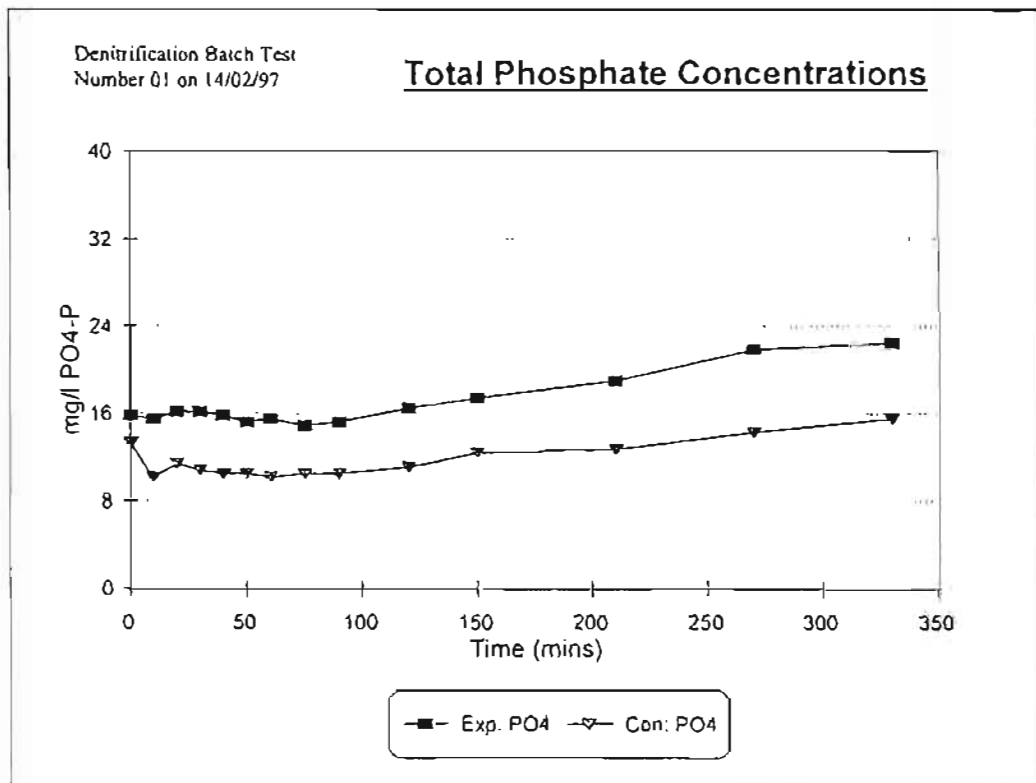
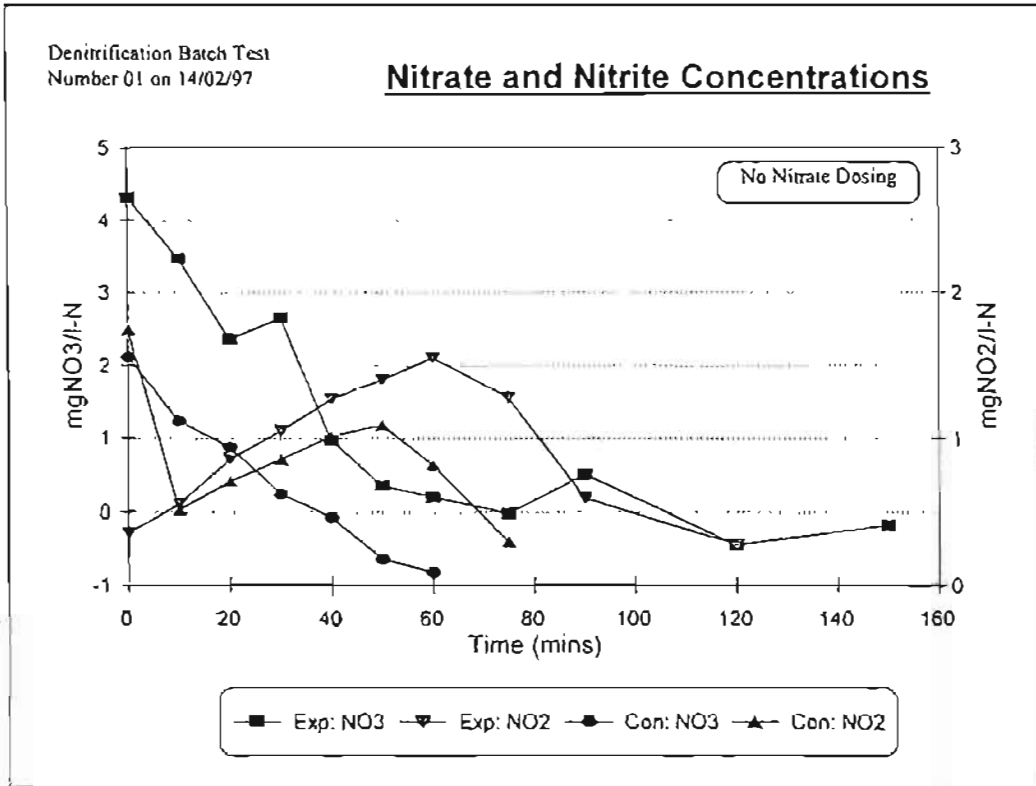
NO3  -0.050

NO3-3/5NO2 mg/min	K2' Rate mgNO3-N/mgAHVSS.d
-0.032	-0.0623

Best fit line: Time Conc. NO2 Rate
min mgNO2/l-N mg/min

NO2  0.030

Xbh 
740 mgVASS/l



Denitrification Batch Test
Number 02 on 24/02/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2110	2650	2558	2110
VSS	1612	2020	1948	1626

Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	26.63	0.45	19.36	51	23.06	0.61	16.60	63
2	10	23.07	0.59	17.52	---	22.83	0.67	16.60	---
3	20	23.37	0.78	18.13	---	21.92	0.77	16.60	---
4	30	22.65	1.01	17.52	---	21.29	0.91	16.60	---
5	40	22.63	1.20	17.52	---	21.40	1.05	15.67	---
6	50	21.10	1.43	17.52	---	20.76	1.20	15.67	---
7	60	20.87	1.66	17.21	---	20.03	1.35	15.67	---
8	75	19.10	1.96	16.90	51	20.42	1.62	15.67	51
9	90	18.07	2.34	16.60	---	19.41	1.81	15.37	---
10	120	16.12	2.99	18.75	---	17.86	2.23	14.75	---
11	150	14.91	3.72	16.60	63	16.50	2.61	14.44	55
12	210	12.38	4.78	16.60	63	15.32	3.14	13.83	51
13	270	9.54	6.15	16.90	59	13.94	3.87	14.75	51
14	330	6.55	7.03	16.60	63	12.86	4.14	14.14	59

Experimental System

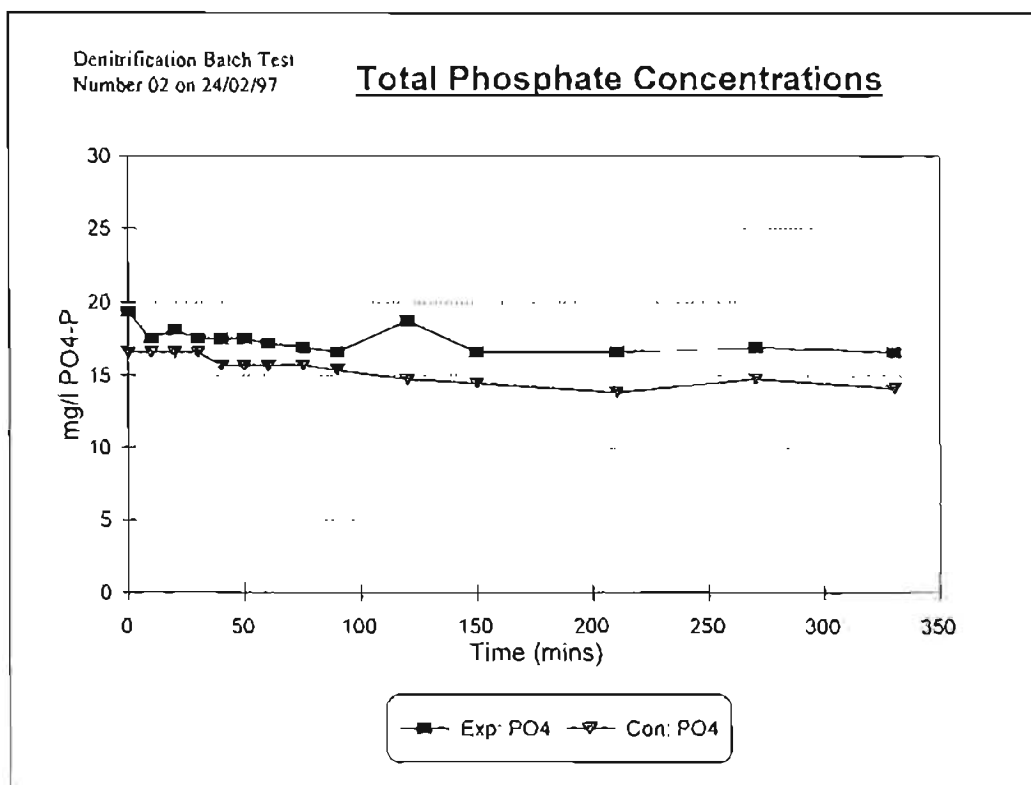
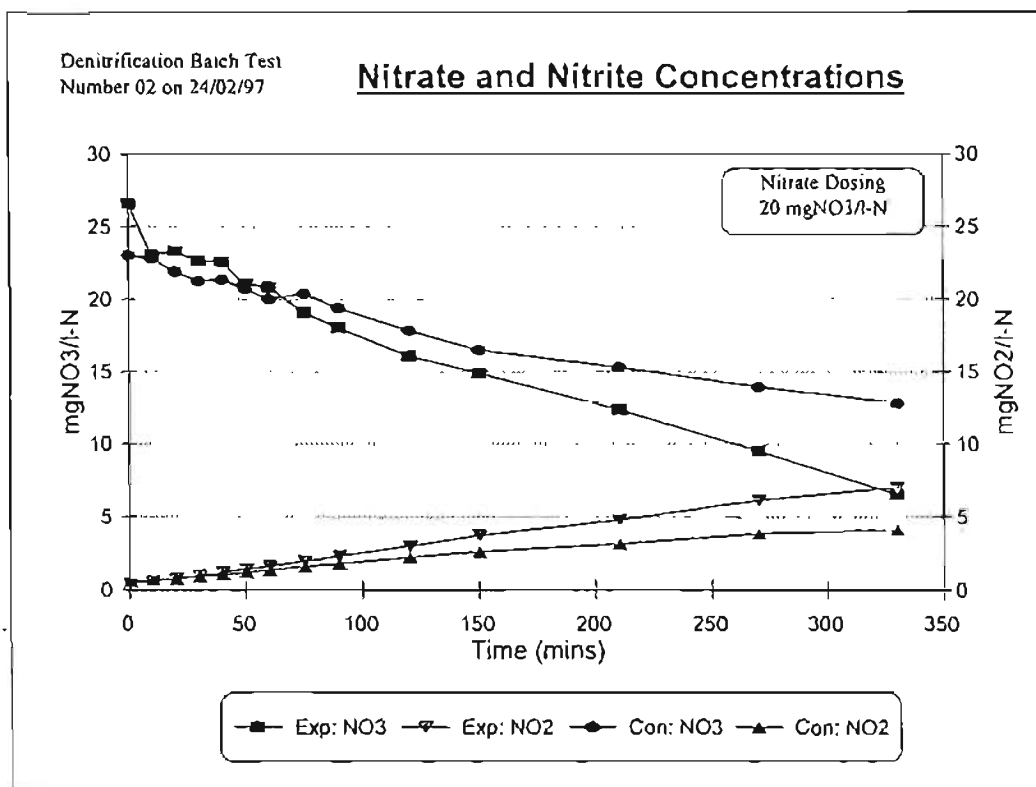
Best fit line:	Time	Conc.	NO3 Rate	NO3-3/5NO2	K2' Rate
	min	mgNO3/l-N	mg/min	mg/min	mgNO3-N/mgAHVSS.d
NO3	0	23.8	-0.053	-0.041	-0.0714
	350	6.0			

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/min
NO2	0	0.5	0.021
	350	7.7	
MXbh	1484	mgVASS	
		823 mgVASS/l	

Control System

Best fit line:	Time	Conc.	NO3 Rate	NO3-3/5NO2	K2' Rate
	min	mgNO3/l-N	mg/min	mg/min	mgNO3-N/mgAHVSS.d
NO3	0	22.7	-0.033	-0.026	-0.0501
	350	11.0			

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/min
NO2	0	0.5	0.013
	350	6.0	
Xbh	14735	mgVASS	
		740 mgVASS/l	



Denitrification Batch Test
Number 03 on 27/02/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	3076	2574	3026	2480
VSS	2344	1960	2292	1890

Experimental System

Best fit line: Time Conc. NO3 Rate
min mgNO3/i-N mg/min

NO3 242 0.222 -0.092

NO3-3/5NO2 mg/min -0.066

K2' Rate mgNO3-N/mgAHVSS.d -0.1155

Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	22.10	0.54	19.03	55	21.85	0.64	17.42	63
2	10	22.26	0.86	19.35	---	21.16	0.85	17.42	---
3	20	19.75	1.23	18.71	---	19.39	1.19	16.45	---
4	30	19.65	1.73	19.35	---	18.57	1.54	16.45	---
5	40	19.94	2.23	19.68	---	19.02	1.88	16.45	---
6	50	17.22	2.57	19.03	---	17.40	2.23	16.45	---
7	60	17.17	3.17	19.03	---	16.09	2.59	16.13	---
8	75	15.51	3.80	19.03	55	15.33	3.04	15.81	55
9	90	19.37	4.38	19.68	---	14.87	3.50	15.81	---
10	120	10.82	5.73	18.71	---	12.34	4.52	15.81	---
11	150	8.09	7.11	18.71	63	11.07	5.71	15.48	63
12	210	3.17	9.49	17.74	68	6.90	6.96	14.84	63
13	270	0.58	8.92	18.06	68	3.86	8.49	14.84	68
14	330	0.28	4.79	17.10	59	0.83	9.15	14.84	68

Best fit line: Time Conc. NO2 Rate
min mgNO2/i-N mg/min

NO2 0 0.5 0.043

MXbh 1663 mgVASS
823 mgVASS/i

Control System

Best fit line: Time Conc. NO3 Rate
min mgNO3/i-N mg/min

NO3 319 0.2016 -0.065

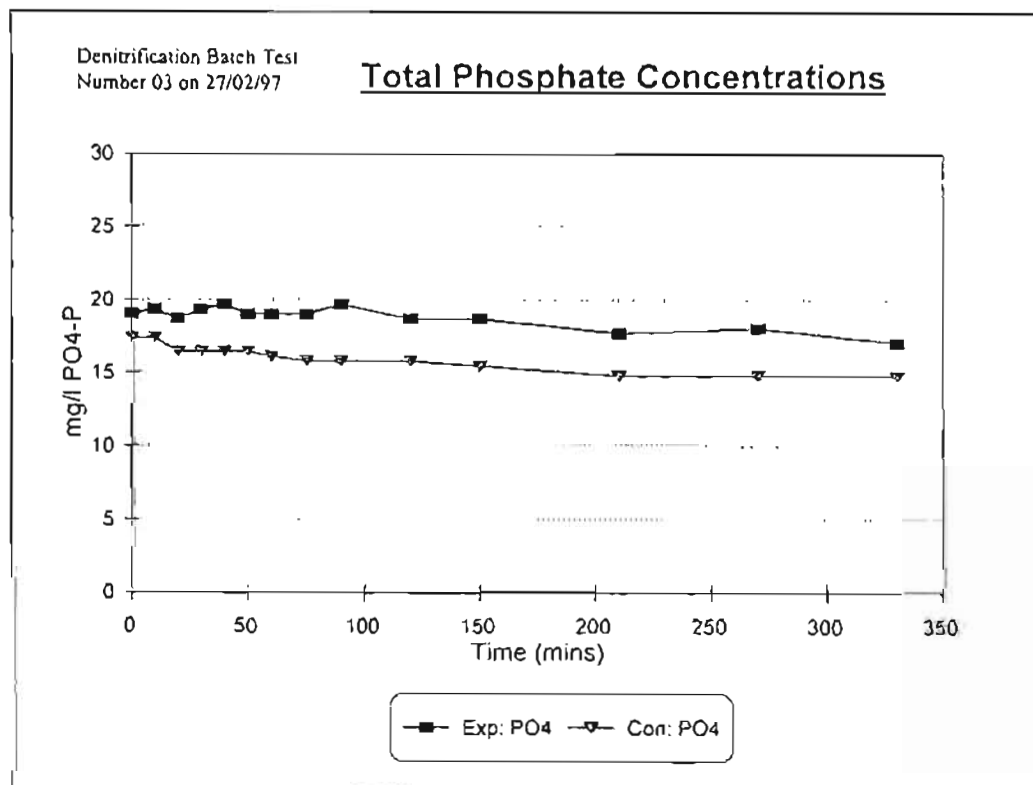
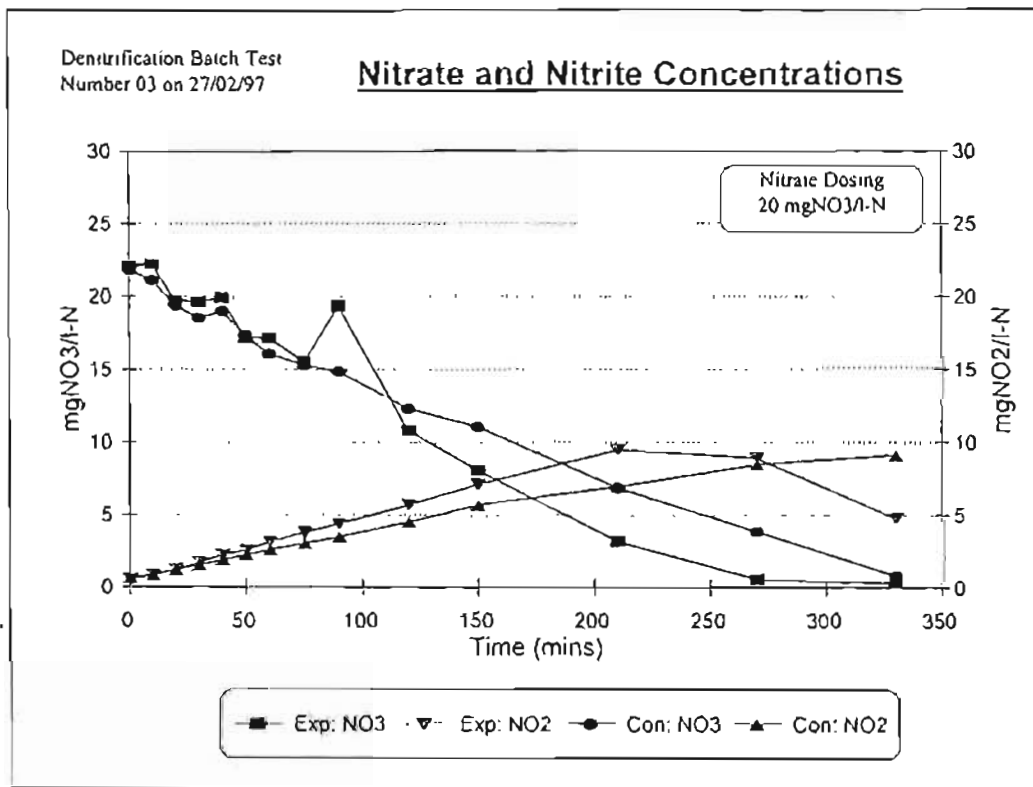
NO3-3/5NO2 mg/min -0.045

K2' Rate mgNO3-N/mgAHVSS.d -0.0877

Best fit line: Time Conc. NO2 Rate
min mgNO2/i-N mg/min

NO2 0 0.5 0.033

Xbh 14793 mgVASS
740 mgVASS/i



Denitrification Batch Test
Number 04 on 07/03/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2864	2020	2796	1944
VSS	2196	1580	2080	1510

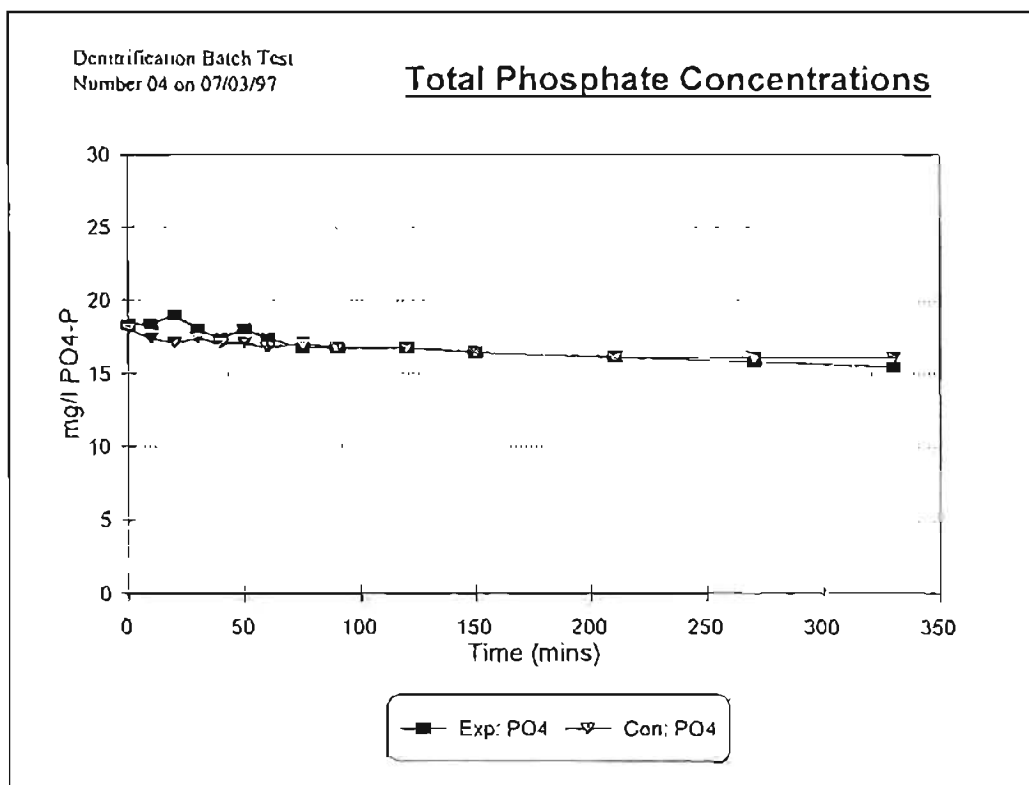
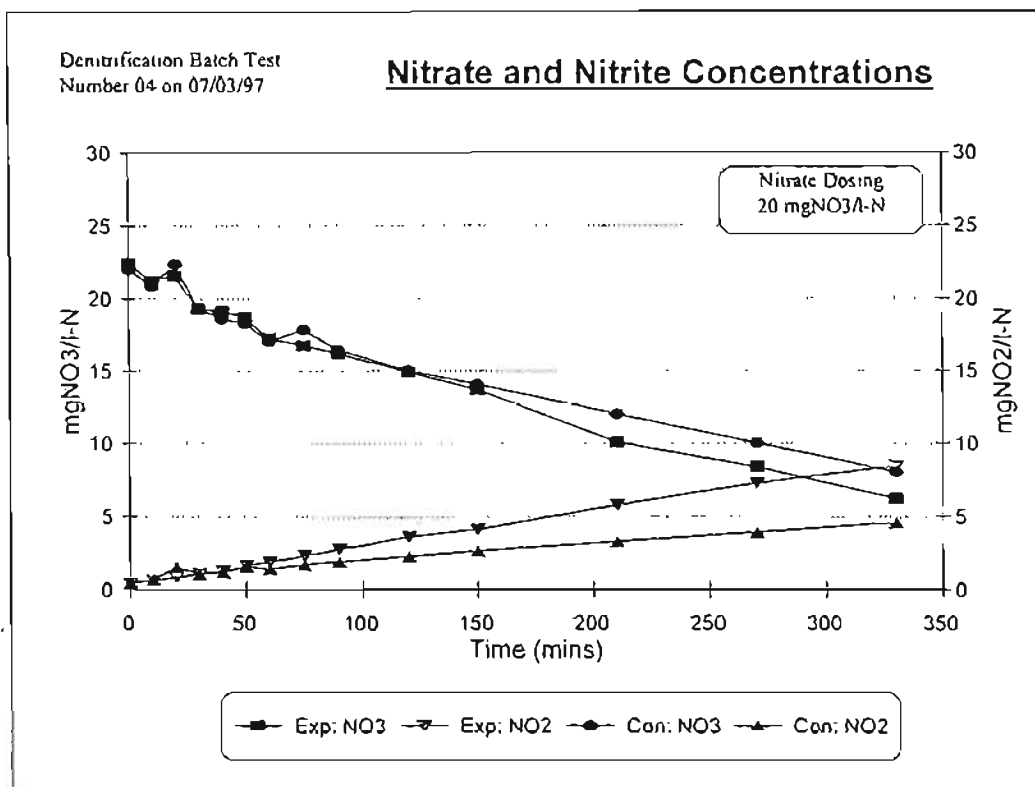
Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	22.49	0.42	18.39	59	22.07	0.52	18.06	51
2	10	21.22	0.66	18.39	---	20.87	0.70	17.42	---
3	20	21.57	0.86	19.03	---	22.42	1.60	17.10	---
4	30	19.35	1.11	18.06	---	19.39	1.07	17.42	---
5	40	19.16	1.30	17.42	---	18.60	1.23	17.10	---
6	50	18.71	1.68	18.06	---	18.32	1.59	17.10	---
7	60	17.26	1.94	17.42	---	17.11	1.46	16.77	---
8	75	16.79	2.33	16.77	55	17.88	1.71	17.10	47
9	90	16.19	2.77	16.77	---	16.47	1.94	16.77	---
10	120	14.93	3.63	16.77	---	15.03	2.27	16.77	---
11	150	13.73	4.12	16.45	51	14.09	2.66	16.45	43
12	210	10.10	5.78	16.13	43	12.03	3.30	16.13	55
13	270	8.40	7.29	15.81	43	10.05	3.94	16.13	43
14	330	6.24	8.45	15.48	47	8.04	4.60	16.13	51

Experimental System
Best fit line: Time Conc. NO3 Rate
min mgNO3/l-N mg/min
NO3 0 212 -0.051
350 3.33
NO3-3/5NO2 mg/min
-0.036
K2' Rate
mgNO3-N/mgAHVSS.d
-0.0701

Best fit line: Time Conc. NO2 Rate
min mgNO2/l-N mg/min
NO2 0 0.4 0.025
350 9.0
MXbh 14860 mgVASS
748 mgVASS/l

Control System
Best fit line: Time Conc. NO3 Rate
min mgNO3/l-N mg/min
NO3 0 207 -0.041
350 6.4
NO3-3/5NO2 mg/min
-0.033
K2' Rate
mgNO3-N/mgAHVSS.d
-0.0743

Best fit line: Time Conc. NO2 Rate
min mgNO2/l-N mg/min
NO2 0 0.4 0.013
350 4.9
Xbh 12839 mgVASS
642 mgVASS/l



Denitrification Batch Test
Number 05 on 10/03/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2650	1902	2264	1386
VSS	1974	1452	1724	1074

Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	24.11	0.58	---	59	21.33	0.66	---	51
2	10	21.29	0.71	---	---	20.40	0.78	---	---
3	20	20.18	0.84	---	---	20.20	0.89	---	---
4	30	19.31	0.97	---	---	18.72	0.98	---	---
5	40	18.05	1.00	---	---	19.08	1.12	---	---
6	50	18.42	1.12	---	---	18.27	1.19	---	---
7	60	18.90	1.29	---	---	17.16	1.23	---	---
8	75	17.18	1.46	---	51	16.73	1.42	---	39
9	90	17.13	1.60	---	---	15.84	1.50	---	---
10	120	14.00	1.86	---	---	14.59	1.76	---	---
11	150	12.70	2.18	---	51	13.11	2.01	---	43
12	210	9.36	2.66	---	43	11.05	2.45	---	43
13	270	7.40	3.48	---	51	8.33	2.71	---	39
14	330	4.19	3.91	---	43	5.98	2.94	---	43

Experimental System

Best fit line: Time min 350 NO3-3/5NO2 mg/min -0.049

Conc. mgNO3//N mg/min 21.5

NO3 Rate mgNO3-N/mgAHVSS/d -0.0939

Best fit line: Time min 350 NO2 Rate mg/min 0.011

Conc. mgNO2//N mg/min 0.5

NO2 Rate mgNO2//N mg/min 0.011

MXbh 14960 mgVASS
748 mgVASS/l

Control System

Best fit line: Time min 350 NO3-3/5NO2 mg/min -0.038

Conc. mgNO3//N mg/min 20.1

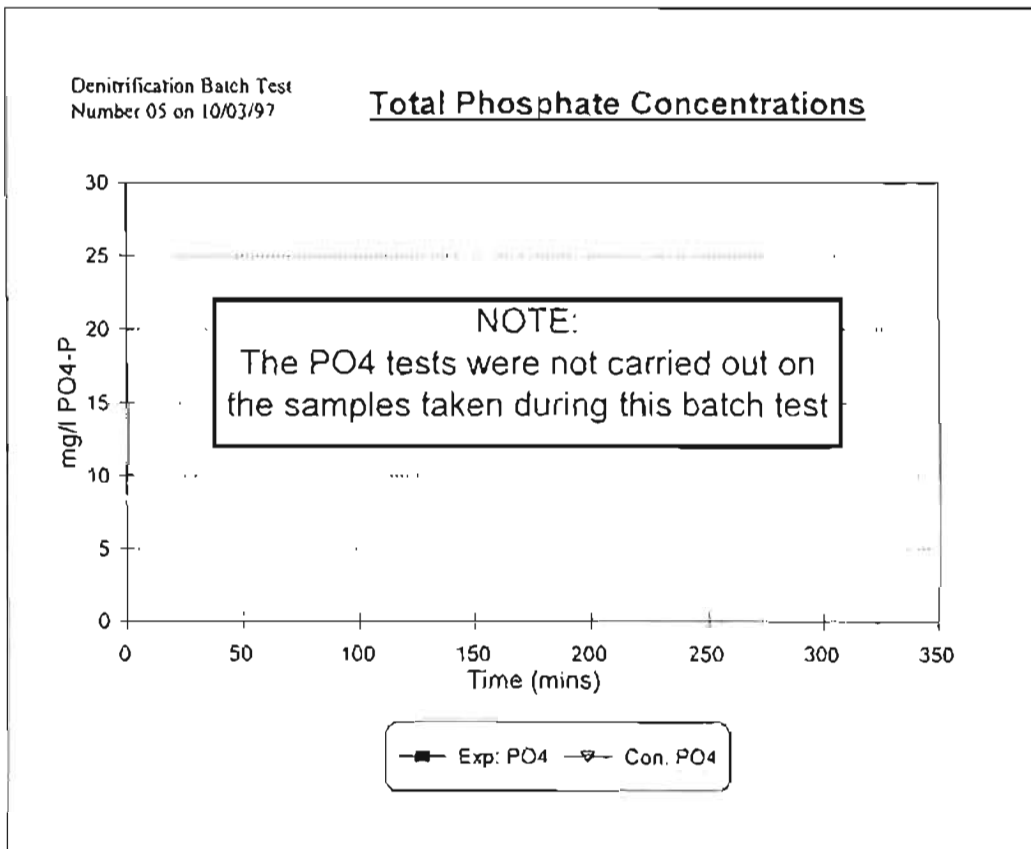
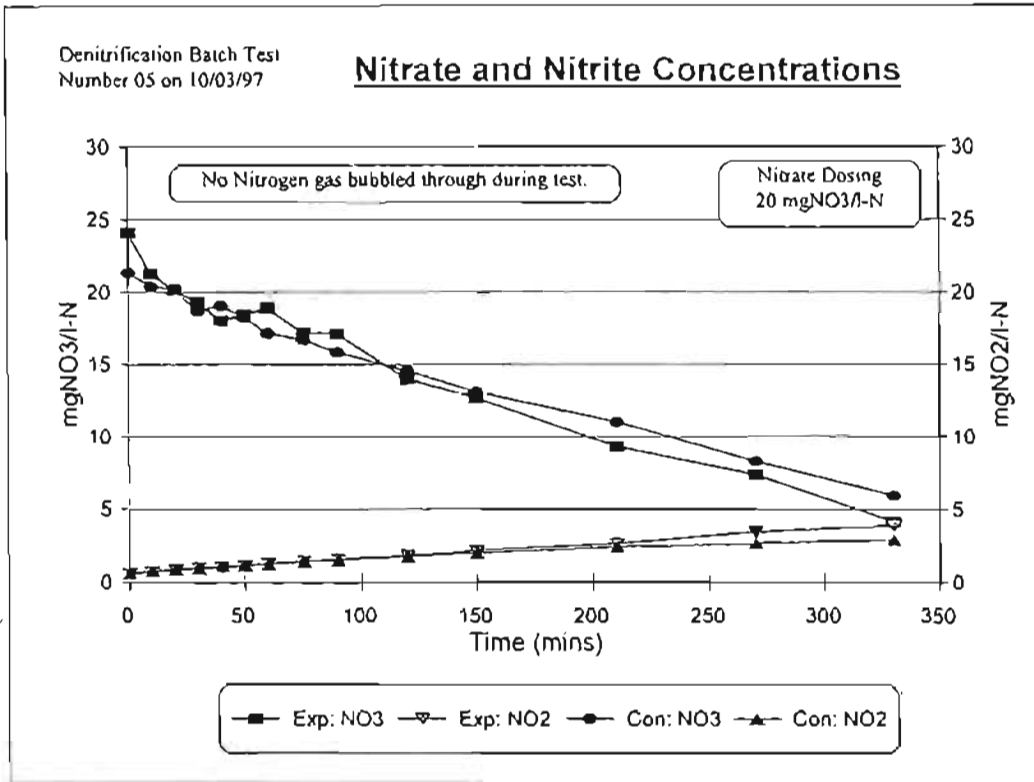
NO3 Rate mgNO3-N/mgAHVSS/d -0.0860

Best fit line: Time min 350 NO2 Rate mg/min 0.008

Conc. mgNO2//N mg/min 0.5

NO2 Rate mgNO2//N mg/min 0.008

Xbh 12839 mgVASS
642 mgVASS/l



Denitrification Batch Test
Number 06 on 13/03/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2818	2166	2794	2122
VSS	2070	1632	2086	1598

Sample Number	Time	Experimental System				Control System			
		Nitrate	Nitrite	PO4	COD	Nitrate	Nitrite	PO4	COD
1	0	22.56	0.12	—	49	20.81	0.09	—	49
2	10	21.53	0.35	—	—	19.63	0.22	—	—
3	20	20.95	0.60	—	—	18.91	0.38	—	—
4	30	20.41	0.82	—	—	19.21	0.57	—	—
5	40	19.21	1.05	—	—	18.58	0.71	—	—
6	50	19.22	1.37	—	—	18.11	0.86	—	—
7	60	18.68	1.58	—	—	18.41	1.04	—	—
8	75	18.17	2.09	—	49	17.07	1.26	—	45
9	90	16.94	2.35	—	—	16.83	1.50	—	—
10	120	15.29	3.27	—	—	15.03	1.84	—	—
11	150	14.37	4.12	—	57	13.99	2.24	—	45
12	210	10.91	5.48	—	57	12.07	3.03	—	45
13	270	7.63	6.83	—	57	9.74	3.67	—	49
14	330	5.33	7.99	—	61	7.56	4.32	—	49

Experimental System

Best fit line: Time min 0 350
Conc. mgNO₃/l-N 22.0
NO₃ Rate mg/min -0.052
K₂' Rate mgNO₃-N/mgAHVSS/d -0.0701

Best fit line: Time min 0 350
Conc. mgNO₂/l-N 0.0
NO₂ Rate mg/min 0.026

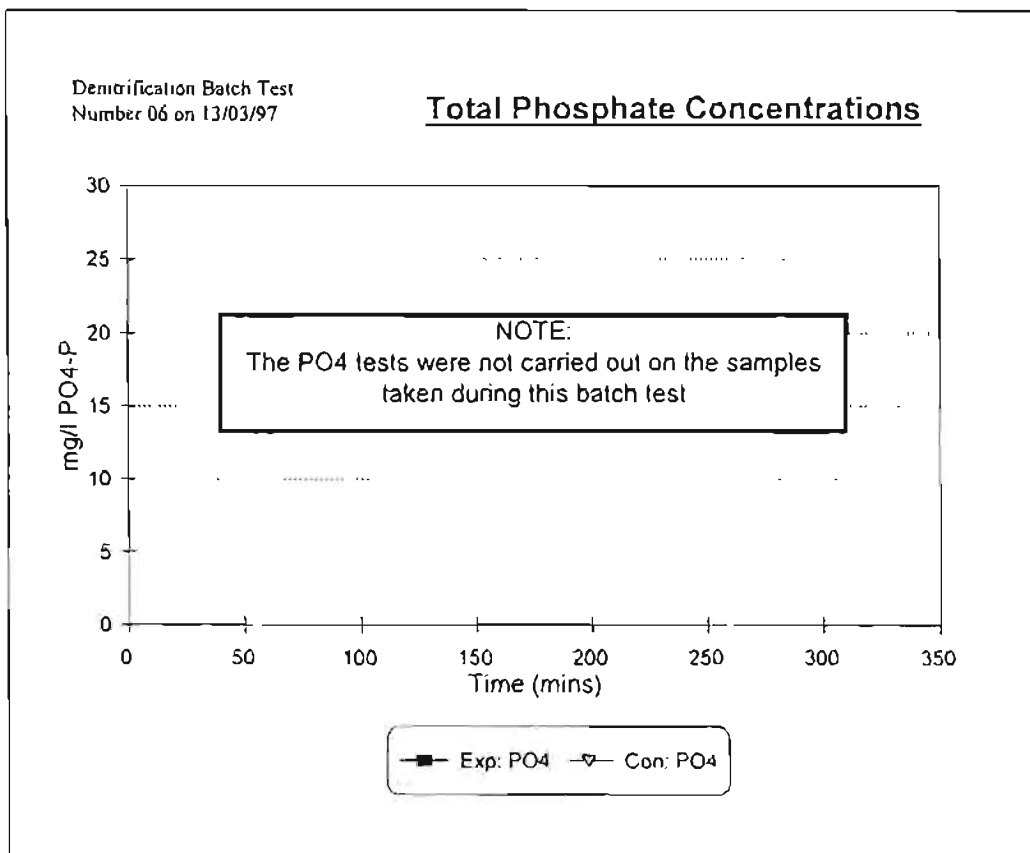
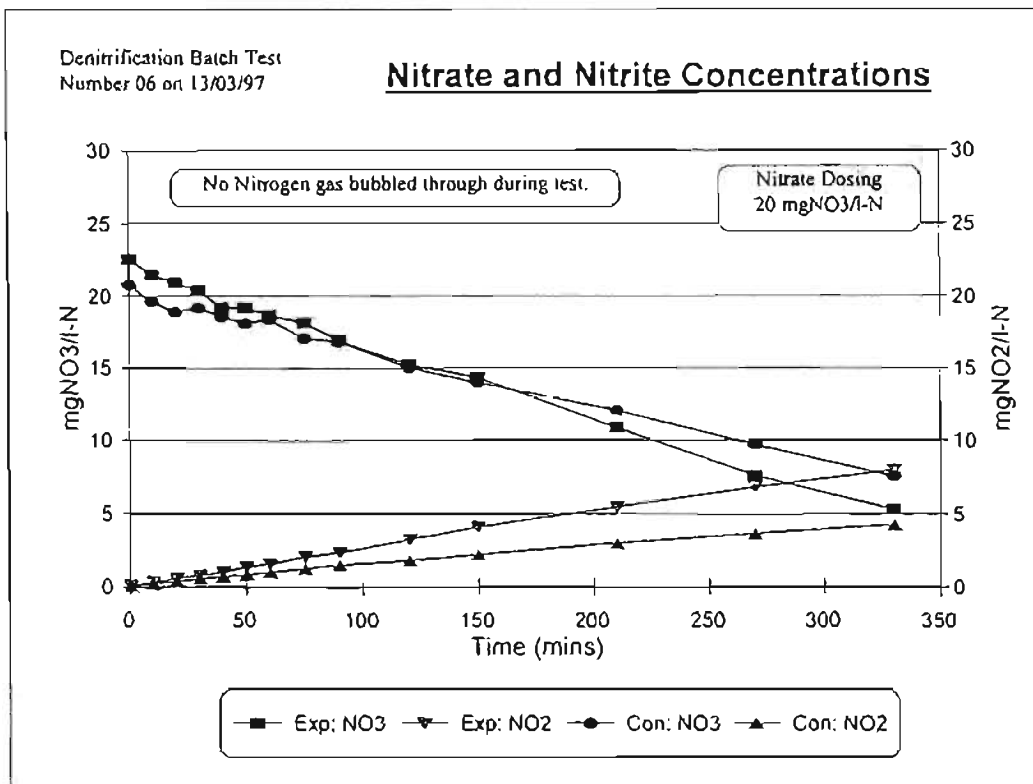
MXbh 14960 mgVASS
748 mgVASS/l

Control System

Best fit line: Time min 0 350
Conc. mgNO₃/l-N 20.0
NO₃ Rate mg/min -0.038
K₂' Rate mgNO₃-N/mgAHVSS/d -0.0664

Best fit line: Time min 0 350
Conc. mgNO₂/l-N 0.0
NO₂ Rate mg/min 0.014

Xbh 12833 mgVASS
642 mgVASS/l



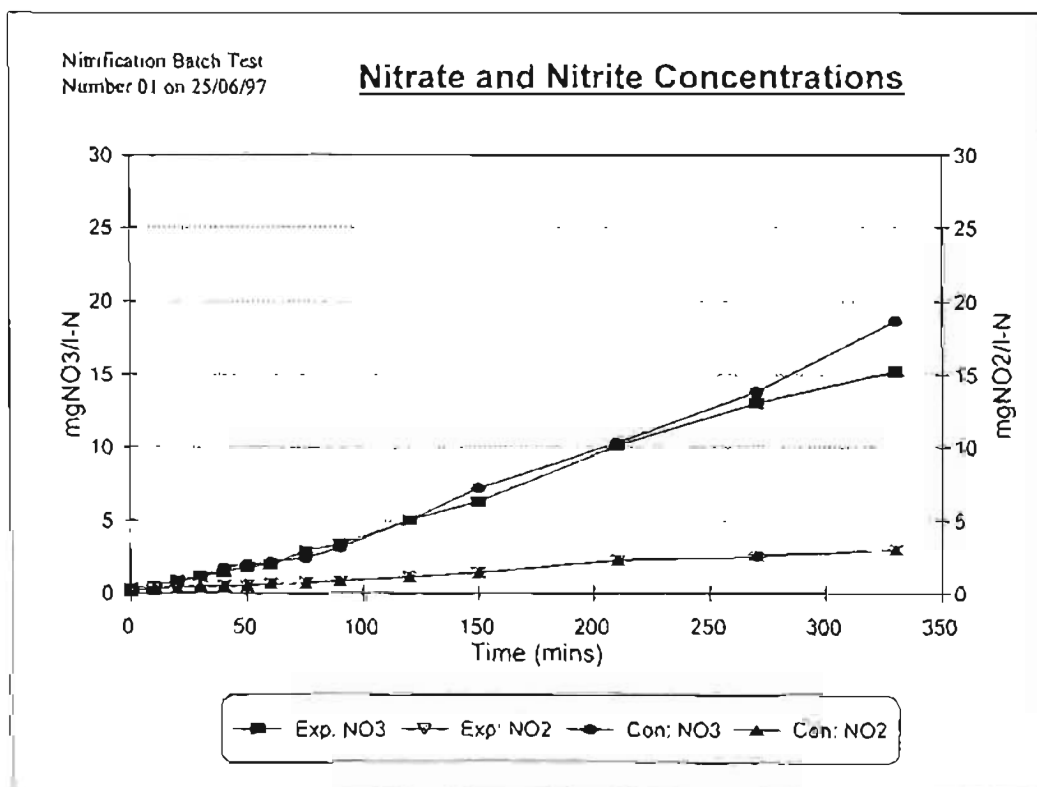
APPENDIX F

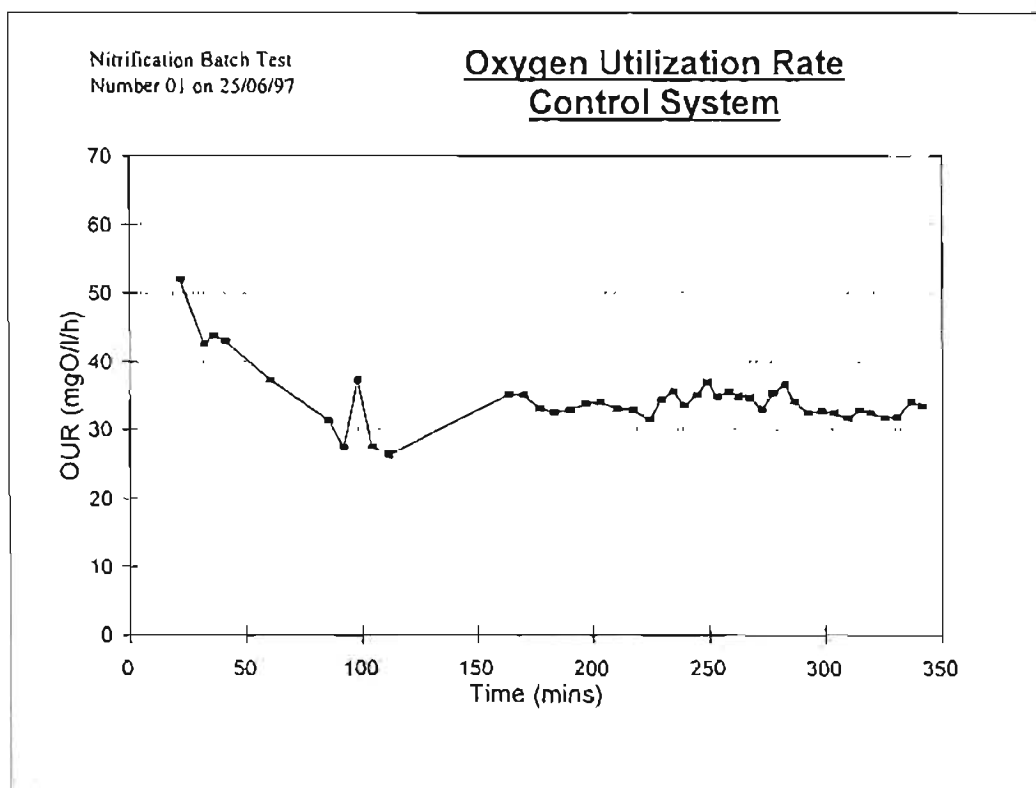
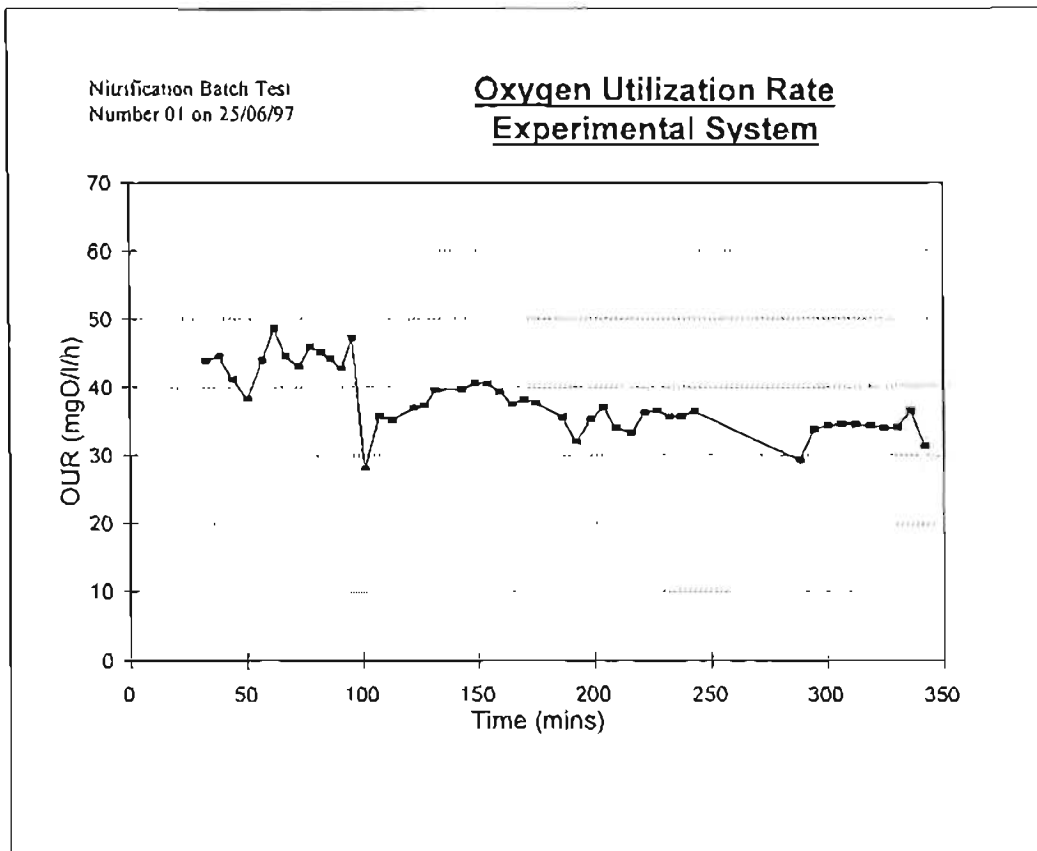
- Nitrification Batch Tests
- Maximum Specific Growth rate of the Nitrifiers

Nitrification Batch Test
Number 01 on 25/06/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2862	2108	3042	2186
VSS	2234	1742	2338	1734

Sample Number	Time	EXP System		CTL System	
		Nitrate mgN/l	Nitrite mgN/l	Nitrate mgN/l	Nitrite mgN/l
1	0	0.33	0.11	0.22	0.18
2	10	0.50	0.27	0.13	0.35
3	20	0.89	0.41	0.70	0.38
4	30	1.19	0.47	1.23	0.51
5	40	1.50	0.52	1.76	0.51
6	50	1.83	0.60	2.04	0.56
7	60	2.04	0.69	2.18	0.69
8	75	2.96	0.77	2.46	0.74
9	90	3.42	0.87	3.20	0.92
10	120	5.06	1.17	5.06	1.17
11	150	6.33	1.46	7.26	1.48
12	210	10.15	2.28	10.35	2.35
13	270	13.05	2.51	13.84	2.68
14	330	15.26	3.02	18.74	3.06





Nitrification Batch Test
Number 01 on 25/06/97

Experimental System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	23	0.0	0.052
	350	16.9	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.1	0.009
	350	3.2	

Total rate of Ammonia Conversion = 3.632 mgNO₃-N//h
 Mass Nitrate in Effluent of Parent System = 13.801 mgN/d
 Mass Nitrate Denitrified in Parent System = 42.088 mgN/d
 Therefore, Nitrification Capacity in Parent System = 55.889 mgNO₃-N/l influent
 Mass of Nitrifiers M(X_n) = 798.414 mgVSS
 Nitrifiers Concentration = 39.921 mg X_n/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = 0.218 /d

Control System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	33	0.0	0.059
	350	18.7	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.1	0.009
	350	3.2	

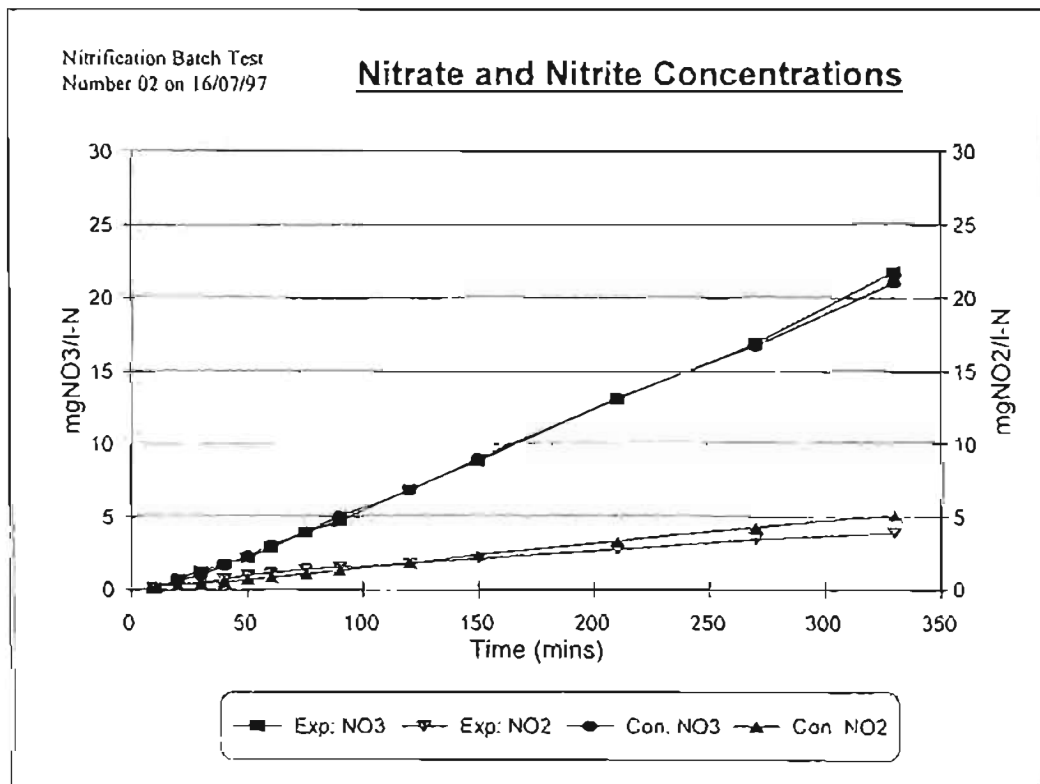
Total rate of Ammonia Conversion = 4.071 mgNO₃-N//h
 Mass Nitrate in Effluent of Parent System = 12.524 mgN/l
 Mass Nitrate Denitrified in Parent System = 36.841 mgN/l
 Therefore, Nitrification Capacity in Parent System = 49.365 mgNO₃-N/l influent
 Mass of Nitrifiers M(X_n) = 705.213 mgVSS
 Nitrifiers Concentration = 35.261 mg X_n/l

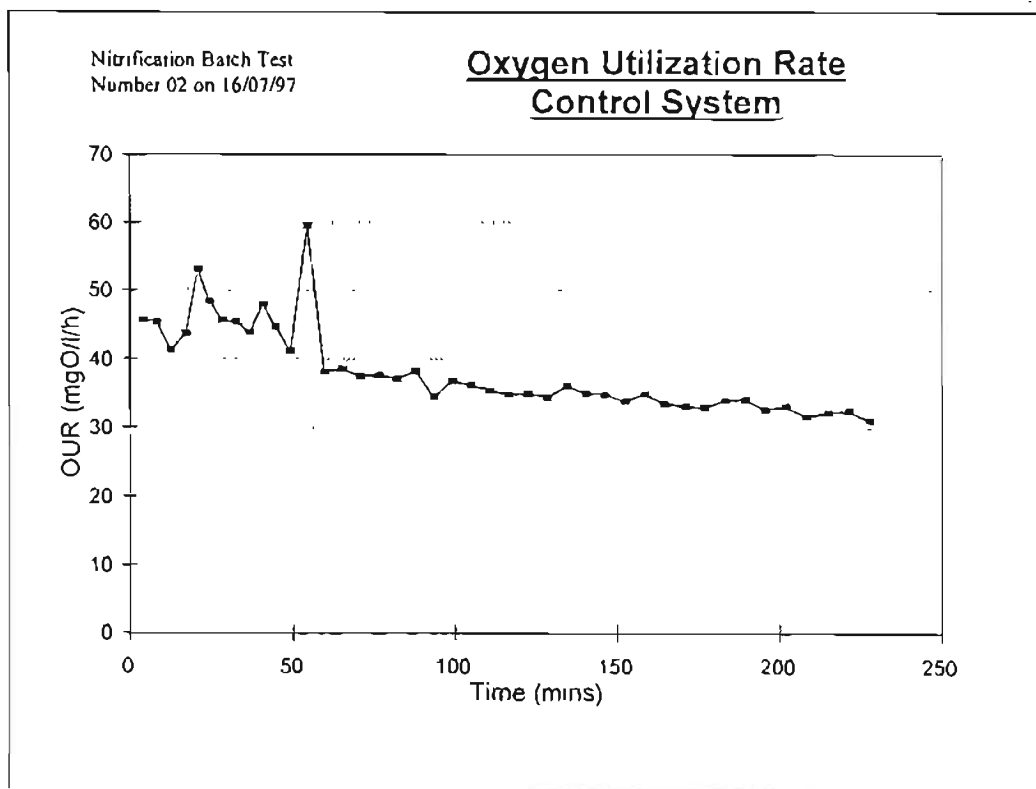
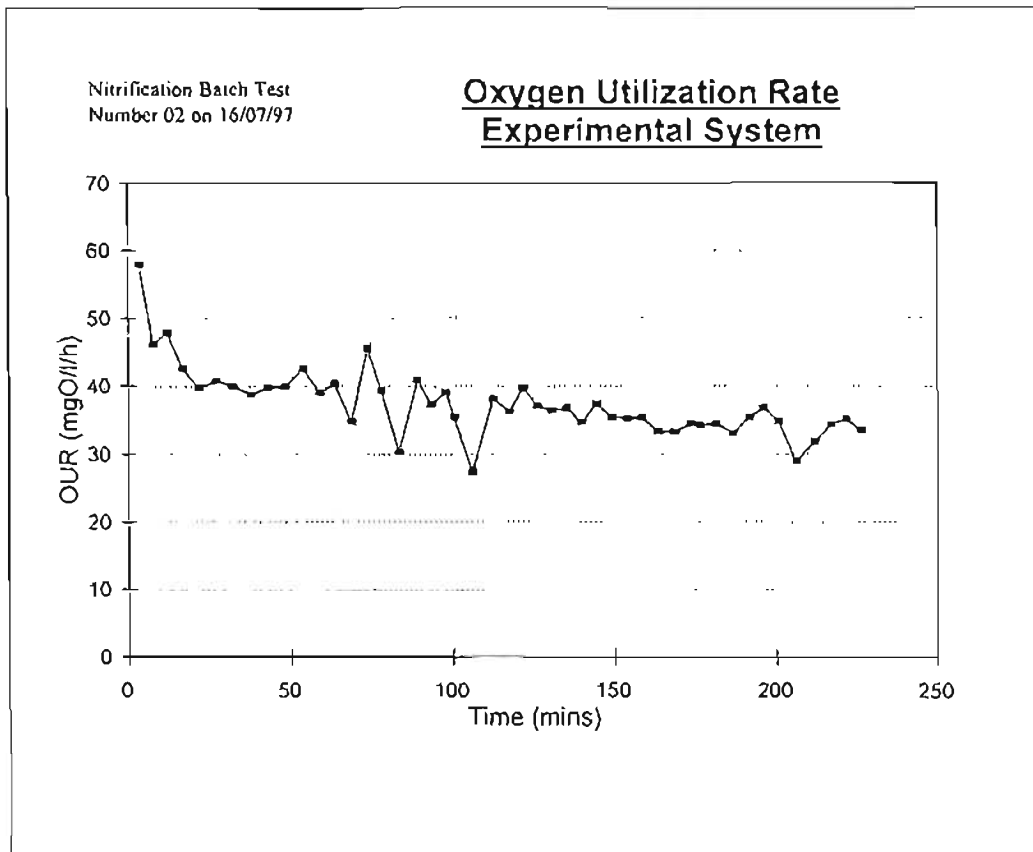
Maximum Specific Growth rate of Nitrifiers μ_{nm} = 0.277 /d

Nitrification Batch Test
Number 02 on 16/07/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	1940	1758	1974	1782
VSS	1486	1520	1482	1566

Sample Number	Time	EXP System		CTL System	
		Nitrate mgN/l	Nitrite mgN/l	Nitrate mgN/l	Nitrite mgN/l
1	0	-0.10	-0.03	-0.13	-0.02
2	10	0.10	0.20	0.13	0.16
3	20	0.75	0.38	0.60	0.34
4	30	1.31	0.52	1.07	0.45
5	40	1.80	0.73	1.66	0.55
6	50	2.25	1.04	2.39	0.70
7	60	2.92	1.19	3.13	0.86
8	75	3.96	1.43	4.01	1.12
9	90	4.72	1.56	5.05	1.35
10	120	6.87	1.81	6.79	1.89
11	150	8.86	2.18	9.04	2.43
12	210	13.12	2.80	13.17	3.39
13	270	16.90	3.47	16.74	4.32
14	330	21.83	3.93	21.06	5.14





Nitrification Batch Test
Number 02 on 16/07/97

Experimental System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	10	0.0	0.066
	350	22.4	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.5	0.011
	350	4.2	

Total rate of Ammonia Conversion =	4.587	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	10.949	mgN/l
Mass Nitrate Denitrified in Parent System =	33.477	mgN/l
Therefore, Nitrification Capacity in Parent System =	44.426	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	634.655	mgVSS
Nitrifiers Concentration =	31.733	mg Xn/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Control System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	10	0.0	0.066
	350	22.4	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.0	0.016
	350	5.5	

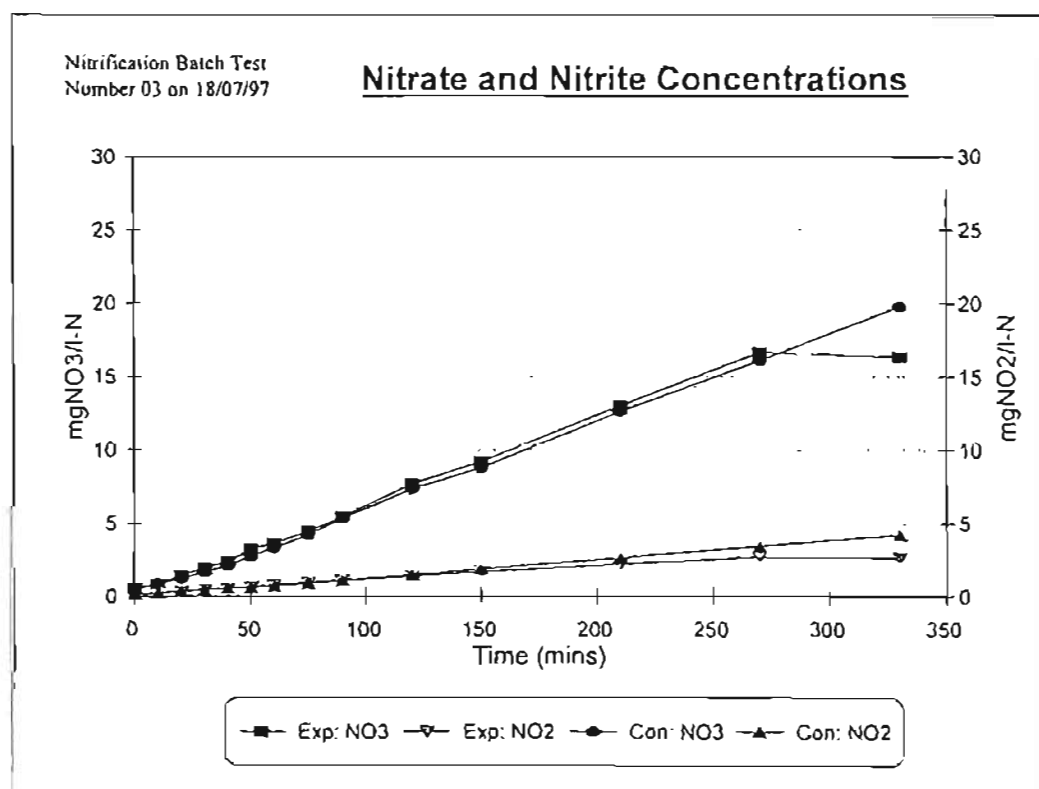
Total rate of Ammonia Conversion =	4.896	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	11.656	mgN/l
Mass Nitrate Denitrified in Parent System =	35.643	mgN/l
Therefore, Nitrification Capacity in Parent System =	47.298	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	675.690	mgVSS
Nitrifiers Concentration =	33.784	mg Xn/l

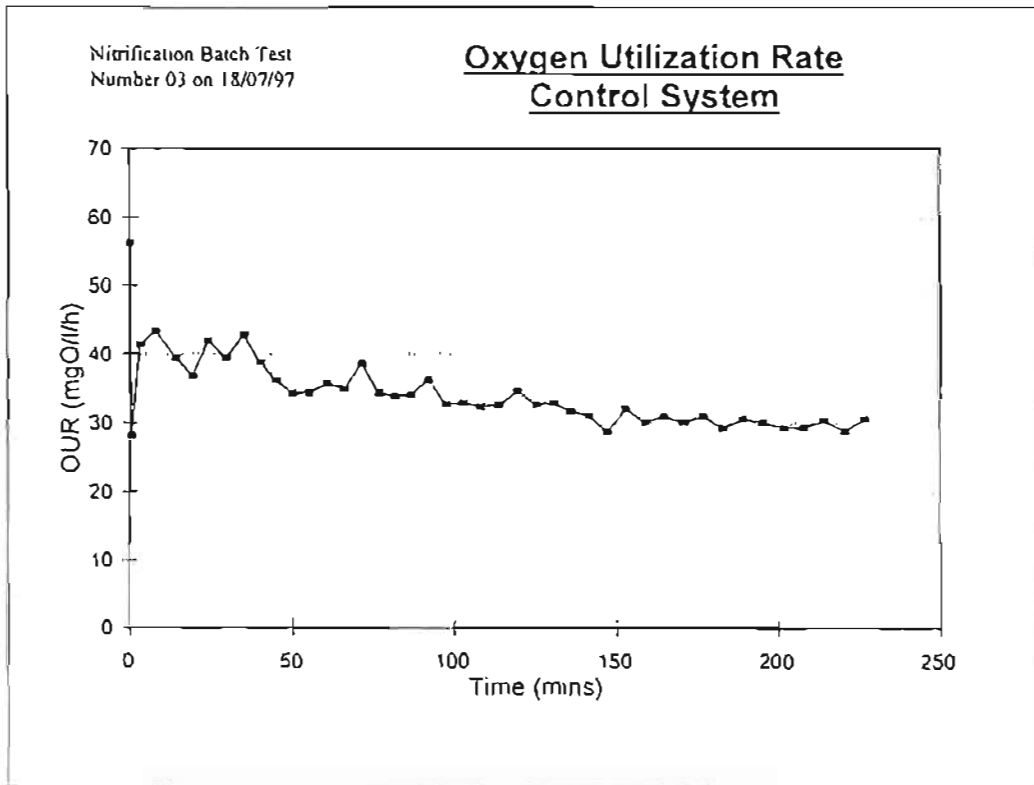
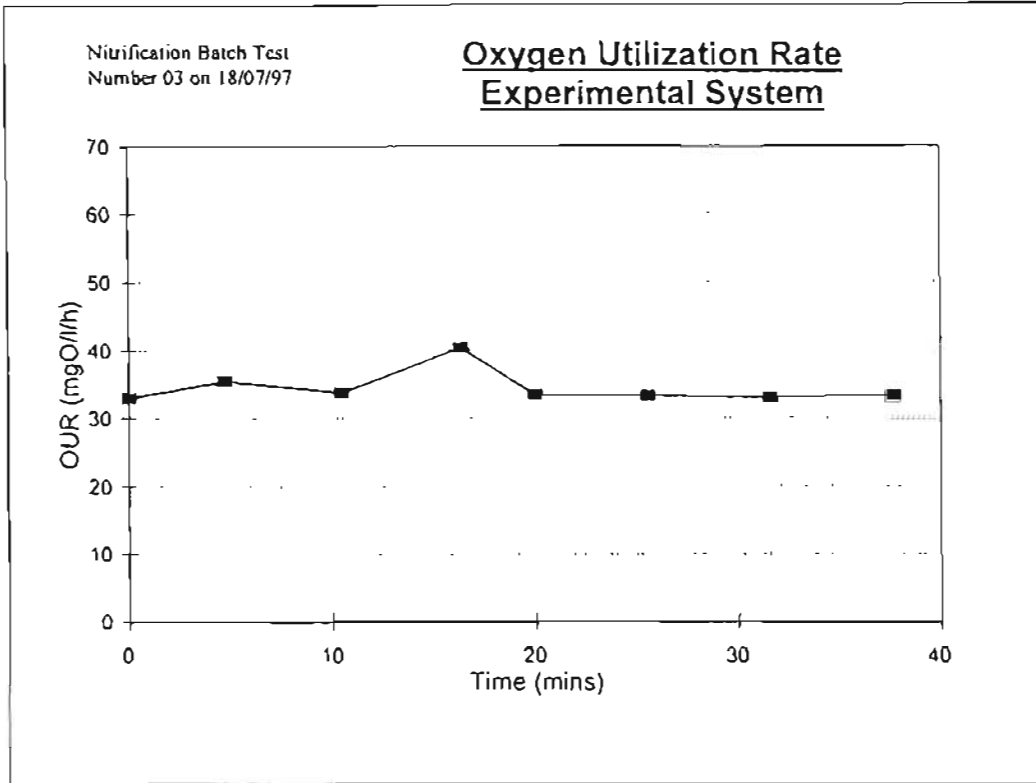
Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Nitrification Batch Test
Number 03 on 18/07/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	1974	1720	1980	1782
VSS	1442	1358	1364	1376

Sample Number	Time	EXP System		CTL System	
		Nitrate mgN/l	Nitrite mgN/l	Nitrate mgN/l	Nitrite mgN/l
1	0	0.56	0.13	0.43	0.14
2	10	0.84	0.22	0.90	0.23
3	20	1.47	0.34	1.27	0.35
4	30	1.98	0.46	1.69	0.43
5	40	2.44	0.56	2.16	0.59
6	50	3.27	0.66	2.80	0.64
7	60	3.67	0.82	3.38	0.74
8	75	4.48	0.95	4.27	0.91
9	90	5.48	1.13	5.36	1.13
10	120	7.72	1.39	7.34	1.52
11	150	9.23	1.76	8.80	1.94
12	210	13.04	2.25	12.63	2.72
13	270	16.70	2.77	16.10	3.50
14	330	16.38	2.72	19.81	4.28





Nitrification Batch Test
Number 03 on 18/07/97

Experimental System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	0	0.1	0.061
	350	21.5	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.1	0.010
	350	3.6	

Total rate of Ammonia Conversion =	4.269	mgNO3-N/h
Mass Nitrate in Effluent of Parent System =	10.949	mgN/l
Mass Nitrate Denitrified in Parent System =	33.477	mgN/l
Therefore, Nitrification Capacity in Parent System =	44.426	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	634.655	mgVSS
Nitrifiers Concentration =	31.733	mg Xn/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Control System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	0	0.1	0.060
	350	21.1	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.1	0.013
	350	4.5	

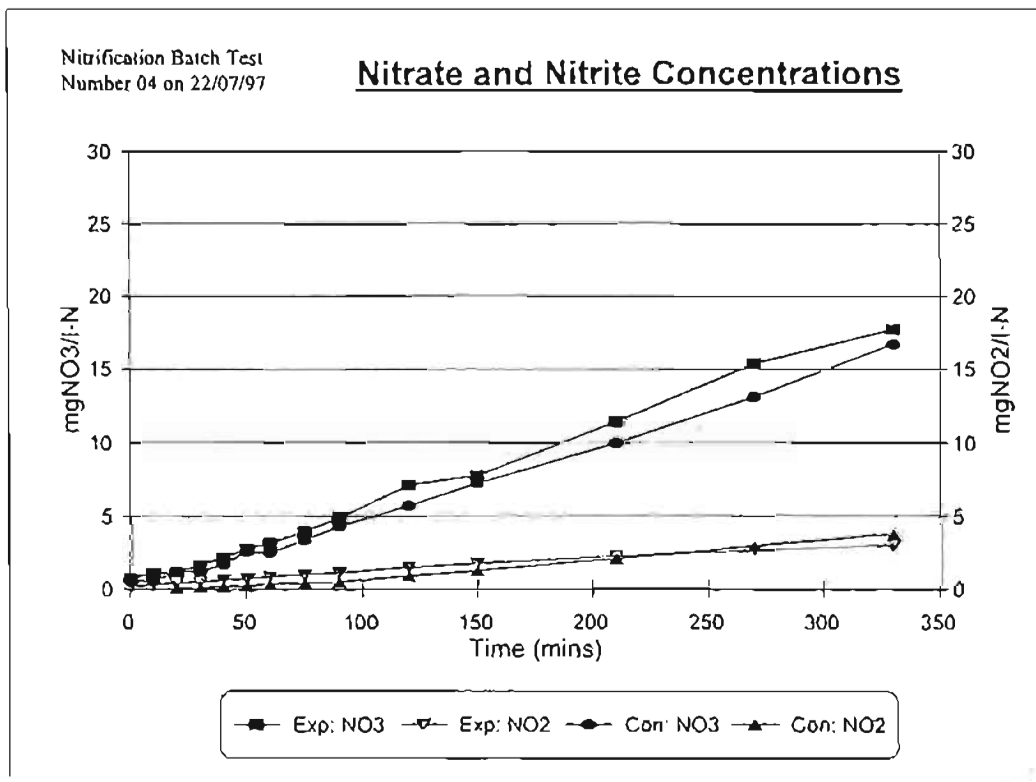
Total rate of Ammonia Conversion =	4.354	mgNO3-N/h
Mass Nitrate in Effluent of Parent System =	11.656	mgN/l
Mass Nitrate Denitrified in Parent System =	35.643	mgN/l
Therefore, Nitrification Capacity in Parent System =	47.298	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	675.690	mgVSS
Nitrifiers Concentration =	33.784	mg Xn/l

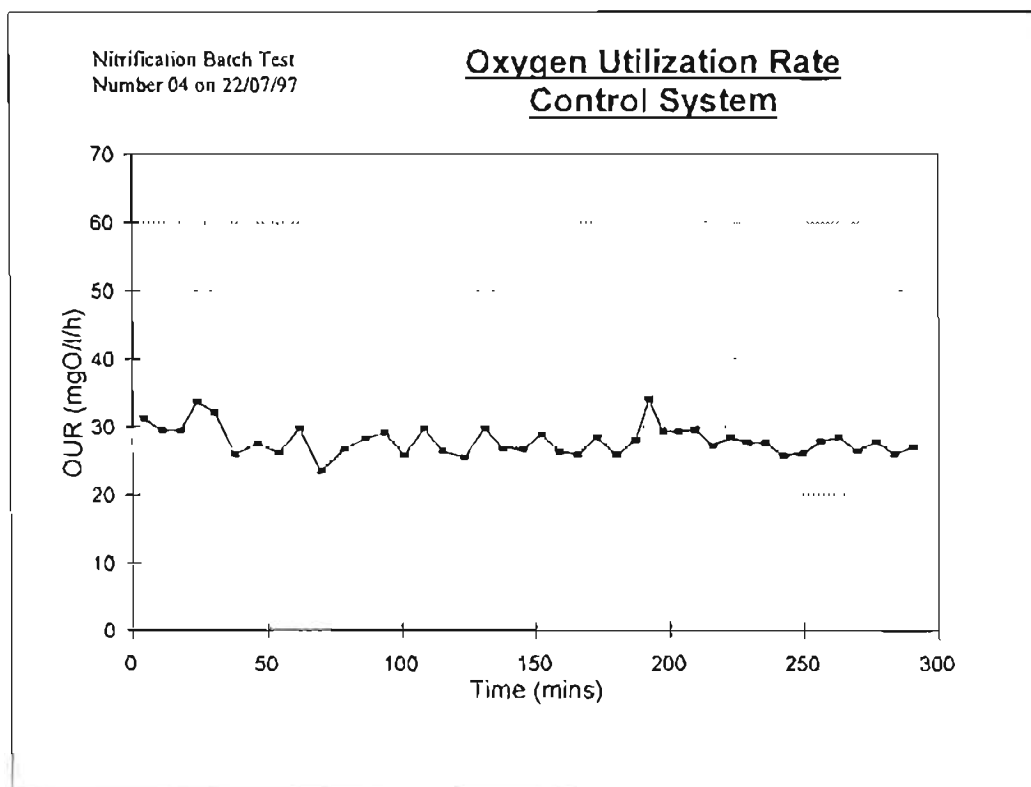
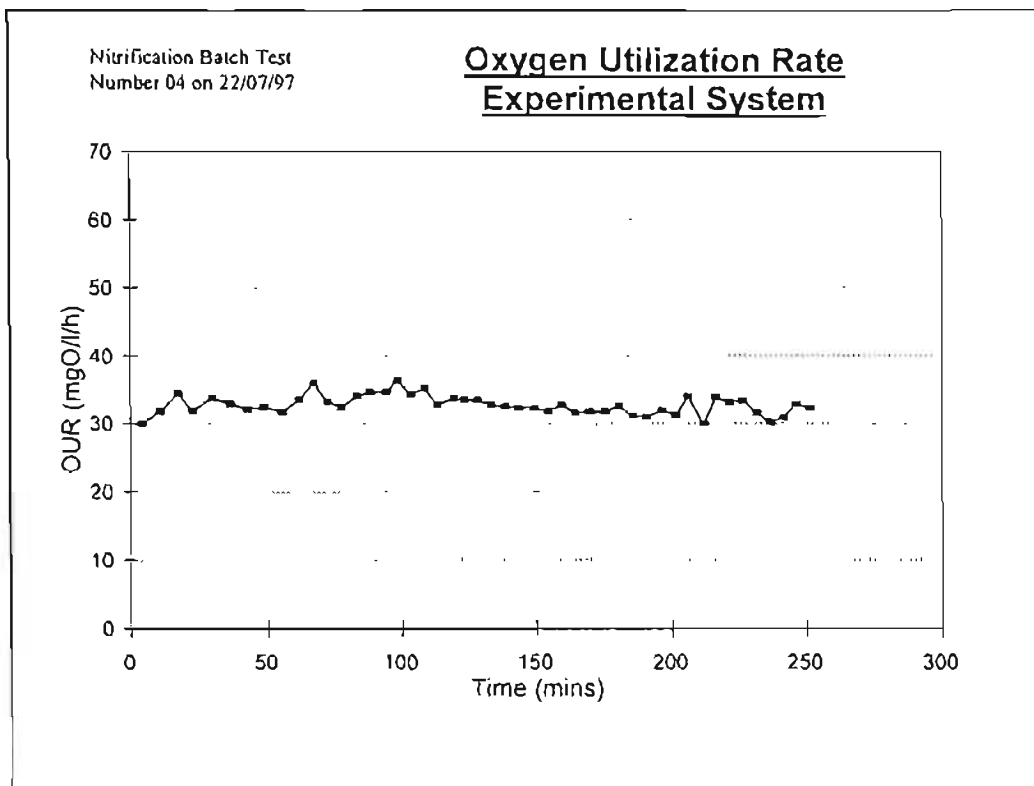
Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Nitrification Batch Test
Number 04 on 22/07/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2084	1660	2172	1742
VSS	1243132	1266100	1279292	1189978

Sample Number	Time	EXP System		CTL System	
		Nitrate mgN/l	Nitrite mgN/l	Nitrate mgN/l	Nitrite mgN/l
1	0	0.79	0.20	0.58	-0.17
2	10	1.10	0.31	0.59	-0.02
3	20	1.23	0.43	1.22	0.09
4	30	1.70	0.52	1.23	0.14
5	40	2.24	0.66	1.75	0.20
6	50	2.82	0.76	2.66	0.25
7	60	3.21	0.86	2.58	0.39
8	75	3.99	1.02	3.42	0.45
9	90	4.92	1.20	4.33	0.56
10	120	7.13	1.53	5.72	0.95
11	150	7.78	1.81	7.26	1.33
12	210	11.44	2.30	10.01	2.15
13	270	15.37	2.71	13.11	3.01
14	330	17.72	3.09	16.73	3.86





Nitrification Batch Test
Number 04 on 22/07/97

Experimental System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	0	0.0	0.055
	350	19.3	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.0	0.010
	350	3.6	

Total rate of Ammonia Conversion =	3.926	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	10.949	mgN/l
Mass Nitrate Denitrified in Parent System =	33.477	mgN/l
Therefore, Nitrification Capacity in Parent System =	44.426	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	634.655	mgVSS
Nitrifiers Concentration =	31.733	mg Xn/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Control System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	7	0.0	0.050
	350	17.3	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	54	0.0	0.014
	350	4.0	

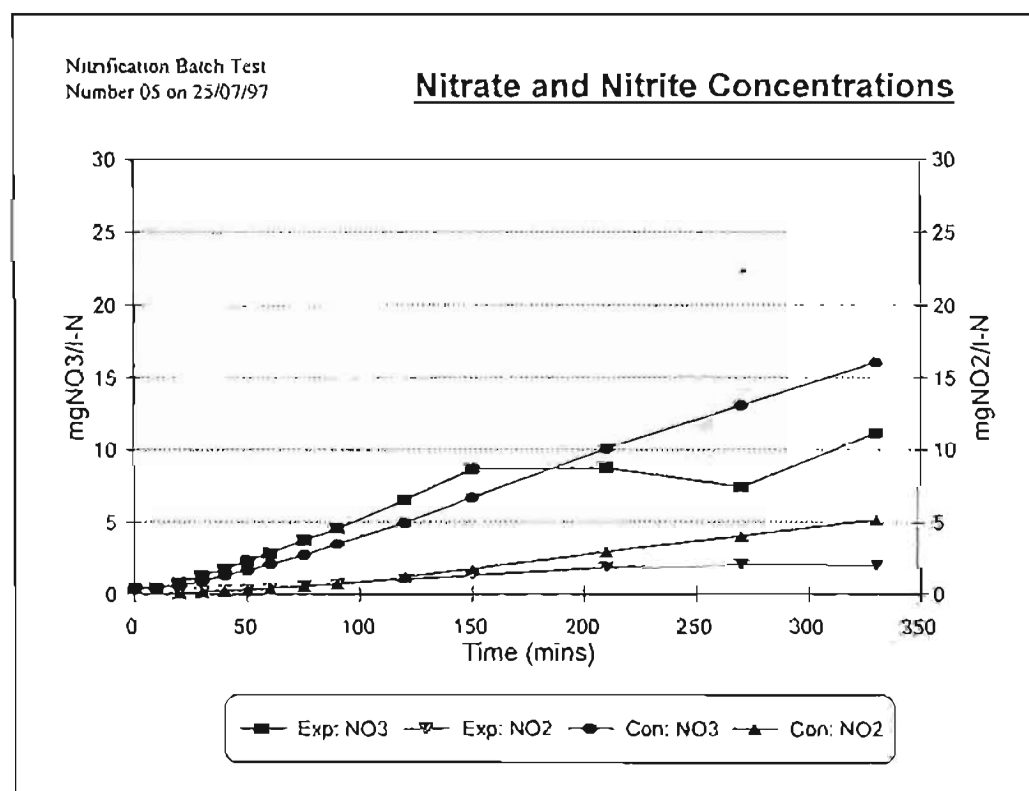
Total rate of Ammonia Conversion =	3.837	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	11.656	mgN/l
Mass Nitrate Denitrified in Parent System =	35.643	mgN/l
Therefore, Nitrification Capacity in Parent System =	47.298	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	675.690	mgVSS
Nitrifiers Concentration =	33.784	mg Xn/l

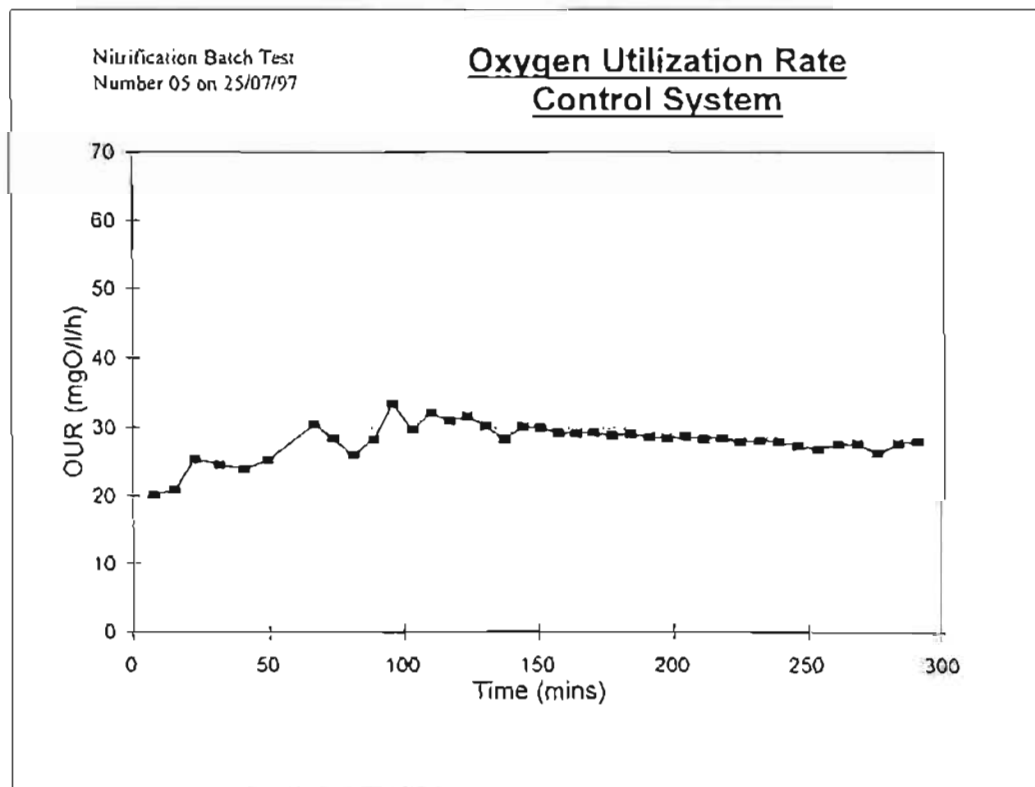
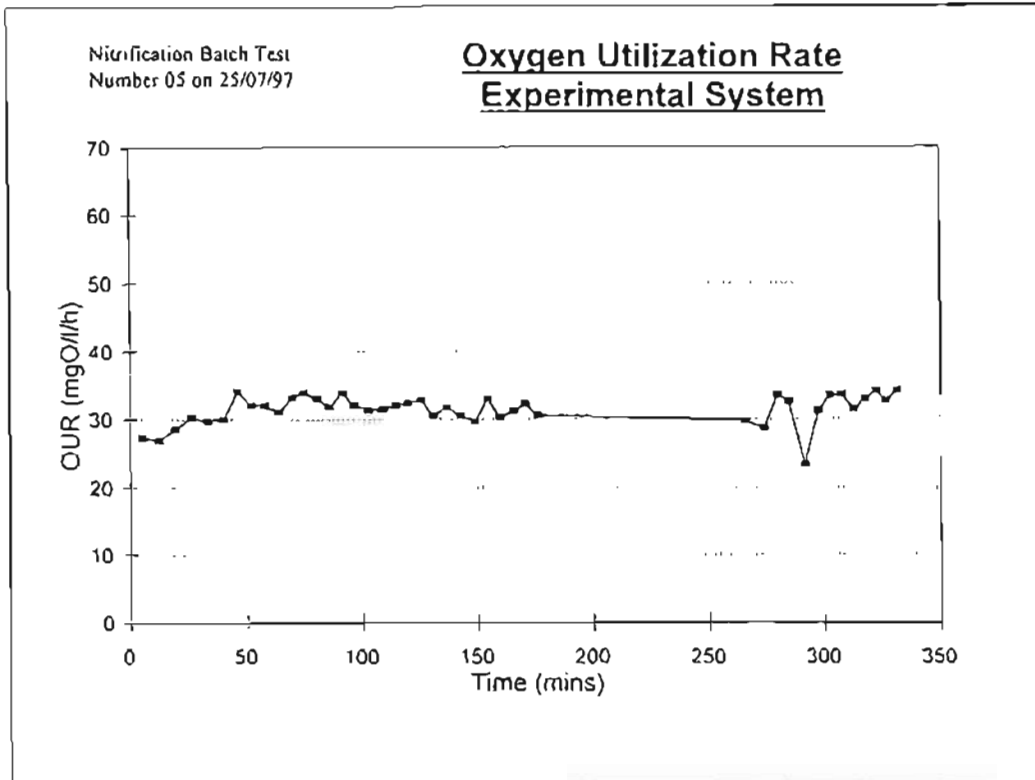
Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Nitrification Batch Test
Number 05 on 25/07/97

	Start		End	
	Exp. Sys.	Con. Sys.	Exp. Sys.	Con. Sys.
TSS	2482	1868	2628	1842
VSS	1794	1412	1826	1374

Sample Number	Time	EXP System		CTL System	
		Nitrate mgN/l	Nitrite mgN/l	Nitrate mgN/l	Nitrite mgN/l
1	0	0.39	-0.10	0.38	-0.09
2	10	0.47	-0.02	0.48	-0.04
3	20	0.84	0.09	0.54	0.06
4	30	1.31	0.16	0.93	0.15
5	40	1.74	0.27	1.34	0.23
6	50	2.38	0.34	1.67	0.28
7	60	2.90	0.45	2.13	0.39
8	75	3.76	0.61	2.77	0.58
9	90	4.54	0.72	3.52	0.72
10	120	6.51	1.05	4.94	1.22
11	150	8.66	1.33	6.69	1.77
12	210	8.75	1.88	10.07	2.98
13	270	7.42	2.13	13.09	4.06
14	330	11.17	2.02	16.07	5.16





Nitrification Batch Test
Number 05 on 25/07/97

Experimental System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	0	0.0	0.055
	350	19.3	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	0	0.0	0.010
	350	3.6	

Total rate of Ammonia Conversion =	3.926	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	10.949	mgN/l
Mass Nitrate Denitrified in Parent System =	33.477	mgN/l
Therefore, Nitrification Capacity in Parent System =	44.426	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	634.655	mgVSS
Nitrifiers Concentration =	31.733	mg Xn/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

Control System

Best fit line:	Time	Conc.	NO3 Rate
	min	mgNO3/l-N	mg/l.min
NO3	7	0.0	0.050
	350	17.3	

Best fit line:	Time	Conc.	NO2 Rate
	min	mgNO2/l-N	mg/l.min
NO2	54	0.0	0.014
	350	4.0	

Total rate of Ammonia Conversion =	3.837	mgNO3-N/l/h
Mass Nitrate in Effluent of Parent System =	11.656	mgN/l
Mass Nitrate Denitrified in Parent System =	35.643	mgN/l
Therefore, Nitrification Capacity in Parent System =	47.298	mgNO3-N/l influent
Mass of Nitrifiers M(Xn) =	675.690	mgVSS
Nitrifiers Concentration =	33.784	mg Xn/l

Maximum Specific Growth rate of Nitrifiers μ_{nm} = /d

APPENDIX G

- Metal Analyses

Metal Samples

Experimental System: Unfiltered Influent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	2.6	3.2	2.2	1.9	2.9	3.1	10.0	3.0	2.7	2.7	0.4
Co	6.0	6.0	9.0	5.0	10.0	11.0	8.0	9.0	7.0	8.1	2.0
Cr	4.0	10.0	16.0	8.0	8.0	12.0	8.0	10.0	12.0	9.8	3.2
Cu	38.0	46.0	37.0	37.0	47.0	46.0	49.0	58.0	67.0	44.8	6.8
Hg	18.0	14.0	1.6	1.1	2.9	2.4	2.2	2.1	1.8	3.5	4.0
Mo	10.0	9.0	0.0	5.0	2.0	4.0	1.0	8.0	8.0	5.2	3.5
Ni	10.0	6.0	9.0	10.0	16.0	13.0	17.0	19.0	12.0	12.4	4.0
Pb	25.0	31.0	28.0	19.0	35.0	40.0	29.0	35.0	46.0	32.0	7.6
Zn	482.0	650.0	68.0	515.0	670.0	680.0	624.0	661.0	559.0	545.4	181.7
As	4.0	2.0	5.0	2.3	3.5	5.8	3.6	4.7	2.8	3.7	1.2
B										ERR	ERR

Control System: Unfiltered Influent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	3.2	2.0	1.6	1.9	2.1	2.5	2.3	2.5	2.0	2.1	0.3
Co	6.0	4.0	5.0	5.0	7.0	8.0	8.0	6.0	6.0	6.1	1.3
Cr	10.0	14.0	12.0	6.0	5.0	11.0	8.0	9.0	7.0	9.1	2.8
Cu	46.0	40.0	39.0	36.0	42.0	44.0	44.0	49.0	61.0	42.5	3.9
Hg	40.0	14.0	2.0	0.7	3.1	1.6	1.4	1.8	1.5	3.3	4.1
Mo	10.0	14.0	0.0	0.0	4.0	9.0	0.0	0.0	11.0	5.3	5.4
Ni	14.0	8.0	7.0	7.0	11.0	13.0	15.0	14.0	12.0	11.2	3.0
Pb	29.0	31.0	23.0	18.0	26.0	30.0	33.0	26.0	47.0	27.0	4.5
Zn	155.0	155.0	171.0	120.0	160.0	176.0	174.0	158.0	161.0	158.9	15.7
As	4.0	3.0	2.7	1.8	3.5	5.2	3.5	3.5	4.3	3.5	0.9
B										ERR	ERR

Denotes statistical outlier and is ignored in the calculation of the average and standard deviation.


Metal Samples

Experimental System: Filtered Influent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	2.0	2.0	1.6	1.2	2.2	2.0	1.9	2.0	1.6	1.8	0.3
Co	5.0	4.0	4.0	4.0	7.0	8.0	7.0	6.0	4.0	5.4	1.5
Cr	4.0	8.0	7.0	2.0	1.0	4.0	0.0	2.0	2.0	3.3	2.5
Cu	6.0	9.0	4.0	6.0	6.0	8.0	7.0	8.0	8.0	6.9	1.4
Hg	2.0	8.0	0.5	0.6	0.0	0.5	1.7	0.4	0.3	0.8	0.7
Mo	2.0	2.0	0.0	0.0	0.0	4.0	0.0	3.0	7.0	1.4	1.5
Ni	7.0	6.0	6.0	5.0	10.0	10.0	10.0	12.0	8.0	8.2	2.2
Pb	10.0	18.0	13.0	8.0	11.0	12.0	13.0	14.0	21.0	12.4	2.8
Zn	138.0	176.0	145.0	40.0	164.0	168.0	180.0	202.0	158.0	152.3	43.6
As	3.0	2.0	2.4	1.3	1.9	2.2	1.4	2.8	1.3	2.0	0.6
B	121.0	244.0	182.0	81.0	95.0	132.0	173.0	81.0	71.0	117.0	40.0

Control System: Filtered Influent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	2.0	1.4	0.9	1.0	1.9	1.6	1.6	1.5	1.1	1.4	0.4
Co	6.0	2.0	3.0	3.0	7.0	6.0	7.0	5.0	5.0	4.9	1.7
Cr	8.0	4.0	5.0	2.0	1.0	2.0	2.0	4.0	3.0	2.9	1.3
Cu	7.0	6.0	4.0	4.0	4.0	8.0	6.0	8.0	6.0	5.9	1.5
Hg	3.0	10.0	0.6	0.5	0.9	0.9	0.6	0.4	0.4	0.9	0.8
Mo	8.0	4.0	0.0	0.0	0.0	4.0	0.0	0.0	9.0	2.8	3.5
Ni	9.0	6.0	6.0	4.0	8.0	9.0	11.0	10.0	8.0	7.9	2.1
Pb	7.0	16.0	13.0	10.0	8.0	13.0	14.0	11.0	14.0	11.8	2.8
Zn	10.0	14.0	20.0	25.0	19.0	22.0	18.0	17.0	17.0	18.0	4.1
As	2.0	2.0	2.2	1.1	2.0	2.0	2.1	2.2	1.8	1.9	0.3
B	114.0	263.0	153.0	137.0	181.0	229.0	166.0	65.0	84.0	154.7	60.6

 Denotes statistical outlier and is ignored in the calculation of the average and standard deviation.

Metal Samples

Experimental System: Reactor

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Cd	9.2	8.6	4.7	4.9	5.5	7.4	7.6	7.2	5.8	6.8	1.5
Co	9.0	17.0	12.0	9.0	16.0	18.0	22.0	15.0	15.0	14.8	4.0
Cr	95.0	89.0	72.0	50.0	50.0	94.0	238.0	122.0	64.0	79.5	23.4
Cu	907.0	771.0	757.0	761.0	720.0	984.0	892.0	485.0	406.0	742.6	179.2
Hg	30.0	21.0	4.0	3.6	4.9	3.8	7.0	18.4	5.3	8.5	6.6
Mo	10.0	13.0	0.0	4.0	7.0	16.0	13.0	7.0	16.0	9.6	5.2
Ni	54.0	43.0	37.0	27.0	60.0	70.0	108.0	60.0	37.0	48.5	13.8
Pb	166.0	164.0	114.0	93.0	117.0	186.0	199.0	160.0	185.0	153.8	34.9
Zn	5090.0	4780.0	3970.0	3780.0	4310.0	5460.0	5720.0	5140.0	3590.0	4648.9	723.4
As	22.0	24.0	20.0	10.8	18.0	22.5	28.9	20.5	15.5	20.2	4.9
B										ERR	ERR

Control System: Reactor

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Cd	8.4	6.1	4.1	3.4	6.3	6.5	6.7	6.5	6.3	6.0	1.4
Co	11.0	11.0	9.0	6.0	15.0	17.0	19.0	14.0	15.0	13.0	3.9
Cr	180.0	140.0	100.0	81.0	113.0	125.0	140.0	148.0	143.0	130.0	27.5
Cu	810.0	597.0	432.0	416.0	642.0	608.0	576.0	480.0	452.0	525.4	83.8
Hg	32.0	11.0	3.6	4.8	3.6	3.6	8.7	18.3	5.2	7.4	4.9
Mo	13.0	29.0	18.0	2.0	15.0	22.0	28.0	12.0	31.0	18.9	9.0
Ni	83.0	52.0	46.0	34.0	85.0	80.0	74.0	69.0	69.0	65.8	16.8
Pb	196.0	174.0	111.0	90.0	134.0	161.0	184.0	166.0	227.0	160.3	40.2
Zn	1750.0	1340.0	1070.0	973.0	1310.0	1400.0	1460.0	1380.0	1130.0	1312.6	219.5
As	22.0	16.0	5.8	10.0	18.5	8.8	6.6	17.6	20.5	14.0	5.9
B										ERR	ERR

Denotes statistical outlier and is ignored in the calculation of the average and standard deviation.

Metal Samples

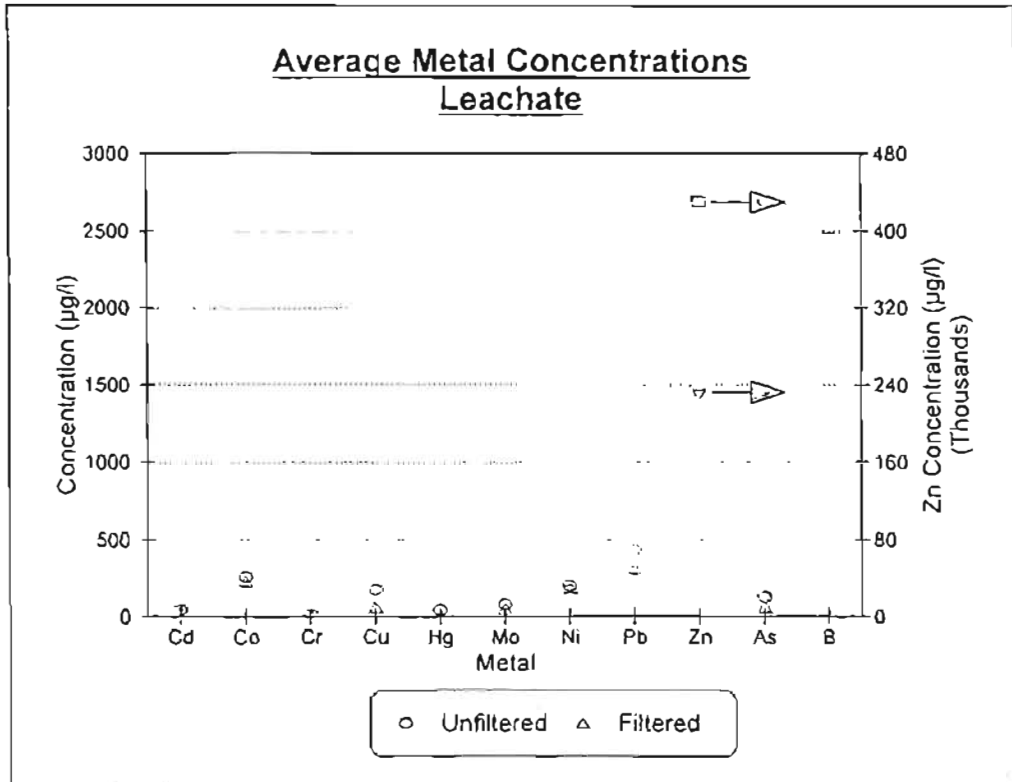
Experimental System: Filtered Effluent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	1.9	2.1	1.3	1.2	1.5	1.7	1.6	1.6	1.3	1.6	0.3
Co	5.0	7.0	4.0	4.0	6.0	7.0	7.0	5.0	5.0	5.6	1.2
Cr	4.0	4.0	4.0	1.0	0.0	2.0	2.0	2.0	2.0	2.3	1.3
Cu	5.0	3.0	6.0	4.0	5.0	4.0	4.0	3.0	4.0	4.2	0.9
Hg	0.0	0.0	0.0	0.3	0.6	0.3	0.0	0.0	0.0	0.1	0.1
Mo	4.0	8.0	3.0	0.0	1.0	0.0	4.0	1.0	5.0	2.3	1.9
Ni	9.0	6.0	6.0	6.0	11.0	12.0	10.0	8.0	8.0	8.4	2.1
Pb	11.0	12.0	11.0	14.0	12.0	10.0	13.0	13.0	16.0	12.0	1.2
Zn	20.0	26.0	38.0	30.0	38.0	37.0	29.0	25.0	22.0	29.4	6.5
As	2.0	2.0	1.1	0.6	0.9	1.2	1.0	1.2	0.9	1.2	0.5
B	215.0	307.0	157.0	108.0	155.0	170.0	172.0	77.0	70.0	140.5	47.4

Control System: Filtered Effluent

	11/04/97	20/04/97	02/05/97	12/05/97	20/05/97	29/05/97	10/06/97	02/07/97	20/07/97	Average	STD
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	
Cd	2.1	2.3	1.4	1.4	1.4	1.6	1.4	1.7	1.1	1.6	0.4
Co	5.0	5.0	5.0	4.0	5.0	7.0	7.0	6.0	5.0	5.4	1.0
Cr	3.0	3.0	4.0	2.0	2.0	2.0	0.0	2.0	1.0	2.1	1.1
Cu	8.0	5.0	6.0	8.0	4.0	4.0	4.0	4.0	3.0	5.1	1.7
Hg	13.0	2.0	0.8	0.8	0.6	1.1	0.2	0.1	0.2	0.7	0.6
Mo	3.0	1.0	0.0	0.0	2.0	2.0	4.0	1.0	1.0	1.6	1.3
Ni	8.0	8.0	7.0	6.0	10.0	12.0	9.0	9.0	7.0	8.0	1.2
Pb	19.0	11.0	10.0	13.0	9.0	11.0	14.0	16.0	14.0	12.3	2.2
Zn	20.0	16.0	19.0	24.0	16.0	19.0	13.0	18.0	13.0	17.6	3.3
As	2.0	1.0	0.6	0.2	1.3	1.4	0.8	1.5	0.8	1.1	0.5
B	227.0	203.0	35.0	161.0	161.0	202.0	179.0	71.0	59.0	144.2	66.6

Denotes statistical outlier and is ignored in the calculation of the average and standard deviation.



Metal Samples

Leachate only

	Unfiltered 11/04/97 µg/l	Filtered 11/04/97 µg/l
Cd	47.0	41.0
Co	260.0	234.0
Cr	18.0	17.0
Cu	176.0	65.0
Hg	46.0	10.0
Mo	80.0	55.0
Ni	202.0	186.0
Pb	438.0	311.0
Zn	431000.0	230000.0
As	129.0	65.0
B		2520.0

