DESIGN AND PERFORMANCE ASSESSMENT OF THREE SEQUENCING BATCH REACTOR SEWAGE TREATMENT PLANTS IN CANADA

by

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ABSTRACT

The successful operation of biological waste treatment systems for small scale applications is not always assured. The frequently reported failures of being unable to meet process effluent criteria of 30 mg/L BOD_5 and 30 mg/L SS is chiefly attributable to a combination of widely varying hydraulic and organic loads to a plant and lack of plant operator availability, skill and attention.

This report describes the performance of three biological treatment systems treating average flows of 4.4 m^3/d, 22.7 m^3/d and 227 m^3/d. Each of the systems were retrofitted to operate in the batch reactor mode.

Detailed process monitoring of one plant over an 88 day period and long term, sporadic monitoring at the other two installations showed that operation of a biological process in the batch reactor mode is simple, yet consistently produces an effluent having a total BOD_5 of 5 mg/L and SS of 3 mg/L. Nitrification, denitrification and biological phosphorus removal were also observed.

Even though costs are highly site specific, the data illustrate that batch reactors represent a cost effective process option for upgrading existing biological waste treatment plants which are subject to widely varying hydraulic and organic loads. Properly engineered batch reactors offer a process alternative which will produce a consistently high quality effluent, even under conditions of minimum operator skill and attention.

The ability to construct a fully functional biological treatment plant or retrofit an existing poorly functioning plant using only a few off-the-shelf mechanical components such as pumps and compressors, make batch reactors an attractive alternative waste treatment process option in isolated regions.

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1 INTRODUCTION

The selection of a technology to treat a waste of municipal or industrial origin is governed by determining the least cost solution for meeting preset process effluent criteria. In most instances these criteria consist of the biochemical oxygen demand (BOD_5) and suspended solids (SS). The recent concern for eutrophication has, where phosphorus is identified as the limiting nutrient, resulted in setting effluent discharge targets for total phosphorus (TP). Furthermore, water bodies may have a limiting capacity for effluent nitrification, thus the nitrogenous oxygen demand will have to be satisfied at the treatment plant through nitrification. This may well be only a seasonal requirement. However, if raw water for potable water supplies is abstracted from sources high in nitrate, denitrification may also have to occur before effluents are discharged.

Concerns over the discharge of bacteria and viruses from treatment plant effluents have also resulted in application of the appropriate technologies to inactivate and/or remove these concerns.

Of late, the discharge of metals and more specifically certain synthetic organic compounds have placed additional emphasis on the selection and application of wastewater treatment technologies which permit not only effective treatment but maximum process flexibility so that the many and varying concerns can be addressed in a cost effective manner.

While a combination of physical-chemical unit processes can be selected to reduce and/or remove undesirable waste constituents to meet any effluent target, by themselves they are energy intensive and expensive. However, when physical-chemical processes are coupled with biological processes more cost effective solutions emerge.

High energy costs in the early seventies had a significant impact on waste treatment process research. The focus was not so much on development of new technology, rather on modification and enhancement of existing technologies with a view to increased overall process performance at reduced cost.

This effort has resulted in the current use of process design approaches and process operational strategies for biological systems which will achieve effluent targets normally associated with physical-chemical processes. Biological processes producing effluents low in BOD_5, SS, nutrients (phosphorus, nitrogen), metals and even certain synthetic organic compounds are available and in use. To a great extent all of this is attributable to a much improved understanding of the biological, microbiological, physical and biophysical interactions in biological waste treatment.

In this search for more cost effective technology old processes such as batch reactor technology (1) were re-examined and some new ones such as the two-stage Absorption-Biodegradation process (AB), (2) emerged. It may come as a surprise to know that the so common activated sludge process had its origin in fill-draw systems dating back to 1893. Pasveer (3) revived the batch reactor concept in the '50s with his original version of the oxidation ditch operated in the fill-draw mode.

2 BATCH REACTORS

Thus, batch reactor technology represents nothing new, rather something old. Batch reactors though, have been used in the laboratory to investigate waste biodegradability and establish the process kinetics prior to running continuous-flow experiments for process design data generation. We have now come to the stage where batch reactor technology is applied on a larger scale.

Batch reactor systems are attractive because they counter normal concerns associated with small municipal wastewater treatment systems such as:

1. erratic hydraulic and biologic loads;
2. inefficient sludge return (air-lift systems offer no sludge return control);
3. problems with clarifiers due to erratic hydraulic loads;
4. limited available operator skill.

As well, batch systems are less susceptible to sludge bulking than continuous flow systems (4). For batch reactors, process operations are reduced to two considerations:

1. mixed liquor settleability;
2. completion of reactions.

Figure 1 compares the conventional activated sludge flow diagram to the batch reactor, and illustrates its compactness and the integration of the biological reactor with the settler.

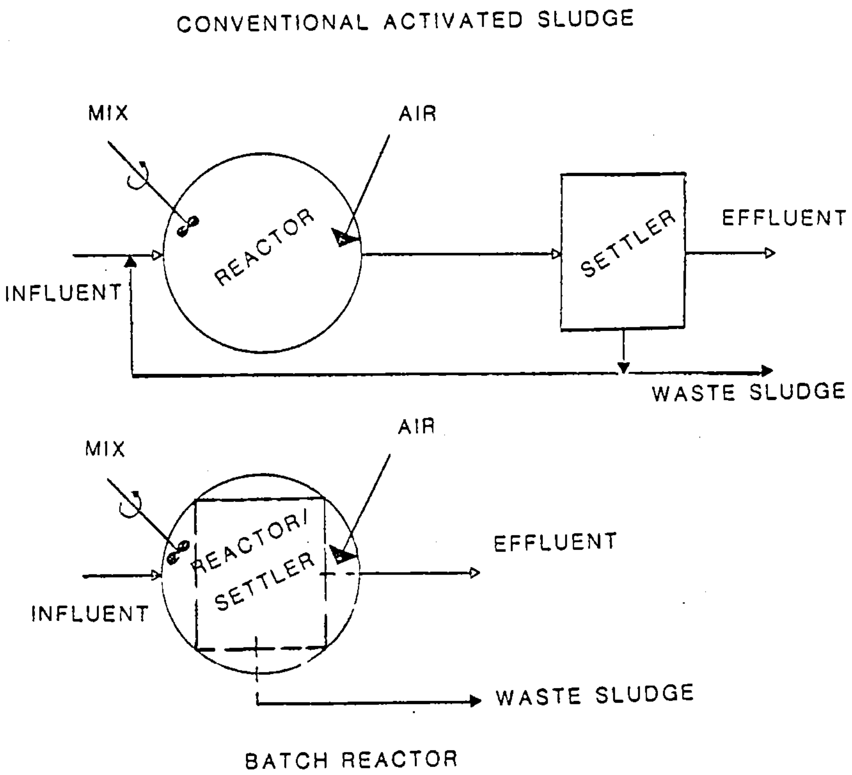

FIGURE 1 CONVENTIONAL ACTIVATED SLUDGE TO BATCH REACTOR COMPARISON

A distinct advantage of batch reactor systems is that it permits you to keep the reactor contents until the previously set effluent criteria are achieved. There is a small problem associated with this though. Facilities to store incoming waste must be available.

Batch reactors are operated on a fill-aerate-settle-decant cycle where liquid/solid separation and biological reactions are integrated within one vessel. A discontinuous system such as a batch reactor, permits settling to occur under almost ideal conditions. In the resulting quiescent environment no new energy is imparted to the liquid. Internal eddies and density currents drop to zero velocity.

2.1 Process Advantages

Batch operated waste treatment systems offer a number of advantages such as:

1. reactor also serves as an equalization basin;
2. organic load is handled by MLSS control;
3. hydraulic load is handled by liquid level control;
4. elimination of sludge recycle;
5. no concern regarding peak hydraulic loads and settling;
6. settling occurs under nearly perfect quiescent conditions;
7. operationally simple;
8. infrequent sludge wasting (based on settling test);
9. low capital cost;
10. good application for retrofitting existing plants;
11. ability to control effluent quality (a plug flow reactor);
12. operation can be fully automated with micro-processors.

2.2 Process Design

The design of batch reactor systems is dependent on the origin and characteristics of the waste to be treated. From a process standpoint batch bench scale reactors are operated in the laboratory to provide information on waste biodegradability and process operation. The various time increments required for each of the fill-react-settle-decant cycles are established. A significant advantage in batch reactor process design consists of the ability to transfer laboratory results directly to full-scale without having to consider the question of scale-up.

3 CANADIAN EXPERIENCE

Encouraged by earlier process performance observations at one batch reactor plant the Glenlea Agricultural Research Station near Winnipeg, Manitoba, Canada, an extensive process monitoring program for 3 batch reactor systems in Canada was supported by both the Department of the Environment and the Department of Supply and Services. One plant, the Glenlea facility, was monitored intensively over a 90 day period.

The experiences reported on here concern the retrofitting of 3 existing small scale treatment systems each treating a different type of sewage:

Glenlea - domestic sewage, Q = 4.4 m^3/d
HBM&S - grey water, Q = 22.7 m^3/d
Rivercrest - settled sewage, Q = 227 m^3/d

3.1 Terms of Reference

The process performance assessment objectives of this study were established in accordance with the contractural requirements as follows:

1. verify and upgrade design requirements;
2. establish operational and maintenance requirements;
3. comment on process stability, reliability and consistency of effluent quality;
4. verify and establish sludge wasting requirements;
5. estimate capital, operating and maintenance costs for various plant sizes (45 - 450 m^3/d).

In addition information concerning location isolation and cold temperature effects is to be noted.

3.2 Investigative Program

The program for data collection was as follows:

Glenlea : January 3 - March 31, 1983
Hudson Bay Mining and Smelting : June 2 - October 25, 1983
Rivercrest : October 3 - December 28, 1983

The number of samples taken during the period were as follows:

Glenlea : 63 composite samples (influent and effluent),
63 grab samples for mixed liquor
HBM&S : 11 grab samples (influent, effluent, mixed liquor)
Rivercrest: 18 grab samples (influent, effluent, mixed liquor)

4 GLENLEA INSTALLATION

4.1 Process Description

The Glenlea plant is a retrofitted, enclosed conventional extended aeration package plant which was sized to handle a flow of 9 m^3/d generated by 5 residences at the Glenlea Agricultural Station just outside the city of Winnipeg (5). The plant had been subject to erratic hydraulic loading, infiltration resulting in solids washout and highly turbulent conditions in the intregal clarifier. All of these factors never permitted the plant to operate as originally envisaged. Mixed liquor suspended solids concentrations (MLSS) of 700 mg/L and effluent BOD_5 values of 90 mg/L were common (6).

The effluent target as required by the Manitoba Department of the Environment is 30 mg/L BOD_5 and 30 mg/L SS.

In 1978 steps were taken to convert the existing plant to operate in the batch reactor mode. The mode of operation for one complete cycle consisted of 4 parts: 1 - fill, 2 - aerate, 3 - settle, 4 - draw. A process schematic for Glenlea is shown as Figure 2.

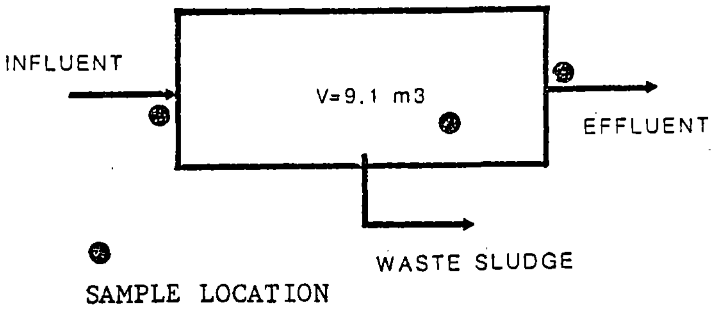

FIGURE 2 GLENLEA BATCH REACTOR INSTALLATION

Initially, the process was run manually. Thirty days after conversion, the MLSS concentration had already increased to 2000 mg/L. The effluent BOD_5 was 22 mg/L. Upgrading of the operations side by installing automatic controls further enhanced the effluent BOD_5 concentration to 7.5 mg/L and permitted the MLSS concentration to increase to 4000 mg/L. In 1980 routine examination showed the process effluent to have BOD_5 and SS values of 7.5 and less than 5 mg/L, respectively.

It should be noted that no attempt at process optimization for the Glenlea plant was made. The data reported on in this report are for the purposes of process assessment after having used minimum resources for process conversion. In fact, the data evaluation will be used to assess the effect of changing from one type of biological process (continuous flow extended aeration) to another (batch, extended aeration).

4.2 Sampling Program

For process assessment purposes parameters summarized in Table 1 were determined from influent and effluent composite samples and mixed liquor grab samples.

TABLE 1 - SAMPLES AND PARAMETERS ANALYSED - Glenlea

PARAMETER	SAMPLE		
	Influent	Effluent	Mixed Liquor
BOD_5 (total)	*	*	
SS	*	*	
Alkalinity	*	*	
TKN	*	*	
NH_4-N	*	*	
NO_3-N		*	
TP	*	*	
pH	*	*	*
Temperature	*		*
Dissolved Oxygen		*	*
MLSS			*
% VS			*
Settleable Solids			*

A total of 63 composite samples of the process influent, effluent and 63 grab samples of the mixed liquor were taken. The sampling period extended from January 3 to March 31, 1983.

All analyses were done in accordance with Standard Methods (7).

4.3 Process Observations and Results

The process analyses concern flow biochemical oxygen demand (BOD_5) conversion, total and soluble, suspended solids removal effectiveness, nutrient removal and general process stability. As well, sludge settleability, sludge production and sludge wasting will be described. Process and aeration energy requirements will also be evaluated.

4.3.1 Flow

The wide flow variations observed during the monitoring period are characteristic of small installations. In many cases, this is coupled with little to no operator attention. These two factors are the main reason for poor process performance and process failure of many small waste treatment installations. Figure 3 shows the daily influent flow over the 88 day period. The average flow was 4.43 m^3/d. Flow variability was extremely high, varying from a low of 0.73 m^3/d to a high of 15.9 m^3/d. The extremely high inflow of 15.9 m^3/d was caused by surface run-off infiltrating into a nearby man-hole. Recurrance of this condition can be avoided by making the appropriate grade changes.

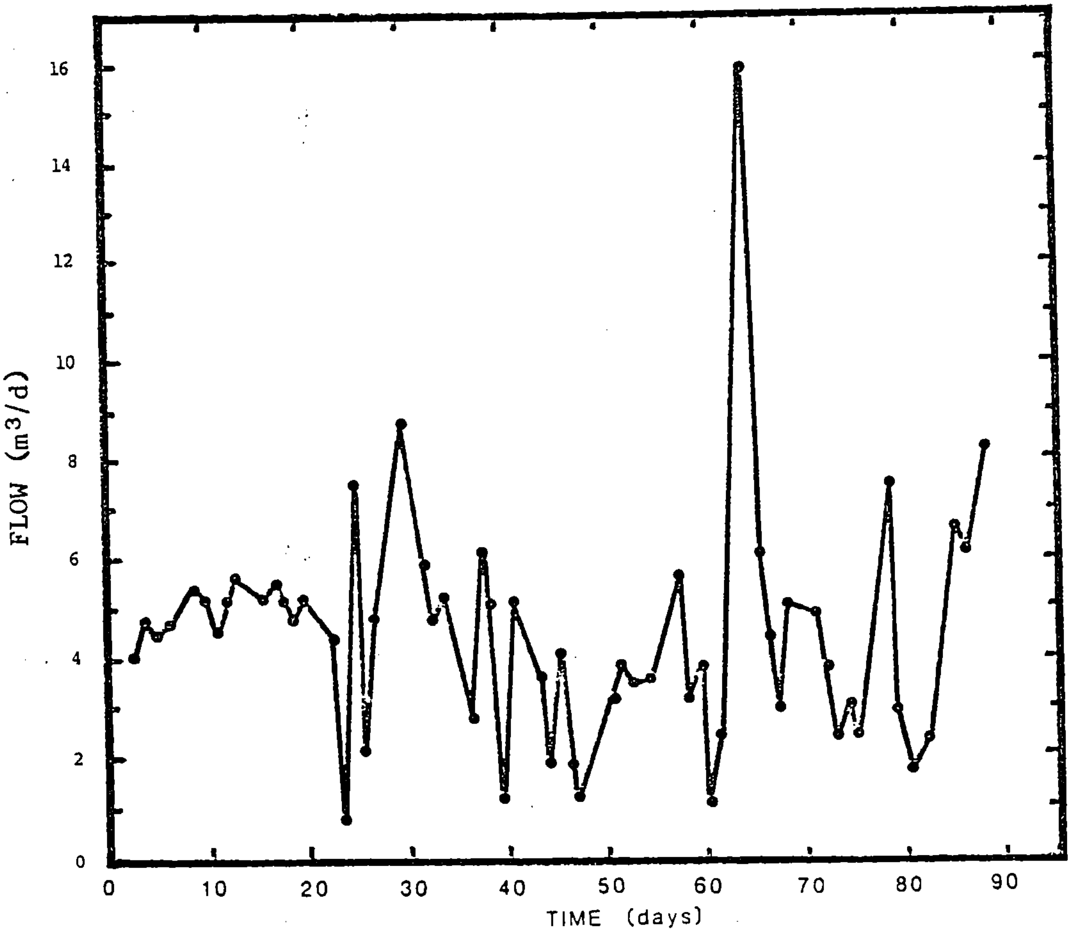

FIGURE 3 HYDRAULIC LOAD TO THE GLENLEA PLANT

In spite of these high flow variations which can be shown as ratios:

low : average	0.16
high : average	3.59
high : low	21.8

the effluent BOD_5 and SS concentrations remained low at 4 mg/L for both parameters during high flow and 7 and 1 mg/L during low flow, respectively.

When analyzing the flow data on a probability basis as illustrated in Figure 4, the data are normally distributed with a mean flow of 4.43 m^3/d and 90% of the flow events being less than or equal to 7.3 m^3/d. Only 10% of the flows during the 88 day monitoring period were less than or equal to 1.5 m^3/d.

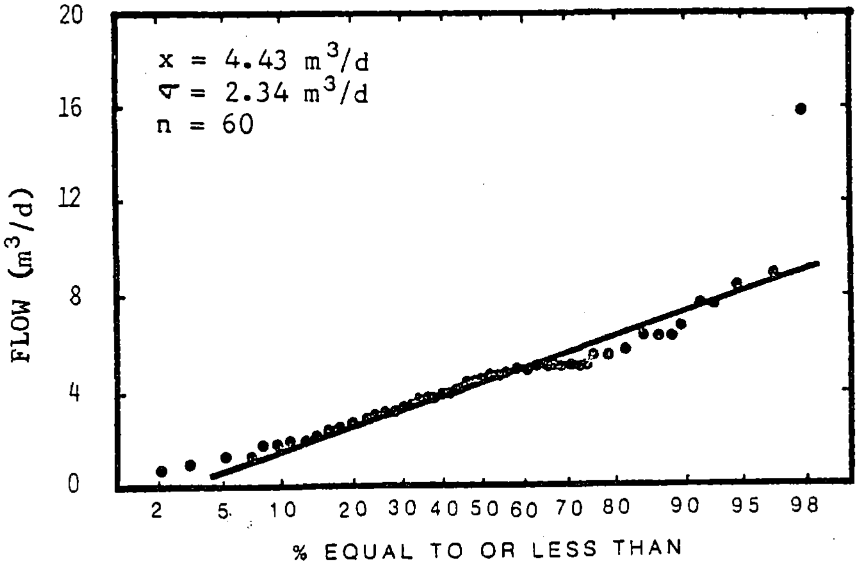

FIGURE 4 HYDRAULIC LOAD PROBABILITY DISTRIBUTION - GLENLEA

4.3.2 Biochemical oxygen demand

Influent BOD_5 concentrations varied from a low of 58 mg/L to a high of 800 mg/L, averaging 251 mg/L. The high fluctuations in influent waste strength are not unusual in small installations and when coupled with erratic flow is frequently the cause for process upsets and failure. For this installation the sewage is considered to be strong. From a probability analysis of the BOD_5 influent data, as shown in Figure 5, 90% of the observations are less than or equal to 468 mg/L and 10% less than or equal to 134 mg/L. The data are log normally distributed which is not unusual for biological samples.

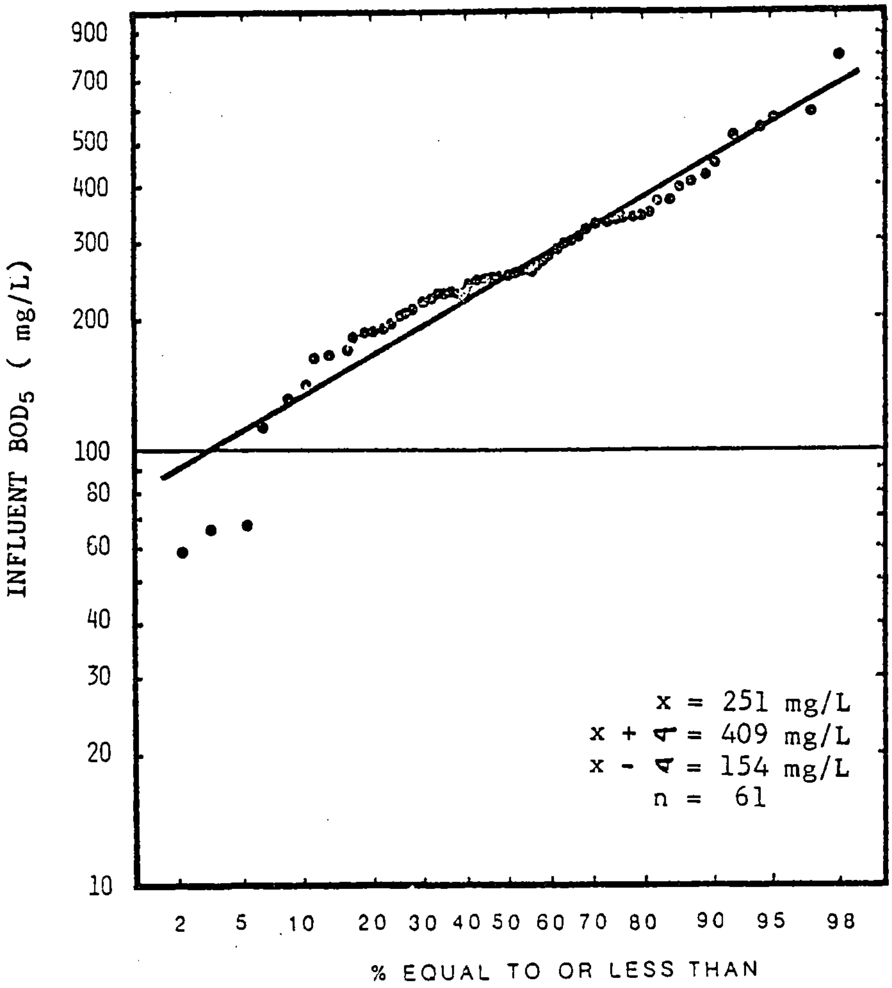

FIGURE 5 INFLUENT BOD_5 PROBABILITY DISTRIBUTION - GLENLEA

An attempt was made to determine the influent soluble BOD_5 fraction. Biological process kinetics are based on the conversion of soluble substrate. Thus the degree of conversion of biological substrate to new cells and providing energy for cell maintenance is a true measure of process efficiency. This could be measured in a number of ways. By direct measurement where the BOD_5 is determined on a filtered sample, or by indirect measurement where the unfiltered BOD_5 is correlated with its corresponding SS concentration. Figure 6 shows such a correlation. The best fit equation for the data is

$$BOD_{5in} = 138 + 0.82\ SSi \qquad (1)$$

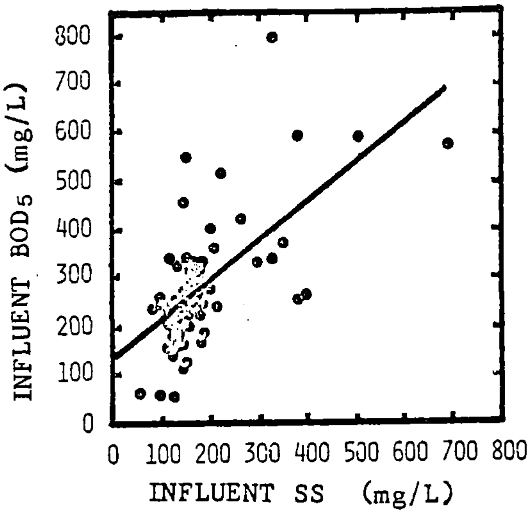

FIGURE 6 INFLUENT BOD_5 vs INFLUENT SS CORRELATION - GLENLEA

Equation (1) shows that the soluble BOD_5 is 138 mg/L and that approxiamtely 82% of the influent SS contribute to the total BOD_5. This information can be used to estimate the soluble BOD_5 fraction of the influent as shown in Figure 7. The mean soluble BOD_5 is 138 mg/L with 90%

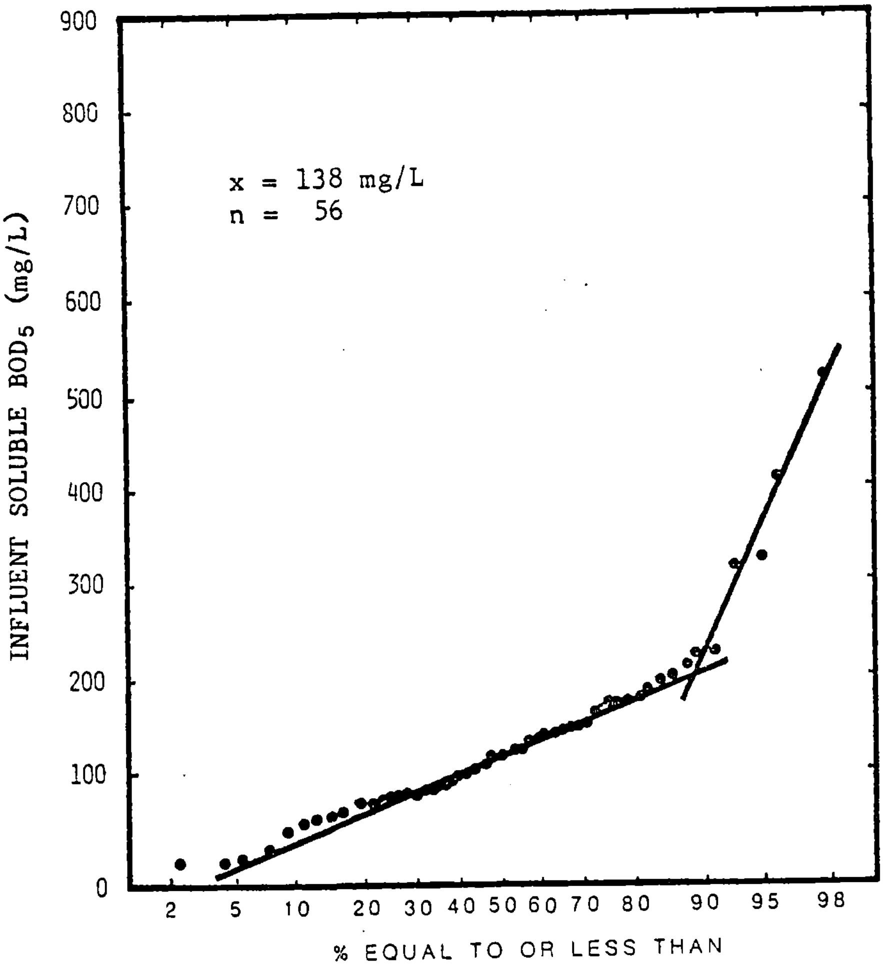

FIGURE 7 INFLUENT SOLUBLE BOD_5 PROBABILITY DISTRIBUTION - GLENLEA

of the soluble BOD_5 values being less than or equal to 246 mg/L and 10% less than or equal to 47 mg/L. The data have two distinct distributions indicating 4 unexplained inputs of high soluble BOD_5 concentrations. The total number of observations were 56.

Effluent total BOD_5 concentrations are shown in Figure 8. The mean effluent BOD_5 is approximately 5 mg/L, with 90% of the observations being less than or equal to 7 mg/L and 10% less than or equal to 3 mg/L. Similar to the influent soluble BOD_5 determination the effluent soluble BOD_5 was calculated as shown in Figure 9. The best fit line for the data follows the equation:

$$BOD_{5e} = 2.9 + 0.44\ SS_e \qquad (2)$$

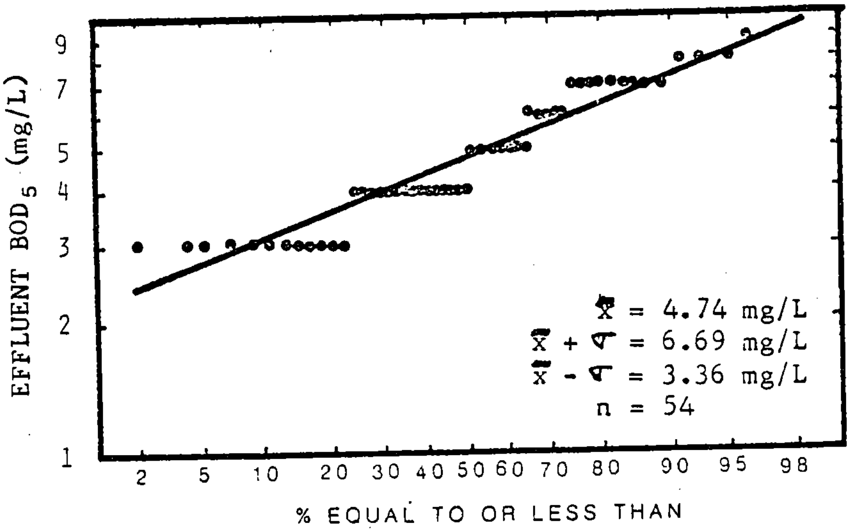

FIGURE 8 EFFLUENT BOD_5 PROBABILITY DISTRIBUTION - GLENLEA

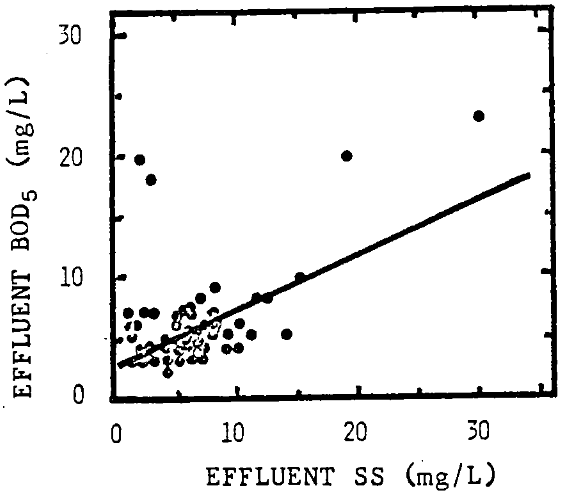

FIGURE 9 EFFLUENT BOD_5 vs EFFLUENT SS CORRELATION - GLENLEA

Equation (2) shows that only 44% of the solids fraction contributes to the effluent BOD_5. This is not unexpected since a large percentage of the biodegradable suspended particulates has been metabolized. As well, the soluble effluent BOD_5 is approximately 3 mg/L. This means that the soluble substrate conversion efficiency is 96% and the overall BOD_5 removal efficiency is 98%. The biological process is operating at high efficiency.

To check on this substrate conversion calculation and more specifically the value of the effluent soluble BOD_5, the method proposed by McKinney (8) is used. Under oxygen limiting conditions the effluent soluble BOD_5 can be calculated as follows:

$$BOD_5\,sol. = \frac{BOD_5}{(k_m t + 1)} \qquad (3)$$

where:

BOD_5 = influent BOD_5, unfiltered, (mg/L)
k_m = substrate conversion rate constant, (1/h)
t = aeration time, (h)

The substrate conversion rate constant, k_m, at 20 °C is assumed to be 15/h. This has been found to apply for wastes of domestic origin. Because of its temperature dependence k_m must be corrected to the prevailing temperature using the relationship (8):

$$k_{mT} = k_{m20}\,(1.072)^{(T - 20)} \qquad (4)$$

where:

k_{mT} = substrate conversion rate constant at operating temperature, °C
k_{m20} = reference substrate conversion rate constant at 20°C
T = operating temperature, °C

Using equations (3) and (4)

t = 17.2 h
k_{m20} = 15/h
$BOD_5 in$ = 251 mg/L
T = 9.75 °C (mixed liquor)

$$\text{EFFLUENT } BOD_5\,sol. = \frac{251}{(7.36\,(17.2) + 1)} = 1.97 \text{ mg/L}$$

Considering the BOD_5 test, the many assumptions made, the calculated effluent soluble BOD_5 of approximately 2 mg/L compares well with the calculated effluent soluble BOD_5 as illustrated in Figures 9 and 10. Figure 10 shows the distribution of calculated soluble effluent BOD_5 concentrations. The mean value is 3 mg/L for all practical purposes, (2.58 mg/L as calculated) with 90% of the values being equal to or less than 5 mg/L and 40% of the values being equal to or less than 2 mg/L. The variations in influent and effluent BOD_5 concentrations over the investigative period are shown in Figure 11. The effluent BOD_5 stability in spite of large variations in influent BOD_5 concentrations is well illustrated.

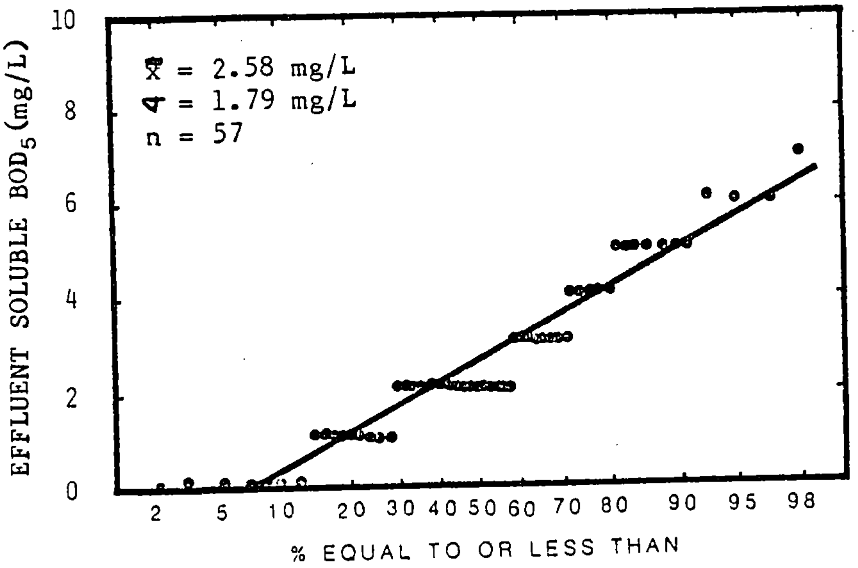

FIGURE 10 EFFLUENT SOLUBLE BOD_5 PROBABILITY DISTRIBUTION - GLENLEA

4.3.3 Process loading

Conventionally, the food the microorganism ratio (F/M, g BOD_5 applied/kg MLSS.d) is used to define the organic loading to a biological process. Generally, conventional activated sludge processes operate at $300 \leq F/M \leq 500$, whereas extended aeration processes at loaded at $F/M \leq 50$. As shown in Figure 12 the calculated F/M values average 25, with 90% of the values being less than or equal to 54 and 10% less than or equal to 12.

In batch reactor technology the F/M ratio will vary continuously not only as the sludge mass increases from day to day, but more importantly from the fill to react through decant cycle. It is evident that the initial F/M will be high and decrease as the food supply for the microorganisms is exhausted. The initially high F/M ratio will also place a high oxygen demand on the system. Thus it is important that a successful process must have sufficient oxygen transfer capacity to meet this demand.

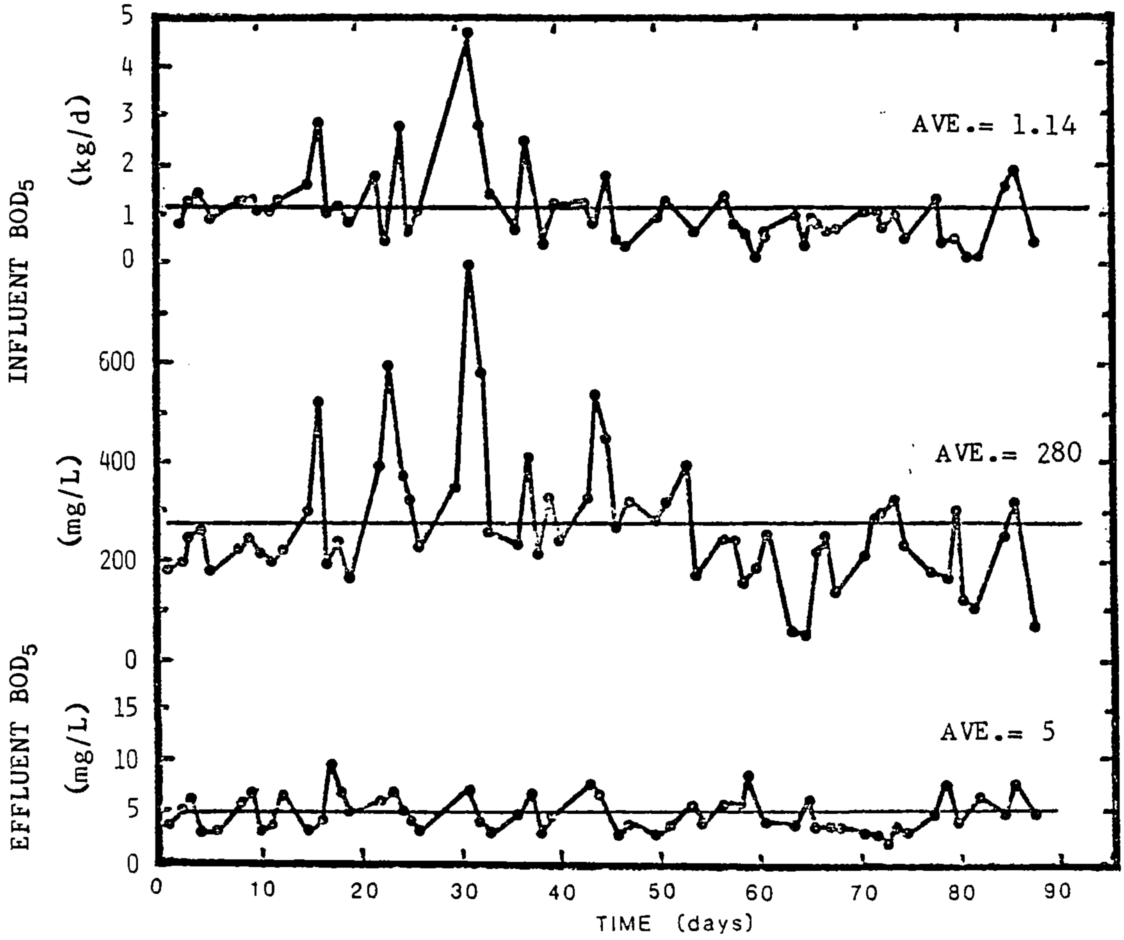

FIGURE 11 BOD_5 CONCENTRATIONS AND LOAD - INFLUENT AND EFFLUENT - GLENLEA

Figures 13 and 14 show the insensitivity of process response (effluent BOD_5) to both organic load (F/M) and volumetric load, respectively.

Organic loading is more appropriately related to the MLVSS rather than just the MLSS. This becomes more important when comparing process loadings between systems were the organic fraction in the mixed liquor are not the same. Thus, the mean organic loading (F/M) is 30 (g BOD_5/kg MLVSS.d).

4.3.4 Sludge growth

Sludge growth is the net result of substrate conversion and endogenous respiration. This is of prime interest in that it establishes the sludge management requirements for the process. Figure 15 shows the net increase in sludge concentration for 5 distinct periods over the 88 day monitoring period. As indicated by the data discontinuities sludge was wasted every 20 to 25 days. This was done with the objective of operating in a MLSS concentration range of 2500 - 4500 mg/L. As shown in Figure 16, the average MLSS concentration was 3855 mg/L, with 90% of the time values are equal to or less than 4800 mg/L and 10% equal to or less than 2930 mg/L.

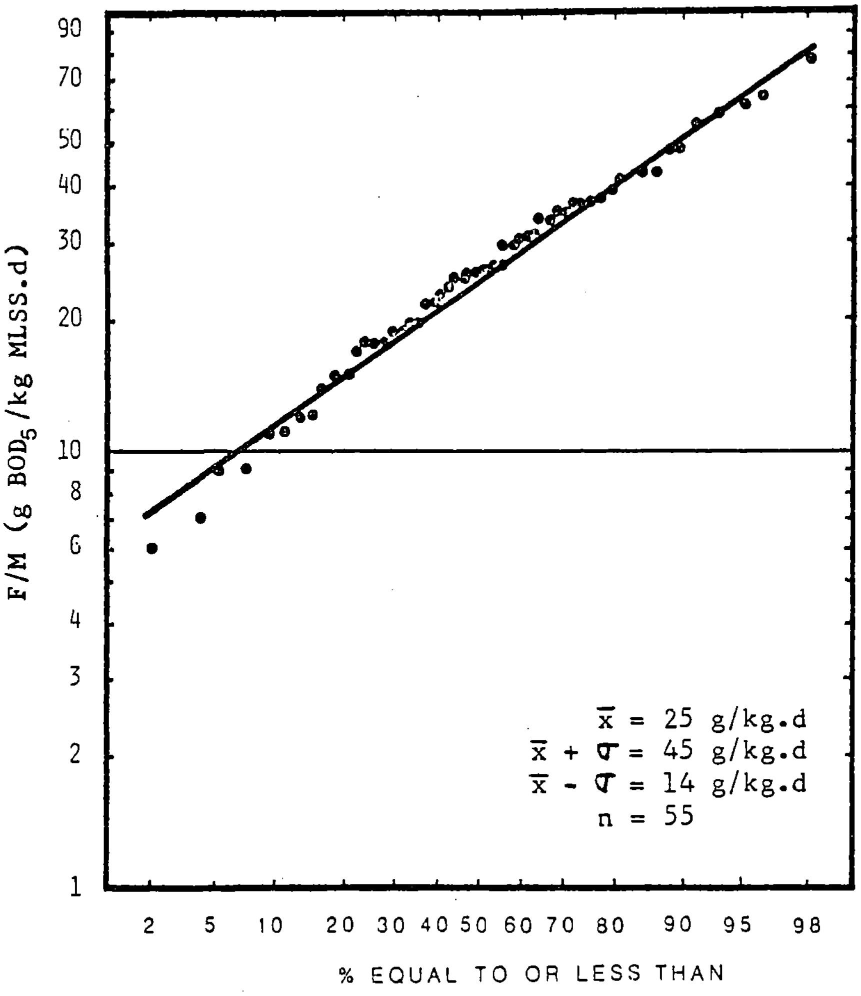

FIGURE 12 F/M PROBABILITY DISTRIBUTION - GLENLEA

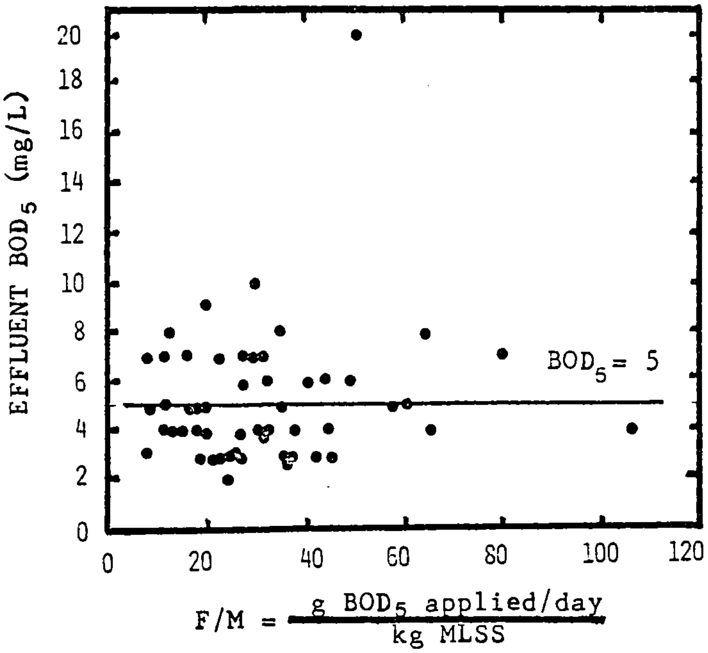

FIGURE 13 EFFLUENT BOD_5 AS A FUNCTION OF ORGANIC LOAD (F/M) - GLENLEA

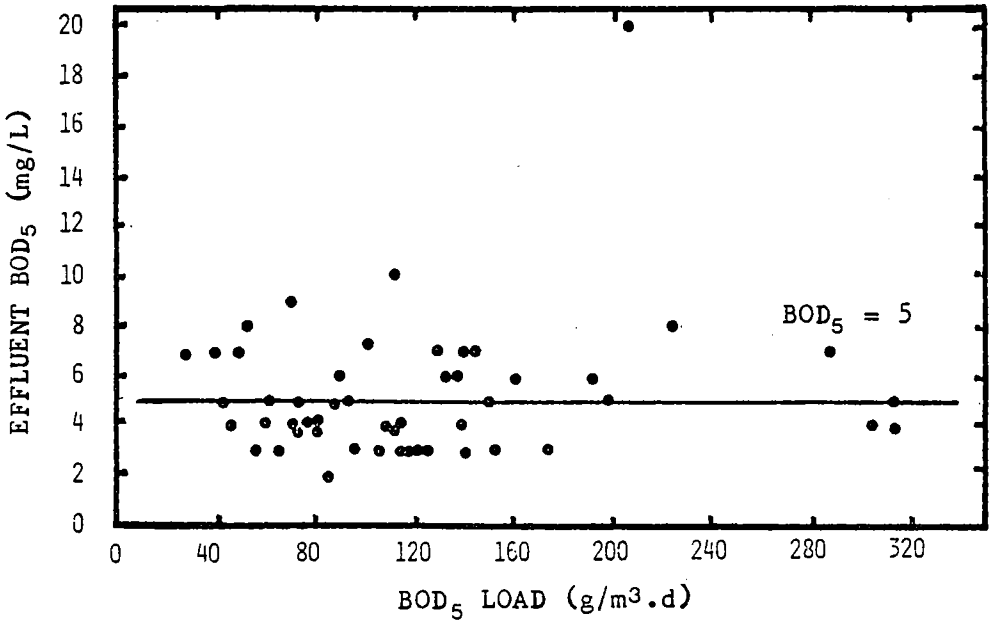

FIGURE 14 EFFLUENT BOD_5 AS A FUNCTION OF VOLUMETRIC LOAD - GLENLEA

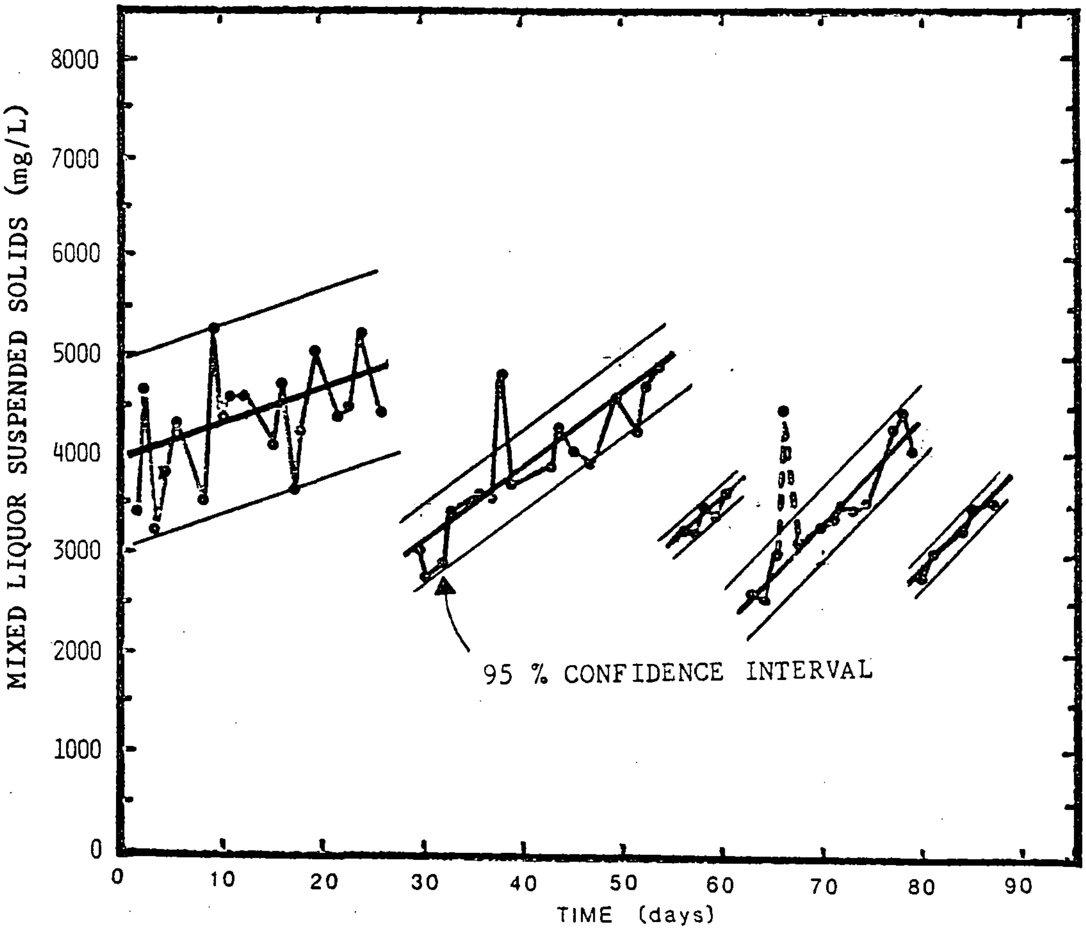

FIGURE 15 MIXED LIQUOR SUSPENDED SOLIDS INCREASES AT GLENLEA

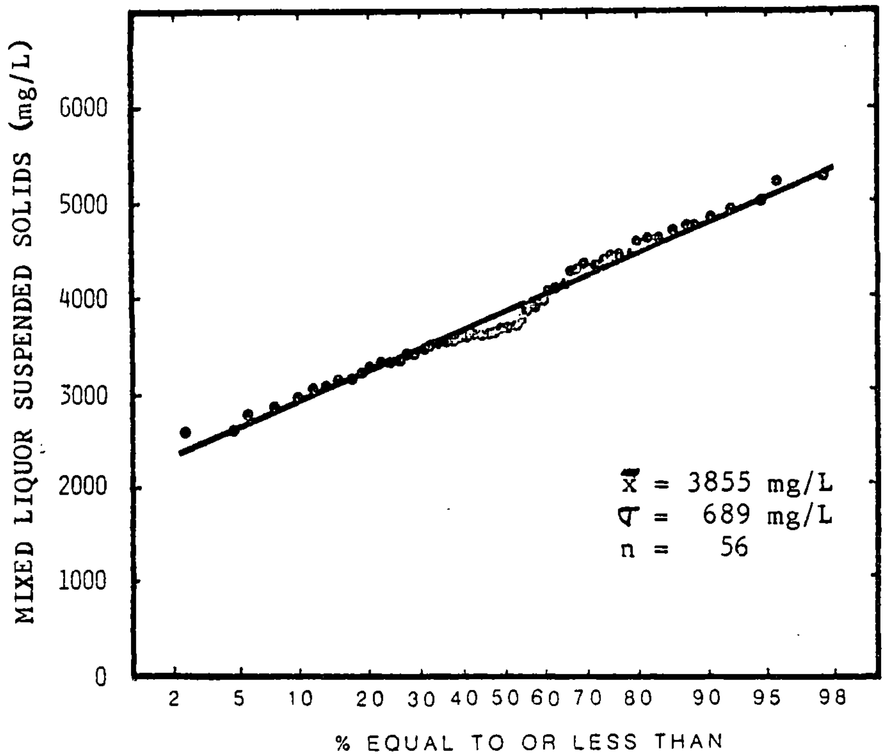

FIGURE 16 MLSS PROBABILITY DISTRIBUTION - GLENLEA

The data in Figure 15 are shown with 95% confidence bands and illustrate the initial problems encountered in trying the determine MLSS concentrations. A fair degree of variability is evident. This is attributable to both sampling and analytical difficulties. As illustrated by the data in the later periods, as the person taking the samples gained more experience and became more familiar with the system and its operation.

The volatile solids fraction of the MLSS averaged 0.825, with 90% being less than or equal to 0.860 and 10% being less than or equal to 0.790 (Figure 17).

Analysis of the MLVSS data results in the following regression equations for the respective periods between sludge wasting:

Period	No. of data	Equation		Regression Coeff.
day	n			r
1 - 26	18	MLVSS = 3327 + 22.4t	(5)	0.373
26 - 54	18	MLVSS = 2619 + 51.3t	(6)	0.815
54 - 61	5	MLVSS = 2570 + 84 t	(7)	0.793
64 - 80	13	MLVSS = 2311 + 64.5t	(8)	0.663
81 - 88	5	MLVSS = 2237 + 90 t	(9)	0.976

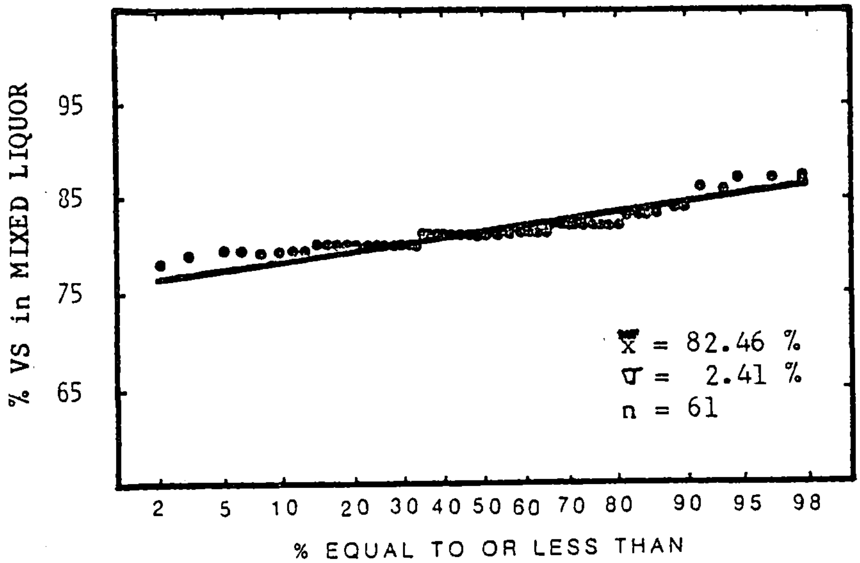

FIGURE 17 PERCENT VS IN MLSS PROBABILITY DISTRIBUTION - GLENLEA

From equations (5) to (9) the rate of change in MLVSS can be determined by differentiating the equations with respect to time. Therefore; for equation (5):

$$\frac{dC}{dt}v = 22.4 \text{ mg/L.d}$$

multiplying the concentration change with the liquid volume of the reactor V, changes the values to a mass basis.

$$V \frac{dC}{dt}v = \frac{dX}{dt}v \qquad (10)$$

For Glenlea:

$$9.1 \text{ m}^3 \frac{22.4 \text{ g}}{\text{m}^3 .\text{d}} = 0.204 \text{ kg/d} = \frac{dX}{dt}v$$

When in the log growth phase, microorganisms increase in proportion to their mass. This is usually defined by:

$$\frac{dX}{dt}v = r_g \qquad (11)$$

where:

$\frac{dXv}{dt}$ = increase in number of microorganisms per, unit time, M/T

rg = rate of microorganism growth, M/T

$$rg = \mu Xv \tag{12}$$

where:

μ = specific growth rate, 1/T

Substituting equation (12) into equation (11) results in

$$\frac{dX}{dt}v = \mu X_v \tag{13}$$

Values for dXv/dt and Xv are calculated and summarized in Table 2. Plotting dXv/dt versus Xv as shown in Figure 18 and calculating the best fit line for the data yields the equation:

$$\frac{dX}{dt}v = 1.86 - 0.054\ X_v \tag{14}$$

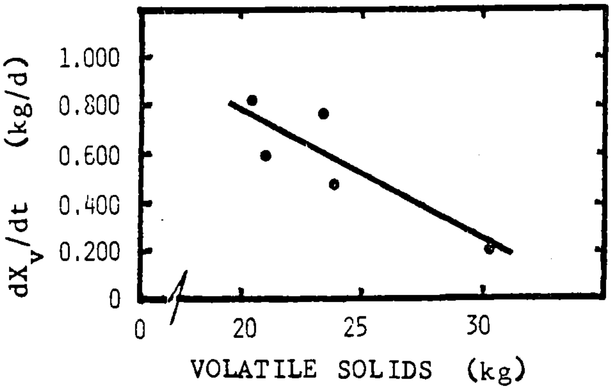

FIGURE 18 BIOMASS GROWTH RATE - GLENLEA

TABLE 2 - BIOMASS GENERATION SUMMARY - Glenlea

$\frac{dCv}{dt}$	V	Cv	Xv	$\frac{dXv}{dt}$
mg/L.d	m^3	mg/L	kg	kg/d
22.4	9.1	3327	30.3	0.204
51.3		2619	23.8	0.467
84		2570	23.4	0.764
64.5		2311	21.0	0.587
90		2237	20.4	0.819

From equation (14) the specific growth rate μ , is determined to be 0.054/day. This means that the average minimum SRT should be

$$\mathrm{SRT} = \frac{1}{\mu} \qquad (15)$$

$$= \frac{1}{0.054} = 18.5 \text{ days}$$

The minimum SRT during the monitoring period was 18 days.

Figure 19 shows the distribution of volatile solids production per day. The average net volatile solids production is 0.57 kg/d, with 90% of the values equal to or less than 0.86 kg/d and 10% equal to or less than 0.29 kg/d.

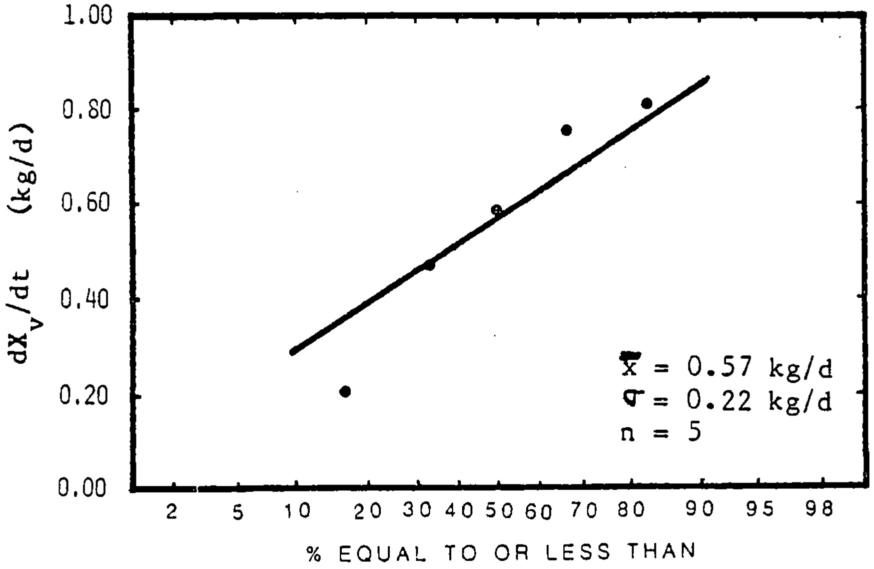

FIGURE 19 BIOMASS GROWTH RATE PROBABILITY DISTRIBUTION - GLENLEA

Comparing sludge production (VS) with the soluble BOD_5 converted

$$\frac{(\text{ INFLUENT } BOD_5\text{sol. - EFFLUENT } BOD_5\text{sol.})(Q)}{1000} = BOD_5\text{ sol. (kg/d)} \qquad (16)$$

$$\frac{(138 - 3)(4.4)}{1000} = 0.59 \text{ kg } BOD_5\text{ sol./d}$$

one can calculate the amount of biomass produced per unit of soluble substrate removed as:

$$\frac{0.57 \text{ kg VS/d}}{0.59 \text{ kg } BOD_5\text{ sol./d}} = 0.97 \text{ kg VS/kg } BOD_5\text{ sol.}$$

For practical purposes, 1 kg of biomass is produced per kg soluble substrate removed. This can be converted to 0.64 kg sludge per kg BOD_5 removed.

4.3.5 Sludge settleability

The successful operation of suspended growth systems is dependent on effective liquid/solid separation. Thus, the microbial population must be maintained in a state where it has good settling properties. A number of methods are available to asses this property.

The method used was the conventional sludge volume index (SVI) as determined by noting the volume occupied by 1 gram of sludge after settling for 30 minutes in a 1 litre graduate cylinder.

$$SVI = \frac{SV_{30}}{SS_i}\,\frac{ml/L}{g/L} = ml/g \qquad (17)$$

where:

SV_{30} = sludge volume after 30 minutes settling
SSi = initial sludge concentration

The SVI is not a fixed index, but actually varies quite unpredictably with suspended solids concentration (9). Lee et al (10) recently examined and compared various quantitative techniques for assessing sludge settleability. Their conclusion was, that a diluted SVI, the sludge is diluted to a concentration of 1.5 g/L ($SVI_{1.5}$), will give the best reproduceable and comparable indication of sludge settleability.

The average SVI, as determined from a distribution plot was 117 with 90% of the values being equal to or less than 145 and 10% equal to or less than 79 (Figure 20).

The variation of the SVI with time is shown in Figure 21.

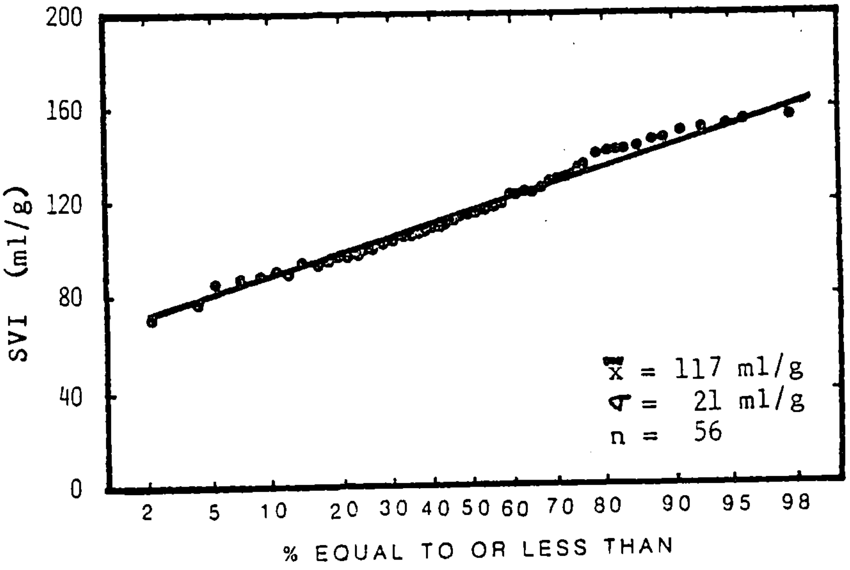

FIGURE 20 SVI PROBABILITY DISTRIBUTION - GLENLEA

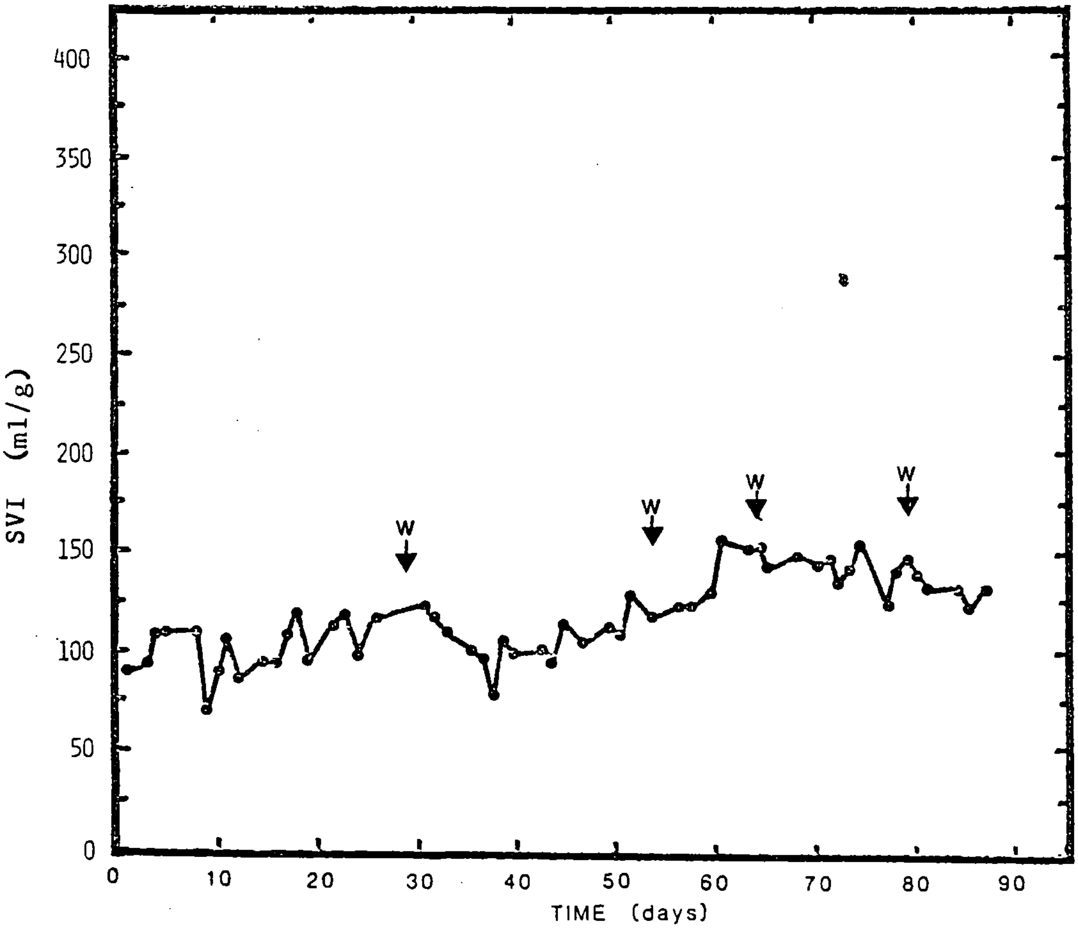

FIGURE 21 SVI HISTORY AT GLENLEA

4.3.6 Sludge wasting

All biological processes generate excess solids which must be removed from time to time. Figure 21 indicates the times (noted with a W) when sludge was wasted from the system. The SVI test was used to determine when sludge should be wasted. When the volume of sludge after 30 minutes settling exceeded 500 ml, sludge was wasted. The quantities varied from approximately 3 m^3 to 2 m^3. The object was to reduce the MLSS concentration to approximately 2500 mg/L. Sludge was wasted approximately every 20 to 30 days. Sludge was wasted to the nearby agricultural land. Insofar as remote, cold climate installations are concerned, the waste treatment facility can be designed for aerobic sludge digestion and storage with application of completely mineralized sludge to surrounding areas when weather conditions permit.

The costs associated with this are highly site specific but are reflected in greater tankage requirements and suitable additional air compressor capacity.

Sludge wasting also determines the solids retention time (SRT). This has special significance when nitrification is a process objective. The SRT was determined from:

$$\text{SRT} = \frac{\text{mass of solids in reactor}}{\text{mass of solids wasted/day}} = \text{days} \qquad (18)$$

The SRT for Glenlea during the monitoring period were calculated to be 71, 84, 18 and 80 days.

4.3.7 Suspended solids

The distribution of influent suspended solids to the system is illustrated in Figure 22. The distribution is not normal. Two distinct distributions were observed. The mean influent SS concentration is 152 mg/L, with 90% of the values being equal to or less than 337 mg/L and 10% equal to or less than 96 mg/L. These high SS values were frequently associated with high BOD_5 values. The ratio between BOD_5 and SS is log normally distributed as shown in Figure 23. Here the average BOD_5/SS ratio is 1.59 with 90% of the values having a ratio of equal to or less than 2.65 and 10% equal to or less than 0.95. This is indicative of a strong sewage.

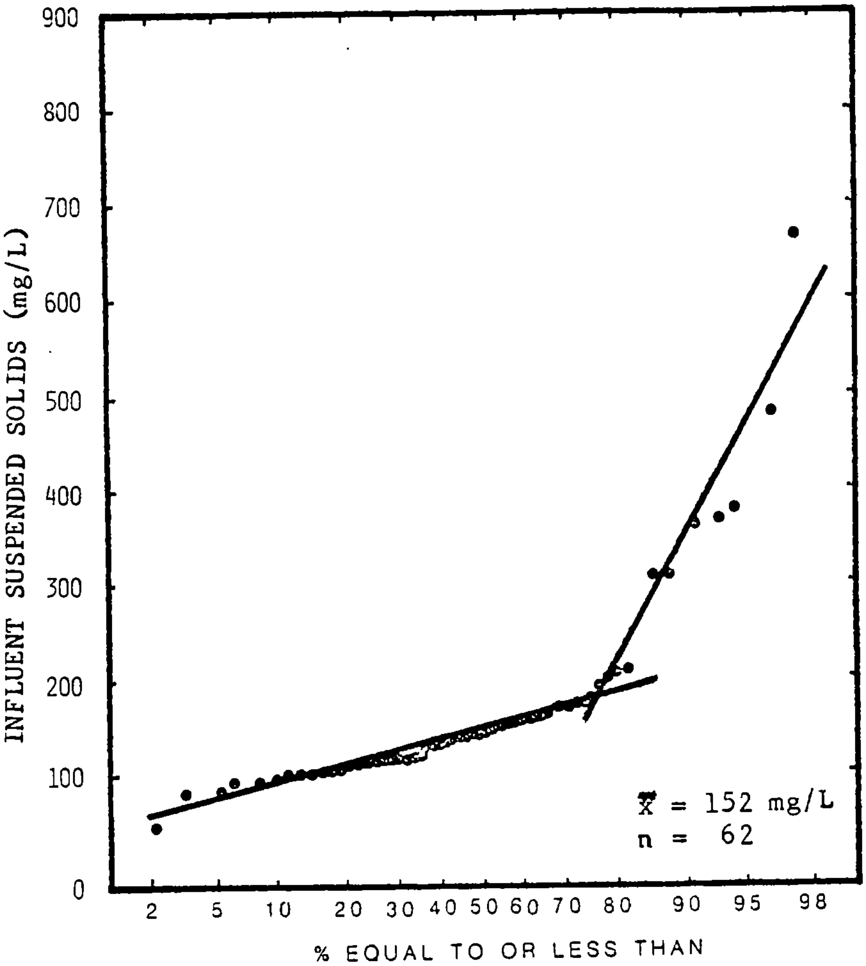

FIGURE 22 INFLUENT SS PROBABILITY DISTRIBUTION - GLENLEA

The effluent SS distribution shown in Figure 24 indicates a mean concentration of 6 mg/L with 90% of the values are equal to or less than 10 mg/L and 10% equal to or less than 1 mg/L. The liquid/solid separation characteristics of the suspension are excellent. This is not surprising since settling is occuring under near perfect conditions. This is one of the strong attributes of batch reactor technology.

The influent and effluent SS for Glenlea over the investigative period are shown in Figure 25. The large degree of process stability in liquid/solid separation is readily seen.

4.3.8 Nitrification/denitrification

It is well known that conditions conducive for growth of nitrifiers are:

Dissolved oxygen	2 mg/L
pH	7 - 8.4

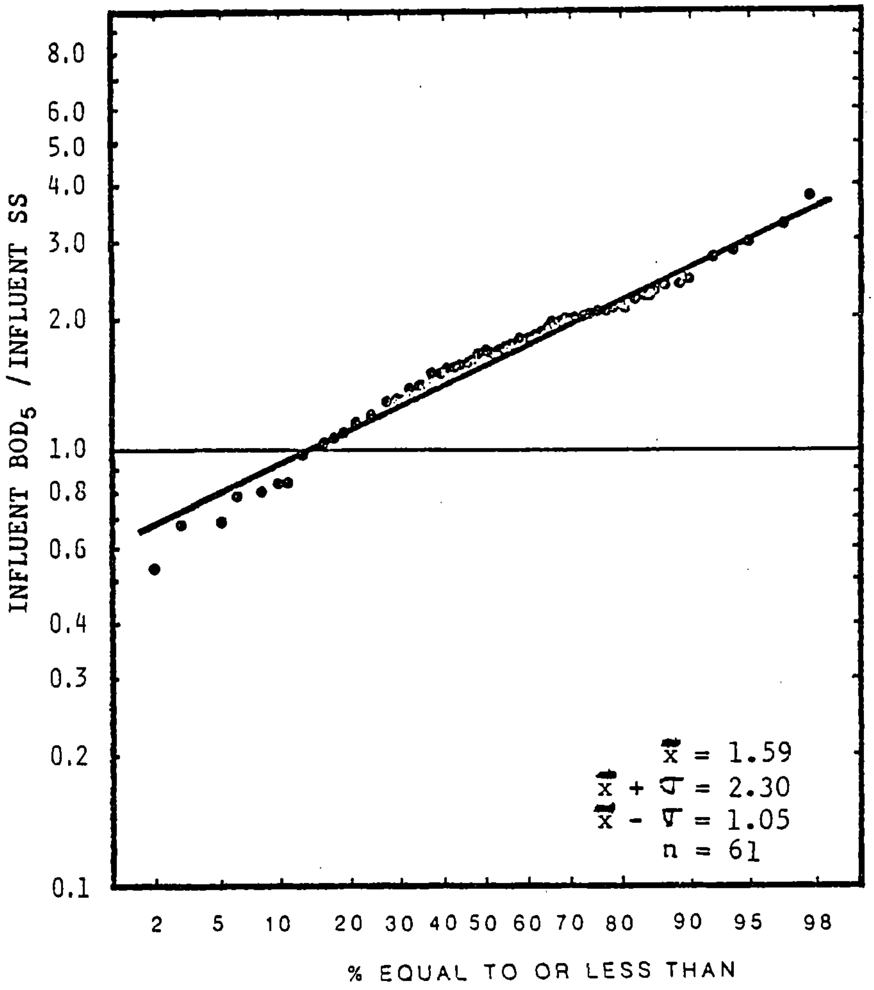

FIGURE 23 INFLUENT BOD_5/SS RATIO PROBABILITY DISTRIBUTION - GLENLEA

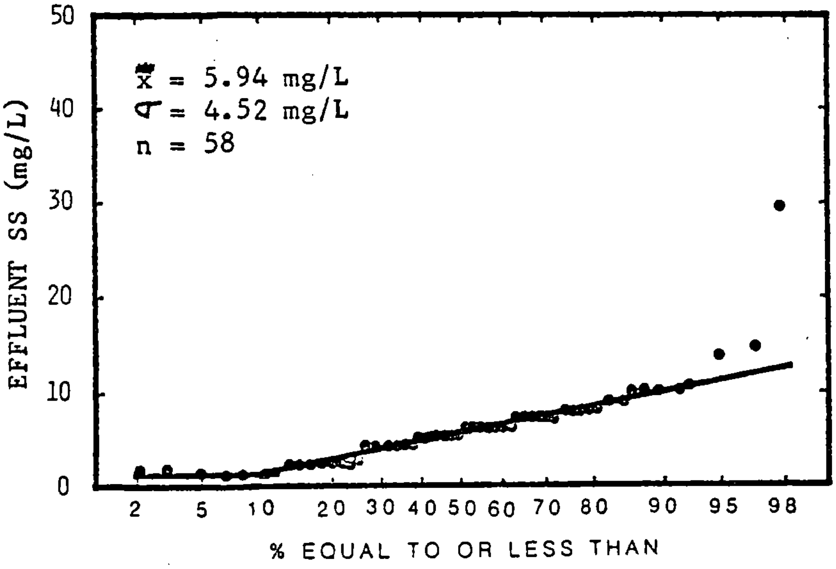

FIGURE 24 EFFLUENT SS PROBABILITY DISTRIBUTION - GLENLEA

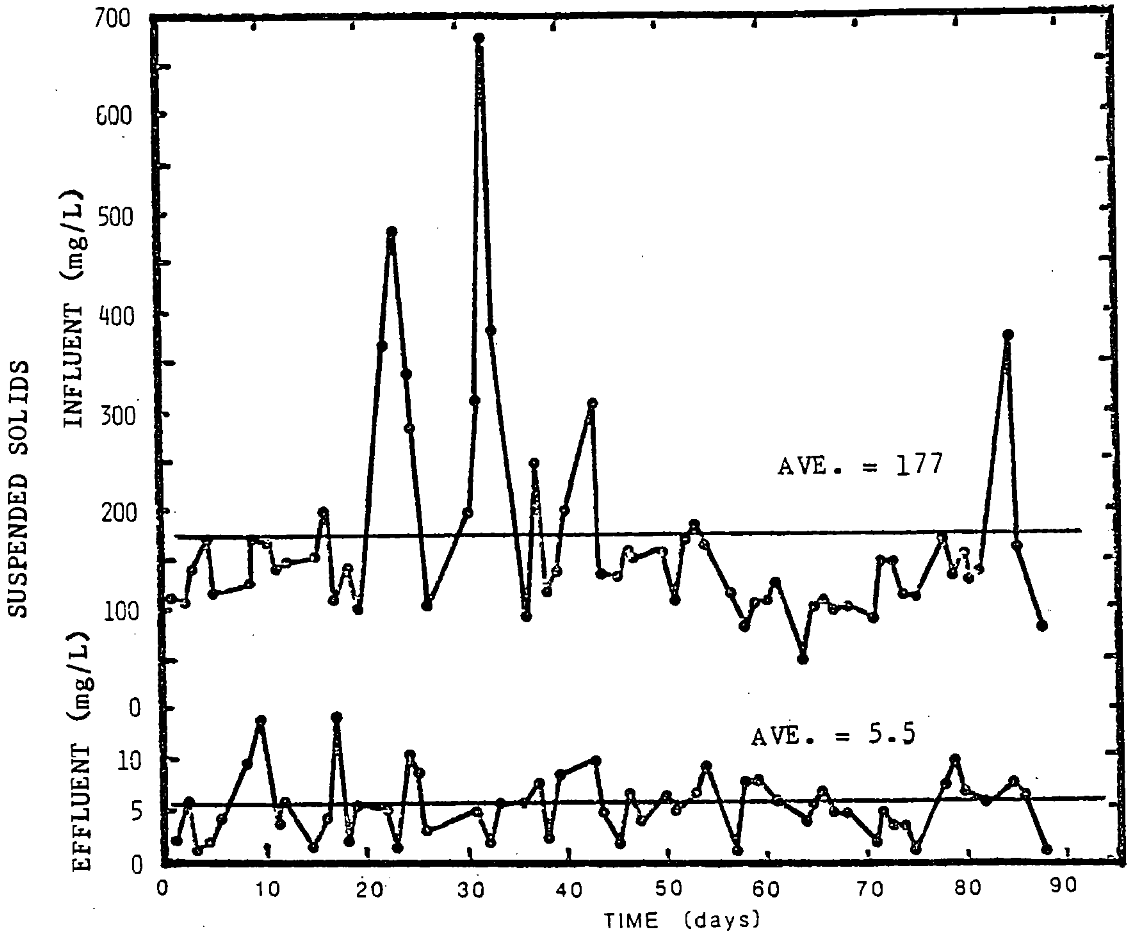

FIGURE 25 INFLUENT AND EFFLUENT SS VARIATIONS - GLENLEA

As well, sufficient alkalinity must be present, because theoretically 7 mg of alkalinity are used for each mg of NH_4-N oxidized.

The mean influent alkalinity for the Glenlea waste water is 314 mg/L with 90% of the values are equal to or less than 430 mg/L and 10% equal to or less than 200 mg/L (Figure 26).

The influent NH_4-N concentration as shown in Figure 27 averages 55 mg/L. This is very high for a domestic sewage which normally averages around 20 to 25 mg/L. The reason for this high concentration is unknown. The data are normally distributed with 90% of the values equal to or less than 80 mg/L and 10% equal to or less than 31 mg/L.

Figure 28 shows the effluent NH_4-N concentrations. The data show that the average concentration is 2 mg/L with 90% of the observations being equal to or less than 6 mg/L and 40% being equal to or less than 1 mg/L. NH_4-N removal of 96% is achieved.

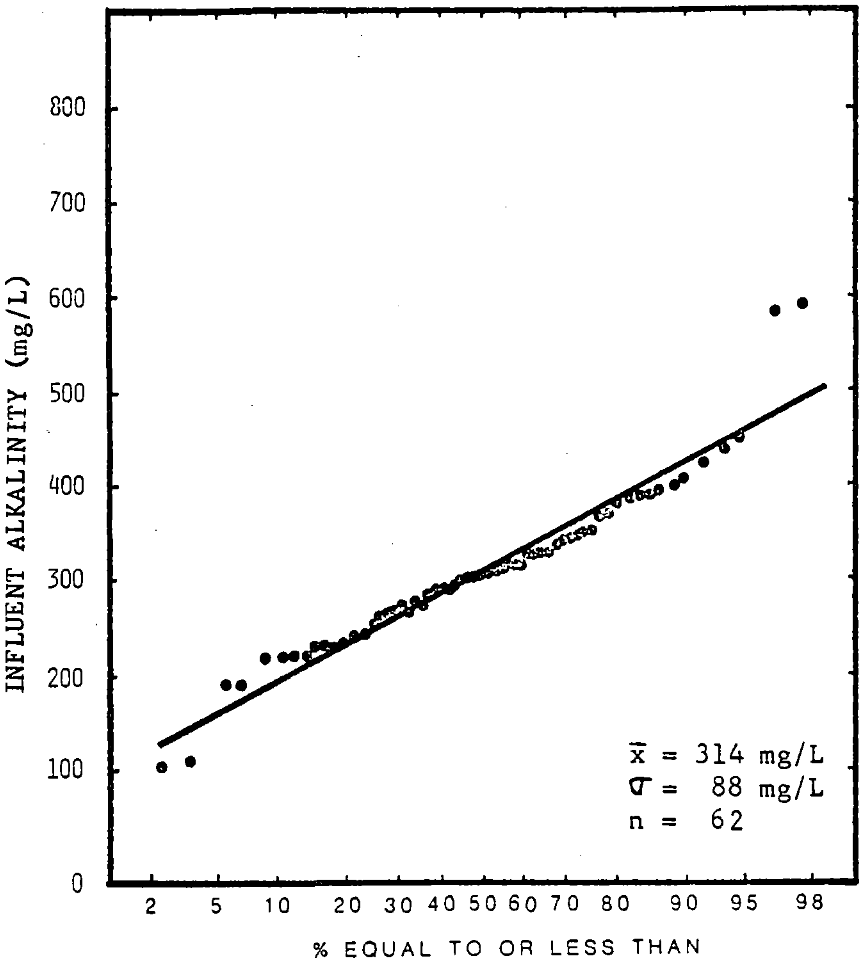

FIGURE 26 INFLUENT ALKALINITY PROBABILITY DISTRIBUTION - GLENLEA

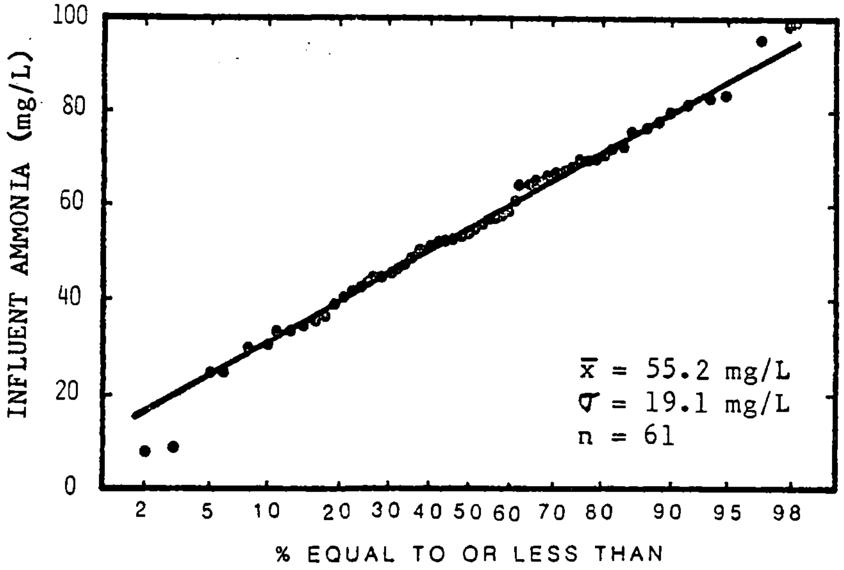

FIGURE 27 INFLUENT NH_4 - N PROBABILITY DISTRIBUTION -GLENLEA

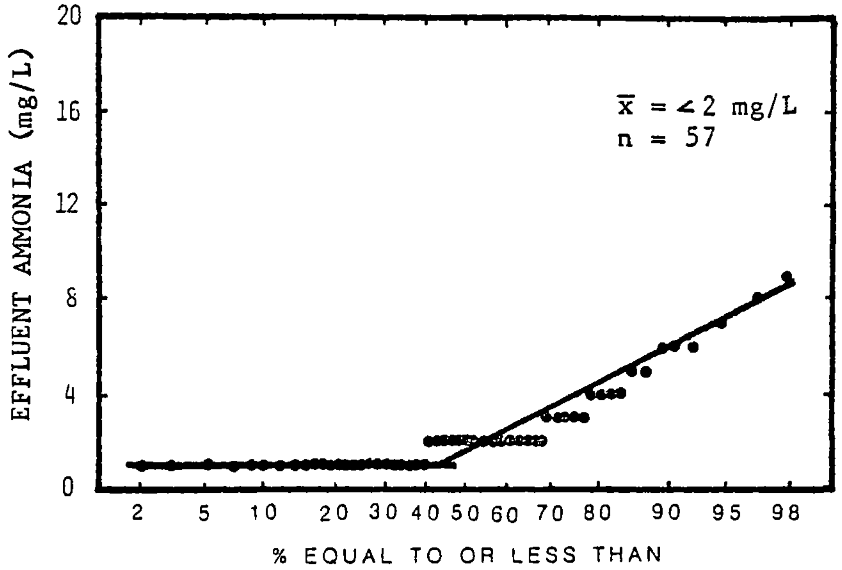

FIGURE 28 EFFLUENT NH_4- N PROBABILITY DISTRIBUTION - GLENLEA

The effluent alkalinity concentrations are shown in Figure 29, indicating an average value of 56 mg/L with 90% of the observations are equal to or less than 90 mg/L and 10% equal to or less than 22 mg/L. Clearly, sufficient alkalinity for nitrification was available. The influent and effluent alkalinity history for the Glenlea data is shown in Figure 30. At no time was all of the alkalinity exhausted.

While stoichiometrically approximately 7 mg of alkalinity per 1 mg NH_4-N oxidized are required, 3.6 mg of alkalinity are returned per 1 mg NO_3-N denitrified. In extended aeration systems, some degree of denitrification always occurs, thus the alkalinity removed to NH_4-N oxidized ratio is less than 7. For Glenlea this ratio was determined for all observations and plotted as shown in the probability distribution of Figure 31. The mean ratio is 4.8 with 90% of the observations being eqal to or less than 6.3 and 10% equal to or less than 3.7. The data are log normally distributed. The alkalinity removed to NH_4-N removed ratios on a daily basis are shown in Figure 32. The data indicate a fairly uniform ratio during the process assessment period.

A number of mathematical expressions for the growth of nitrifying organisms exist. One, defines the net growth rate of nitrifiers under steady state conditions by a function which is a product of Monod-type factors (11):

$$\mu = \mu_m \underbrace{\left(\frac{NH_4 - N}{K_N + NH_4 - N}\right)\left(\frac{DO}{KO_2 + DO}\right)}_{\substack{\text{generally less than} \\ \text{5 \% and therefore neglected}}}\left(1 - 0.833\ (\ 7.2 - pH\ )\right) \qquad (19)$$

and

$$\mu_m = 0.47\ e^{\,0.098\ (\ T\ -\ 15\ )} \qquad (20)$$

where:

μ = net growth rate of nitrifying organisms, 1/d

μm = max. growth rate of nitrifying organisms, 1/d

NH_4-N = ave. NH_4-N concentration, mg/L

K_N = half rate NH_4-N oxidation constant, mg/L

DO = dissolved oxygen concentration in reactor, mg/L

KO_2 = half rate dissolved oxygen constant, mg/L

pH = pH of reactor contents

T = temperature of liquid in reactor, °C

Neglecting the first two terms of equation (19) and combining equations (19) and (20) results in:

$$\mu = \left(0.392\ pH\ -\ 2.35\right) e^{\,0.098\ (\ T\ -\ 15\ )} \qquad (21)$$

The average pH of the mixed liquor was 6.7 and the average temperature 9.75 °C (Figure 33). The net growth rate for the nitrifiers under these conditions is

$$\mu = \left(0.392(\ 6.7\ )\ -\ 2.35\right) e^{\,0.098\ (\ 9.75-15\ )}$$

$$\mu = 0.165\ /\ \text{day}$$

The solids retention time (SRT) is the reciprocal of the net growth rate (μ).

$$SRT = \frac{1}{\mu} \qquad (15)$$

Hence, the minimum required SRT for nitrification to occur at Glenlea is:

$$SRT = \frac{1}{0.165} = 6.1\ \text{days}$$

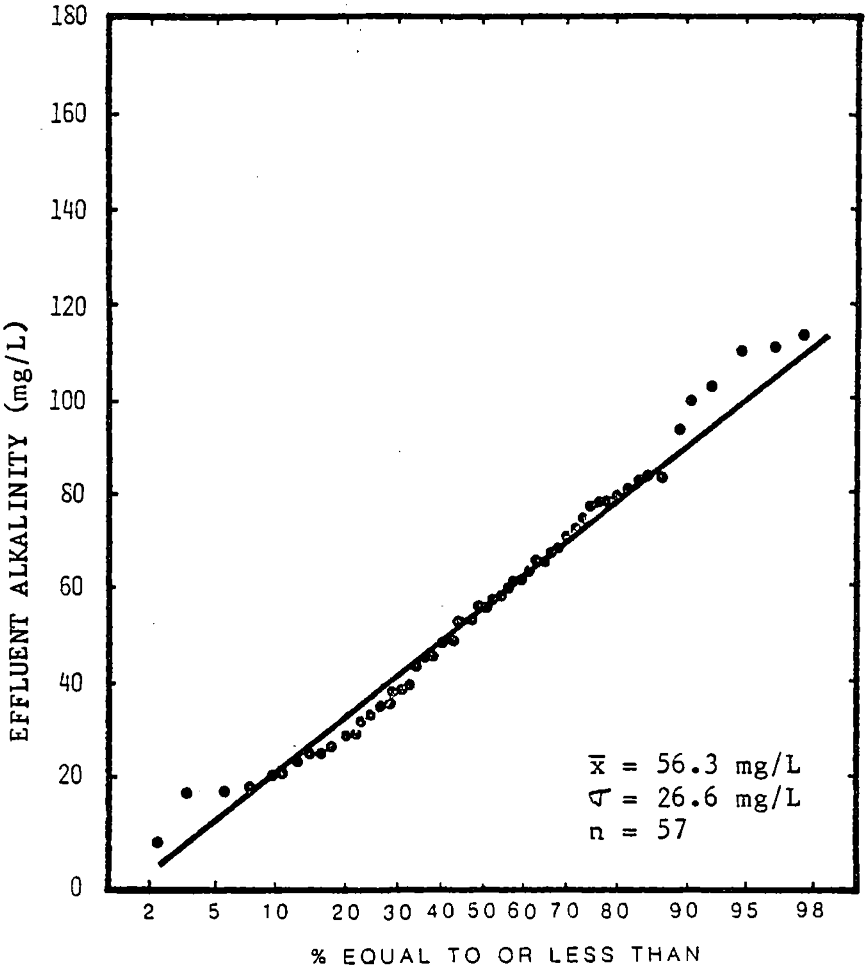

FIGURE 29 EFFLUENT ALKALINITY PROBABILITY DISRIBUTION - GLENLEA

As noted in Section 4.3.6, the minimum SRT during the monitoring period was 18 days. Based on the foregoing, conditions for nitrification were always present.

The NH_4-N load on the system can also be expressed on the basis of g NH_4-N applied/kg MLVSS.d. Figure 34 shows the distribution of the NH_4-N loading data. The data exhibit two distributions. The mean value is 7.8 g NH_4-N applied/kg MLVSS.d and ranges between 15.5 and 3.2 for 90% and 10% of the values being equal to or less than those stated, respectively. Another way of stating NH_4-N removal efficiency is based on the mass of NH_4-N removed per day per unit mass of MLVSS. Figure 35 illustrates this concept. Because of the high degree of NH_4-N conversion, it is not surprising to see that the average mass of NH_4-N removed per day, per unit mass of MLVSS is identical to the load, i.e. 7.8 g NH_4-N/kg MLVSS.d. Ninety percent of the data are equal to or less than 15.5 and 10% equal to or less than 3.2 g NH_4 -N/kg MLVSS.d.

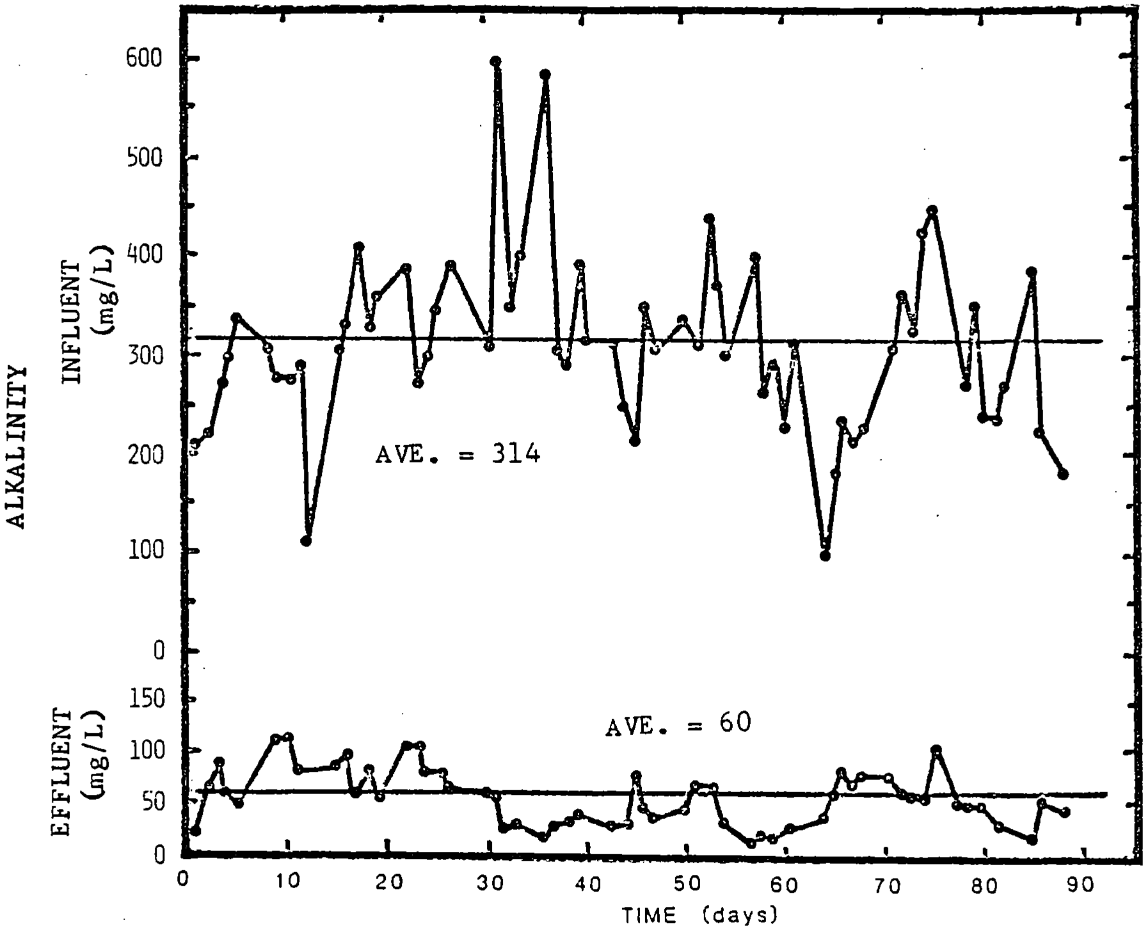

FIGURE 30 ALKALINITY VARIATIONS - INFLUENT AND EFFLUENT - GLENLEA

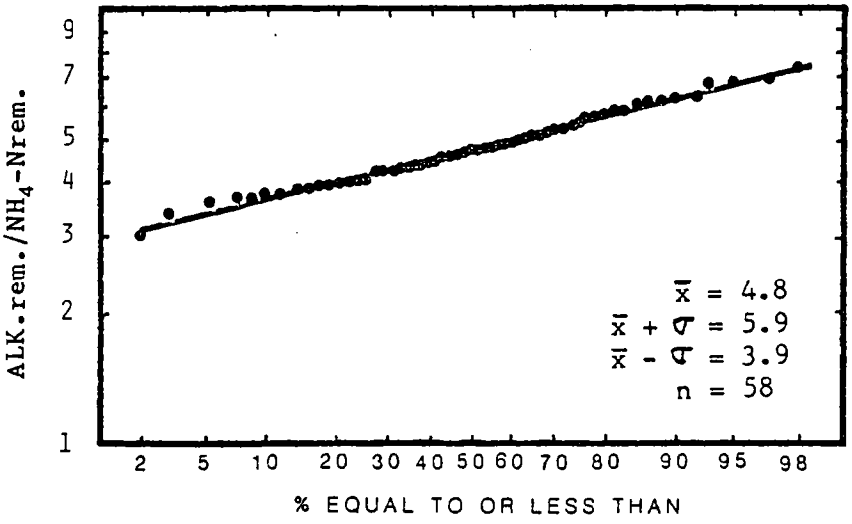

FIGURE 31 RATIO OF ALKALINITY REMOVED TO NH_4- N OXIDIZED PROBABILITY DISTRIBUTION - GLENLEA

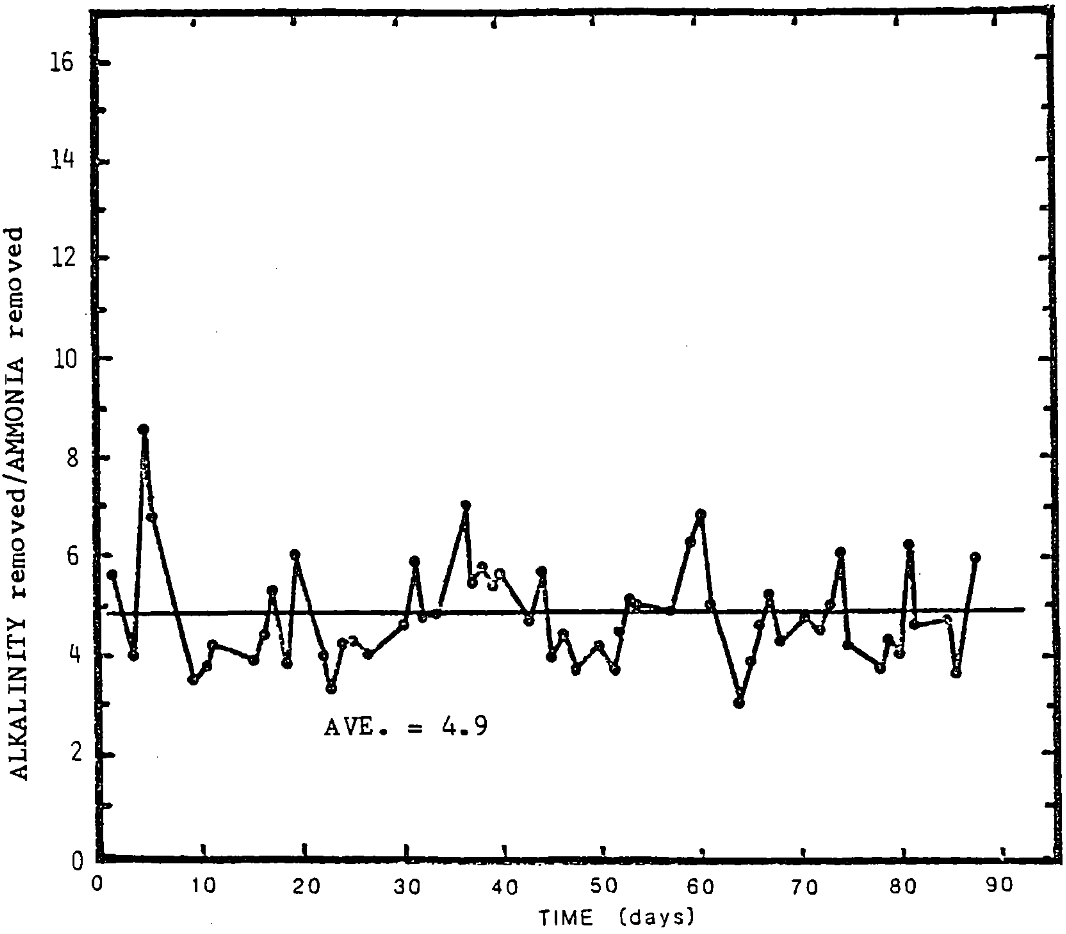

FIGURE 32 ALKALINITY REMOVED/NH_4- N OXIDIZED VARIATIONS - GLENLEA

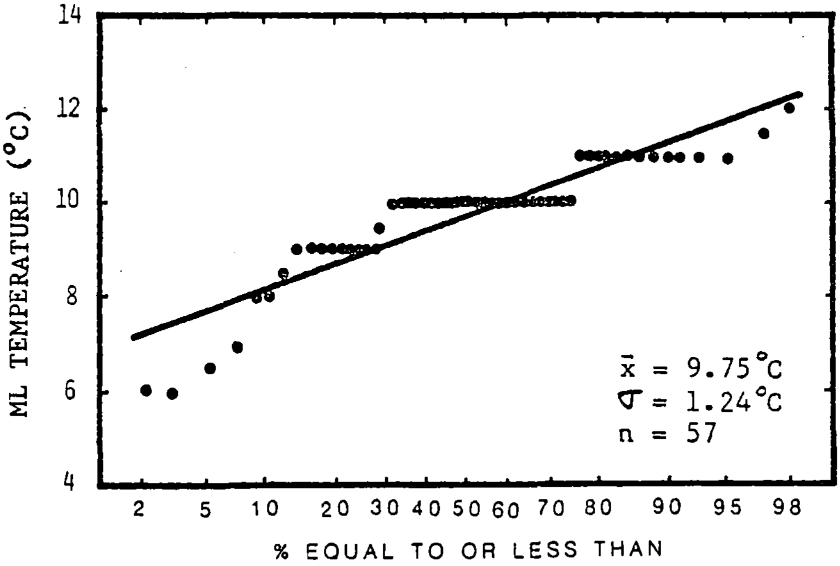

FIGURE 33 MIXED LIQUOR TEMPERATURE PROBABILITY DISTRIBUTION - GLENLEA

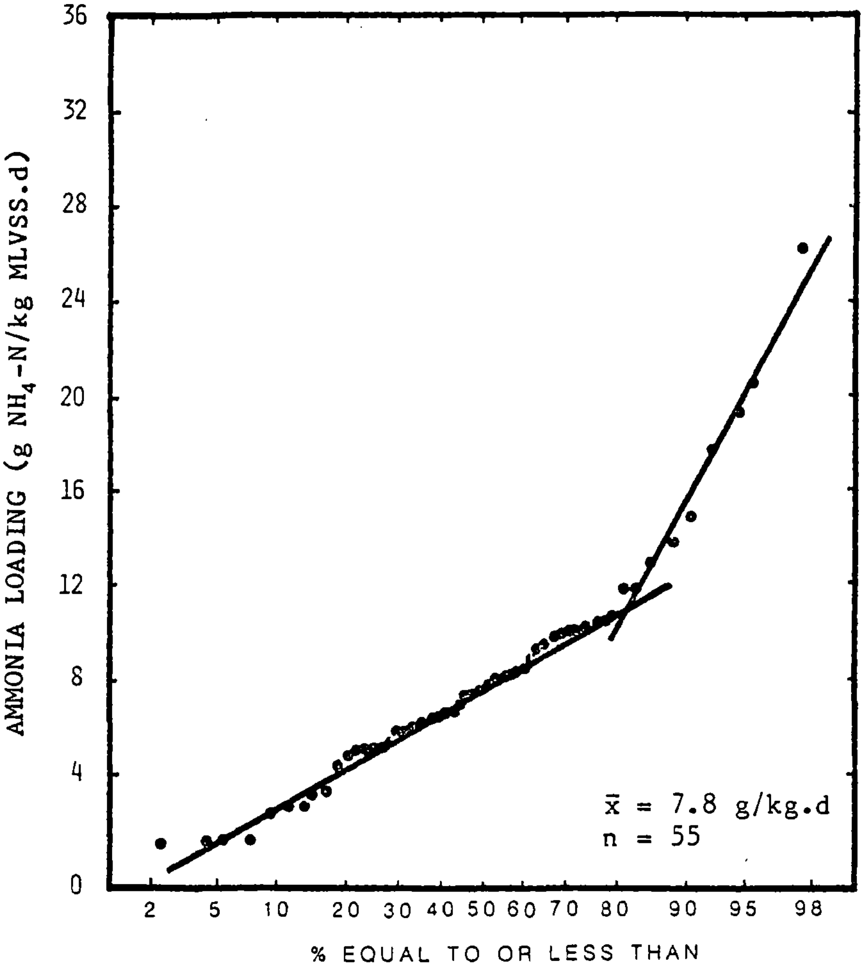

FIGURE 34 NH_4- N PROCESS LOADING PROBABILITY DISTRIBUTION - GLENLEA

Nitrification rate determinations by others are shown for comparison purposes in Table 3.

TABLE 3 - NITRIFICATION RATES (adapted from Smith (12)

RATE	TEMP.	REFERENCE
g NH_4-N removed/kg MLVSS.d	°C	
32	14	Wuhrmann
30	15	Bishop
89	25	Bishop
110	27	Bishop
120	26	Bishop
12*	14	Barnard
6*	12	Matché
12*	20	Matché
56	23	CMHC (13)
8	9.75	This Analysis - Glenlea
44	20	This Analysis - Rivercrest

* calculated on basis of 80% VS.

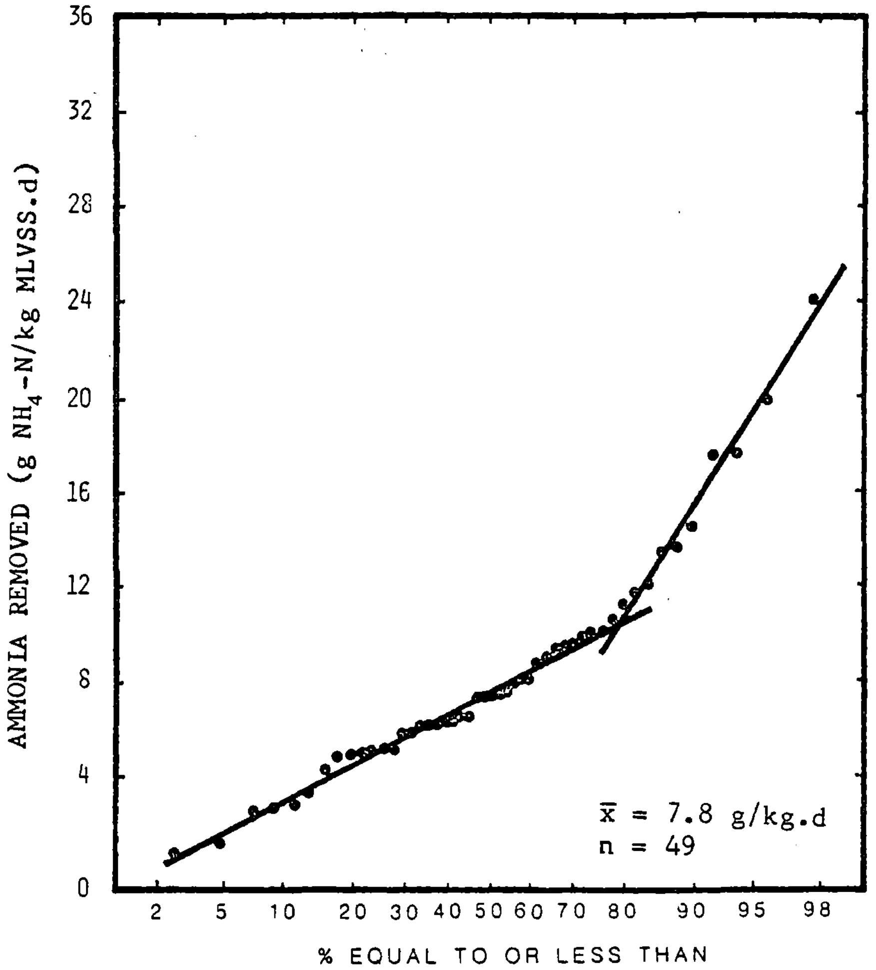

FIGURE 35 NH_4- N REMOVED PER UNIT MASS MLVSS PROBABILITY DISTRIBUTION - GLENLEA

The nitrification rate calculated for the Glenlea installation and Rivercrest are shown in Figure 36 in relation to nitrification rates determined by others. An excellent fit of the data are indicated. (the Glenlea and Rivercrest data are not included in the regression)

The equation describing the nitrification rate as a function of temperature over the temperature range of 10 - 30 °C is shown as:

$$n_{rT} = 0.0071\ T^{2.89} \qquad r = 0.839 \tag{22}$$

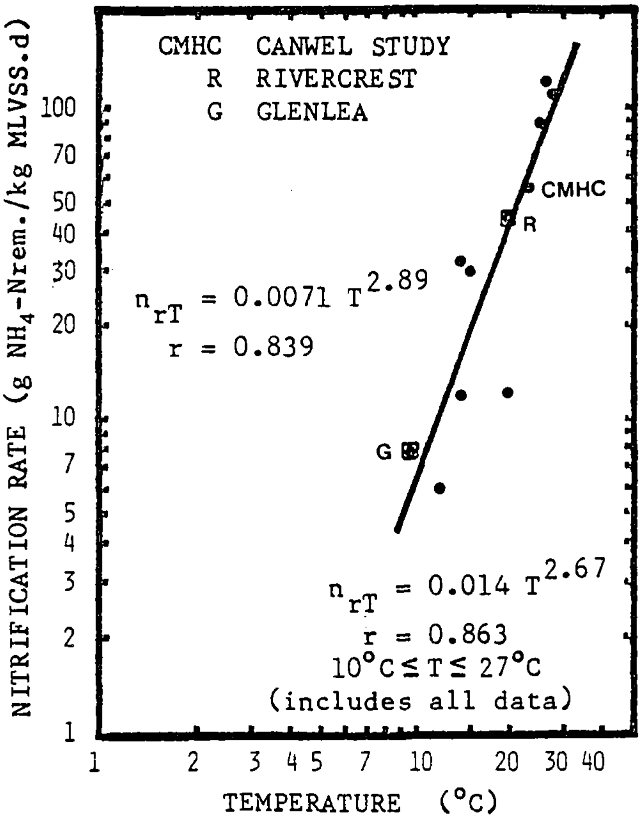

FIGURE 36 COMPARISON OF NITRIFICATION RATE DATA

Inclusion of all data refines the nitrification rate function (22) to:

$$n_{rT}\ 0.014\ T^{2.67} \qquad r = 0.863 \qquad (23)$$

$$10°C \le T \le 30°C$$

The function (23) is plotted on Figure 37 for comparison purposes with data collected by others (14). The observation made by Sutton and Jank (14) that increased SRT results in decreased temperature sensitivity to nitrification is further substantiated by this function.

Figure 38 illustrates the influent and effluent NH_4-N data over the entire process assessment period. Even though the influent NH_4-N concentration varied considerably, the effluent NH_4-N concentration is stable.

The distribution of NO_3-N concentrations are shown in Figure 39. The data are normally distributed with an average value of 31 mg/L with

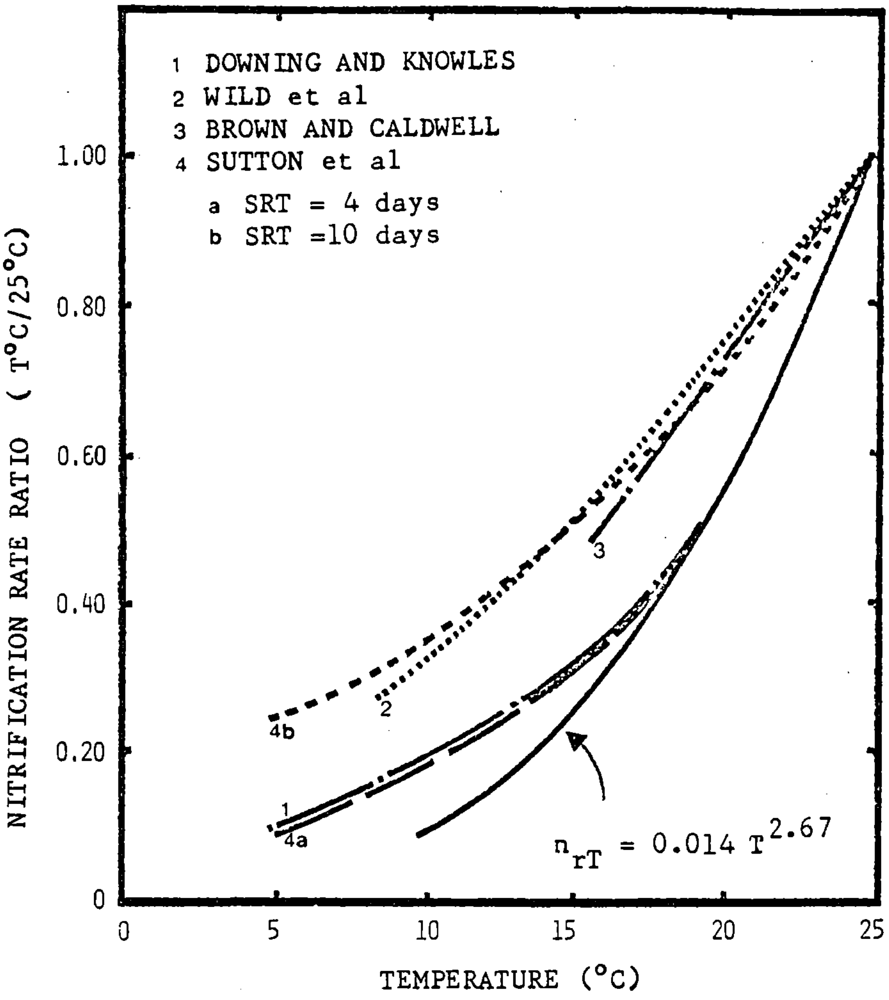

FIGURE 37 DEPENDENCY OF NITRIFICATION RATE ON TEMPERATURE

90% of the observations are equal to or less than 43 mg/L and 10% equal to or less than 18 mg/L. The history of the daily amount of NH_4-N removed and NO_3-N formed during the investigative period is shown in Figure 40. As expected the NO_3-N formed profile pretty well followed the NH_4-N removed profile.

Hydrogen in production, as a result of nitrification, lowered the influent pH of 7.7 to 6.7 in the mixed liquor (Figure 41). The time plot of pH values is shown in Figure 42.

If full nitrification occurs, then the amount of NH_4-N oxidized is for all practical purposes equal to the amount of NO_3-N generated, having a 1 to 1 relationship. Plotting these data for Glenlea (Figure 43), show that a certain amount of denitrification must have occured. As illustrated by the data located to the right of the diagonal (more NH_4-N is removed than NO_3-N generated). Even though the data indicate an effluent pH mean value

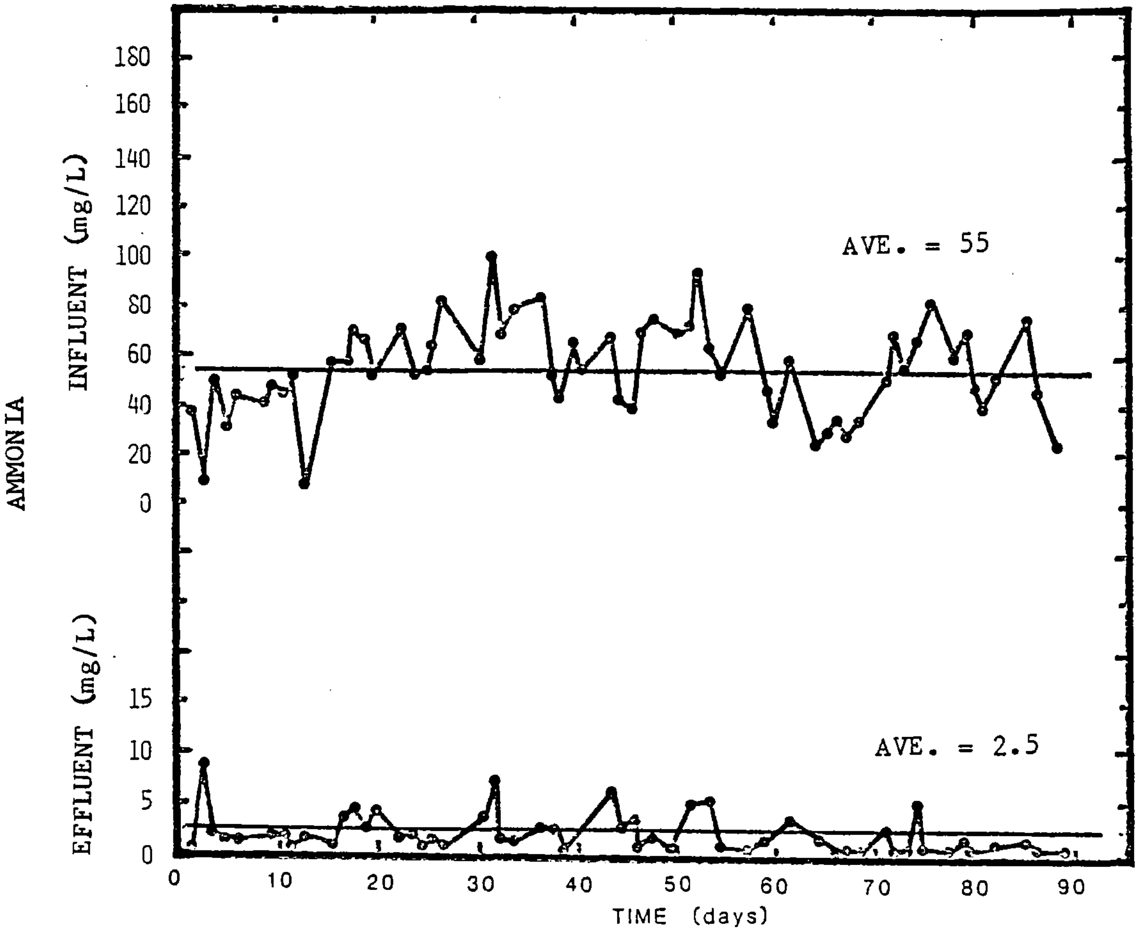

FIGURE 38 INFLUENT AND EFFLUENT NH_4- N VARIATIONS - GLENLEA

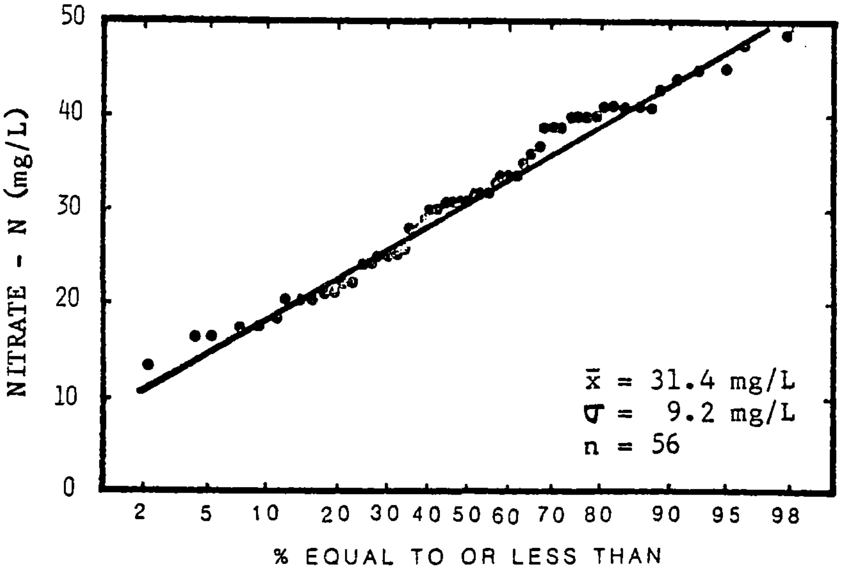

FIGURE 39 NO_3- N PROBABILITY DISTRIBUTION - GLENLEA

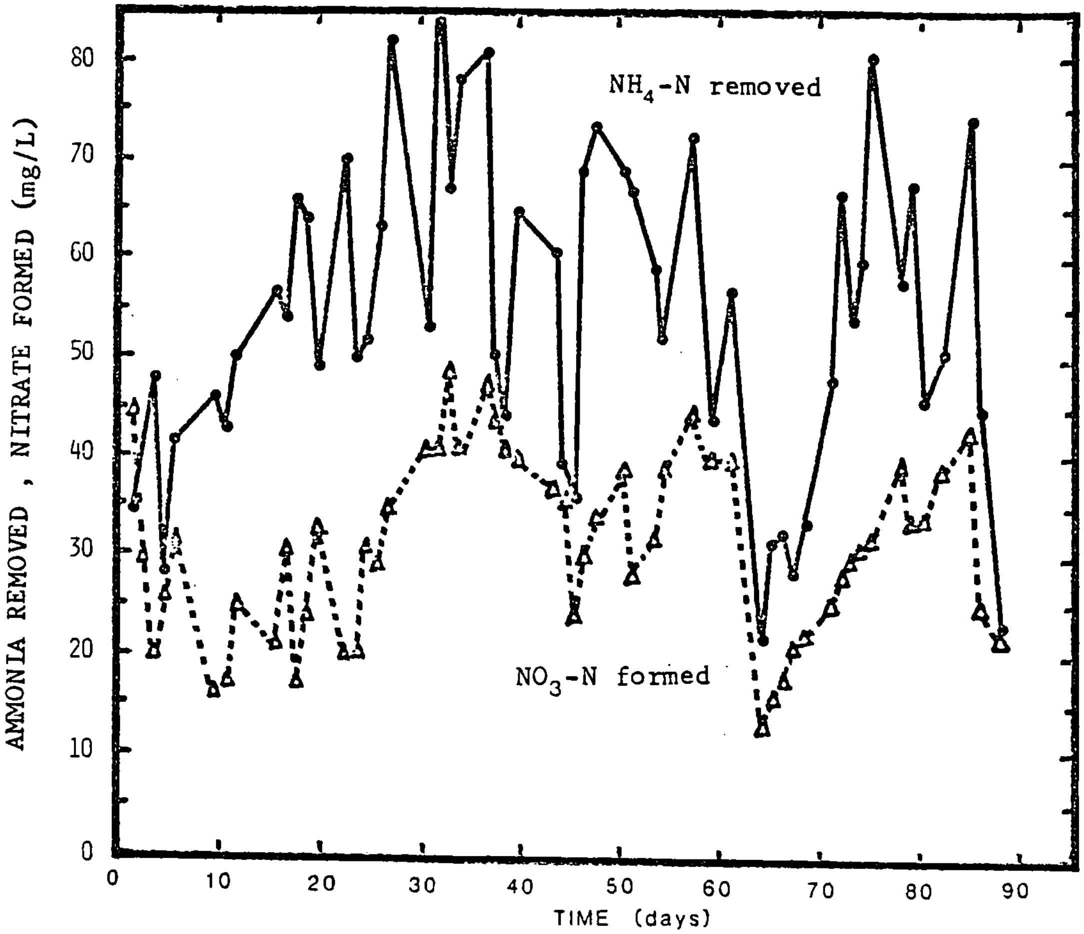

FIGURE 40 NH$_4$- N REMOVED AND NO$_3$- N FORMED - GLENLEA

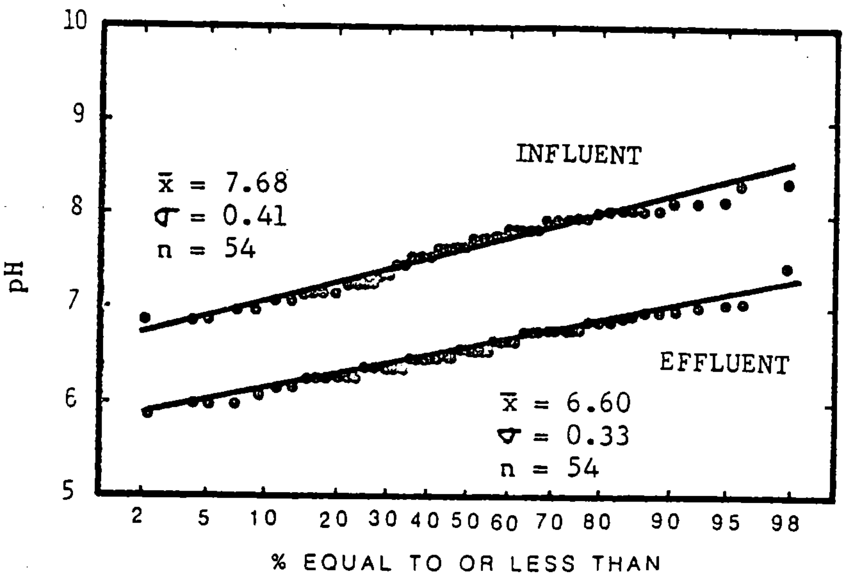

FIGURE 41 INFLUENT AND MIXED LIQUOR pH PROBABILITY DISTRIBUTIONS - GLENLEA

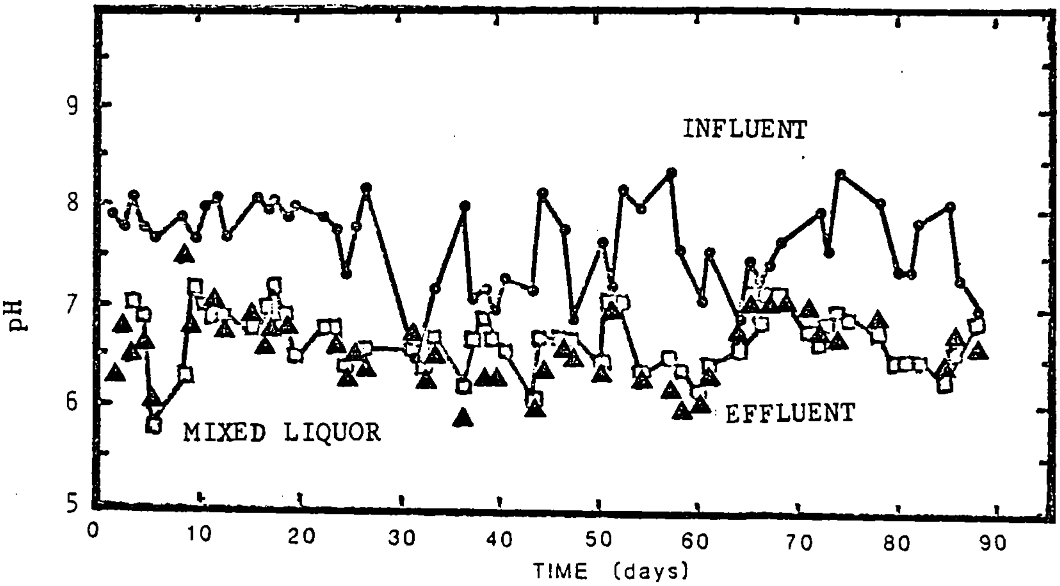

FIGURE 42 INFLUENT, EFFLUENT AND MIXED LIQUOR pH VARIATIONS - GLENLEA

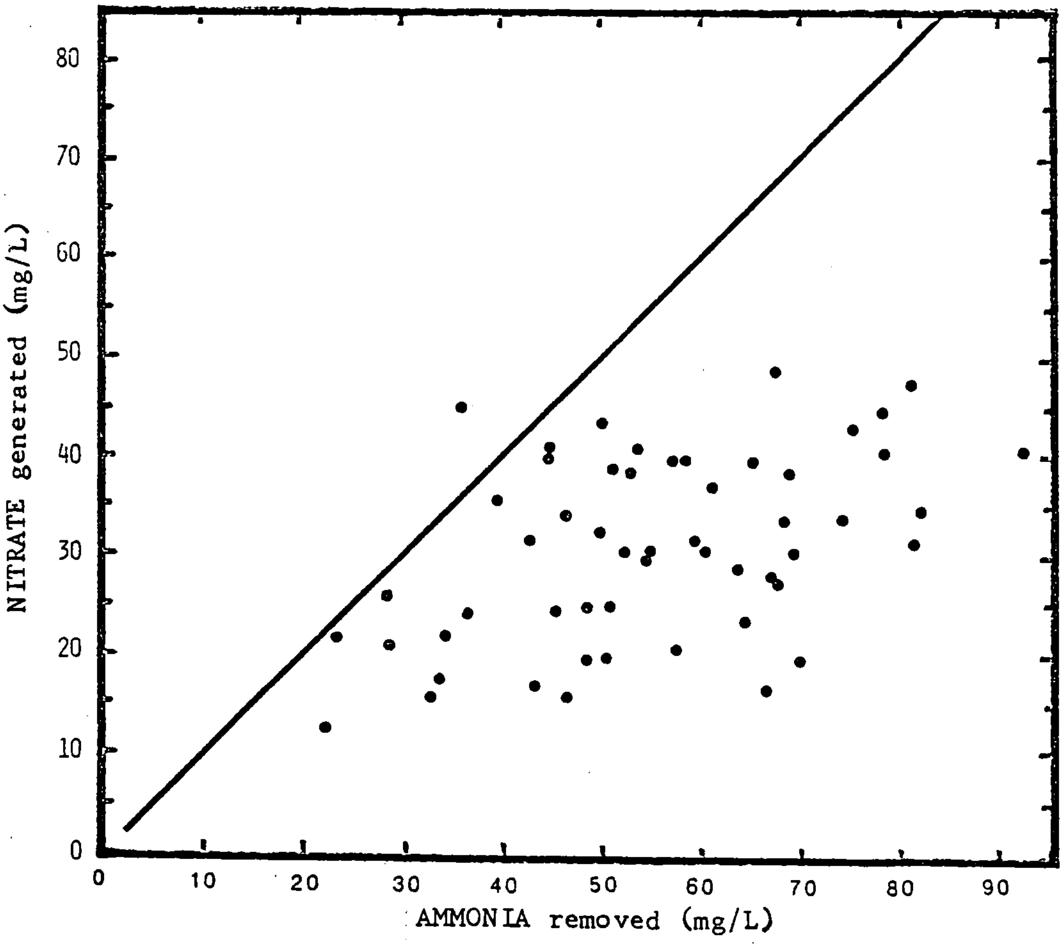

FIGURE 43 NO_3- N GENERATED TO NH_4- N OXIDIZED RELATIONSHIP - GLENLEA of 6.6 which is 0.1 units lower than the mixed liquor pH, it can be shown that at the 95% confidence level the apparent difference is <u>not</u> statistically significant (Appendix D).

4.3.9 Nitrogen removal

Examination of the influent and effluent organic nitrogen data (Figures 44 and 45) indicates a significant removal of organic nitrogen. The data were analyzed using the criterion that events where the organic nitrogen value in the effluent was greater than in the influent would be deleted. As well, one influent organic nitrogen value of 153 mg/L was ignored. It was judged to represent sampling and/or analytical error. The influent mean organic nitrogen was 27 mg/L with 90% of the values being equal to or less than 53 mg/L and 10% equal to or less than 13 mg/L. The effluent organic nitrogen mean concentration was determined to be 8 mg/L with 90% of the values being equal to or less than 20 mg/L and 10% equal to or less than 4 mg/L. This represents an average organic nitrogen removal of 70%.

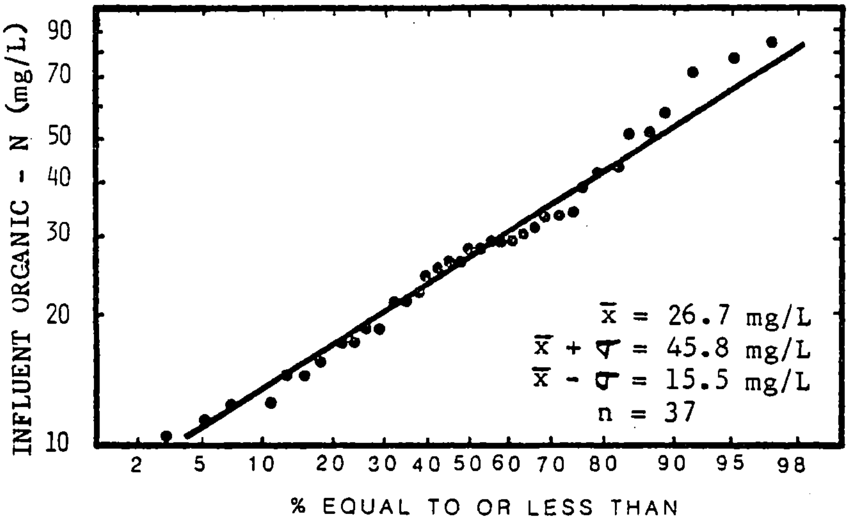

FIGURE 44 INFLUENT ORGANIC NITROGEN PROBABILITY DISTRIBUTION - GLENLEA

On a total Kjeldahl nitrogen (TKN) basis the mean influent concentration was determined to be 79 mg/L (Figure 46) with 90% of the distribution having values equal to or less than 126 mg/L and 10% equal to or less than 32 mg/L. As stated earlier, this is judged to be an extremely strong sewage the reasons for which are unknown. The effluent mean TKN concentration was calculated to be 14 mg/L (Figure 47) with 90% of the values equal to or less than 22 mg/L and 10% equal to or less than 6 mg/L. TKN removal averages 82%.

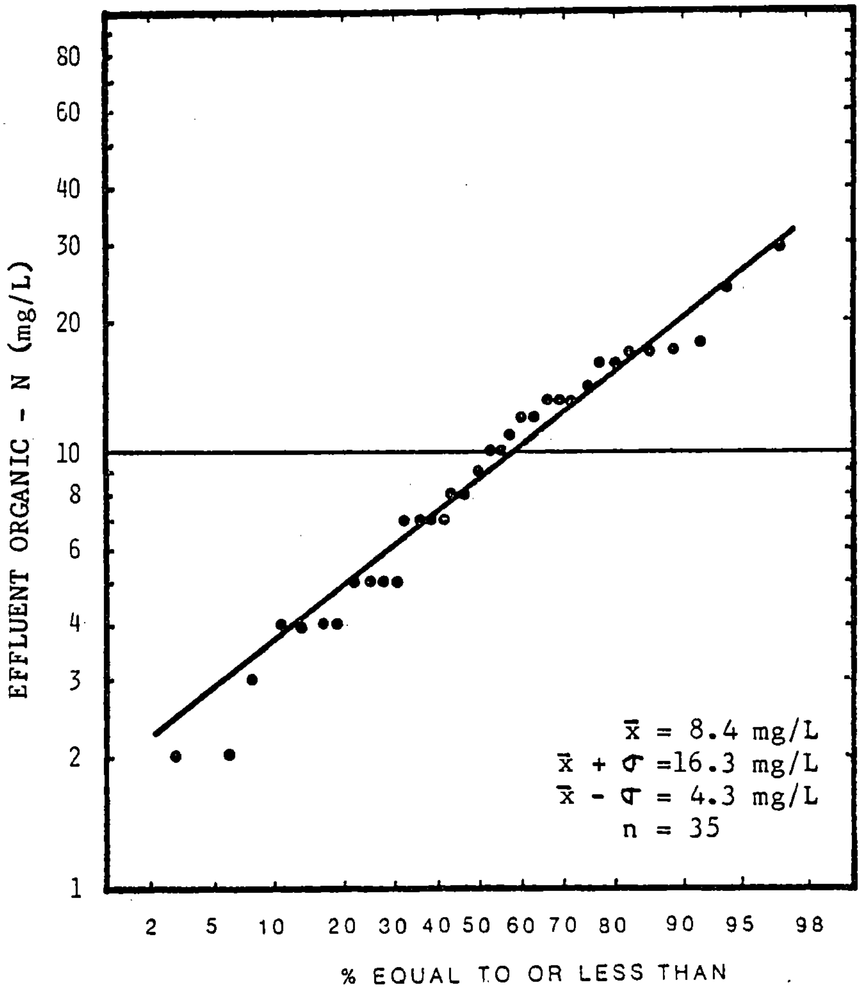

FIGURE 45 EFFLUENT ORGANIC NITROGEN PROBABILITY DISTRIBUTION - GLENLEA

One can finally look at the removal of total nitrogen (TN) by this batch process installation. The total influent nitrogen is in this case the TKN. Thus as shown in Figure 45 the mean influent concentration is 79 mg/L. The effluent TN is represented by:

$$TN = (TKN) + (NO_3 - N) + (NO_2 - N) \qquad (24)$$

The NO_2-N was not determined and for all practical purposes can be taken as zero. The effluent TN is therefore the sum of the effluent TKN and the NO_3-N. Figure 48 shows the effluent TN concentration distribution. The mean value was calculated to be 45 mg/L with 90% of the values being equal to or less than 60 mg/L and 10% equal to or less than 29 mg/L. Total nitrogen removal at Glenlea was therefore 43%.

Because nitrification at the Glenlea installation was consistent, a nitrogen balance for the system can be established (Appendix D).

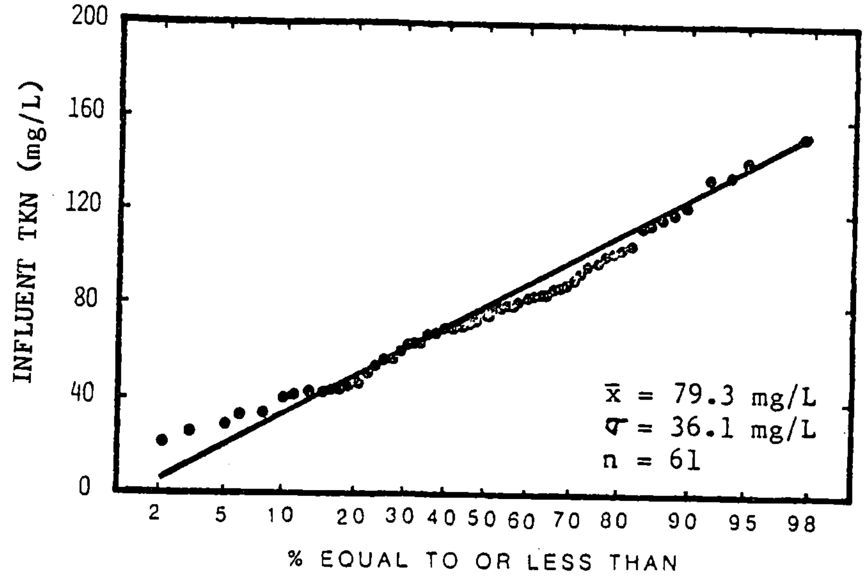

FIGURE 46 INFLUENT TKN PROBABILITY DISTRIBUTION - GLENLEA

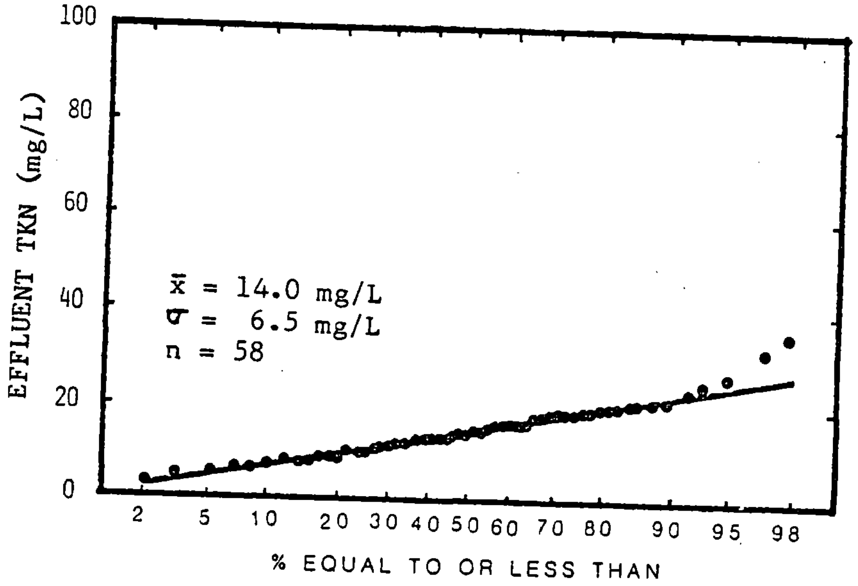

FIGURE 47 EFFLUENT TKN PROBABILITY DISTRIBUTION - GLENLEA

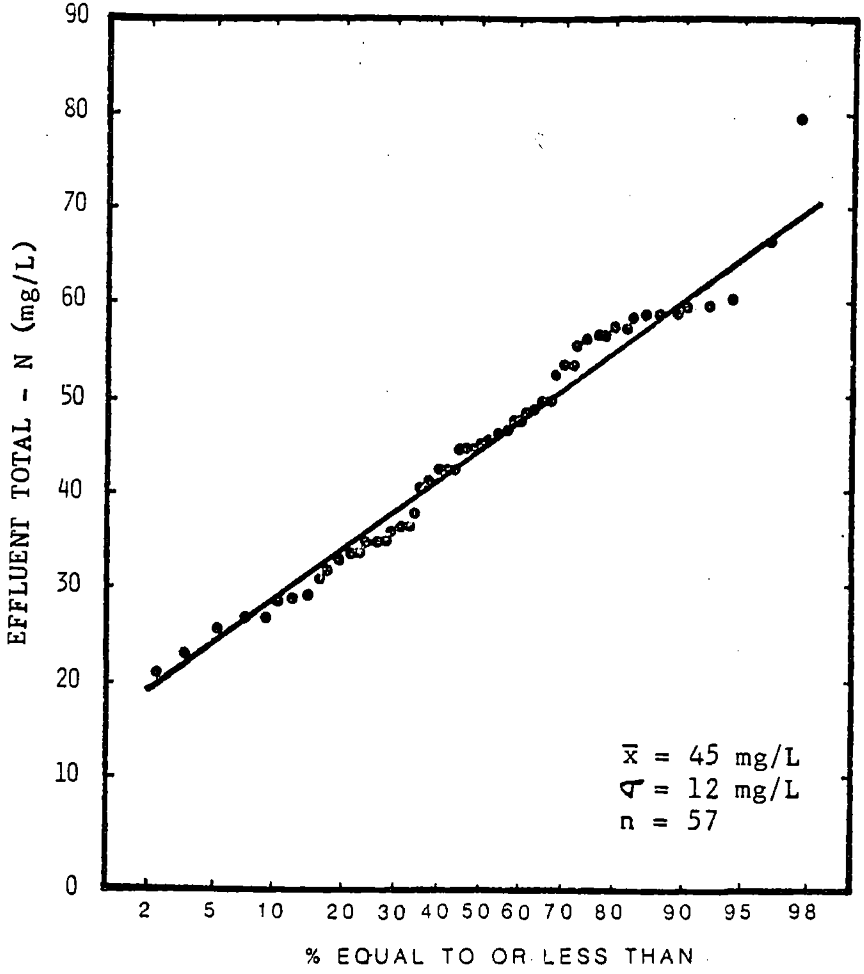

FIGURE 48 EFFLUENT TN PROBABILITY DISTRIBUTION - GLENLEA

Using values of 6.5 and 3.0 for alkalinity lost and generated per mg N oxidized and reduced respectively results in a calculated NO_3-N reduced concentration of 29 mg/L. The values of 6.5 and 3.0 are more in line with what has been observed in practice (11).

The calculated NO_3-N concentration decrease due to denitrification can be used to obtain an estimate of the peak denitrification rate, expressed as kg NO_3-N removed per kg MLVSS per day (r_{DN}).

$$r_{DN} = \frac{(NO_3 - N_r)(Q)}{(MLSS)(\%VS)(V)} \tag{25}$$

where:

NO_3-N_r = oxidized nitrogen concentration decrease, mg/L
Q = average waste flow, m^3/d
MLSS = average mixed liquor suspended solids concentration in reactor, mg/L
% VS = percent volatile solids in reactor, fraction
V = liquid volume in reactor, m^3

substituting the appropriate values into equation (25).

$$r_{DN} = \frac{(22)(4.4)}{(3855)(0.825)(9.1)}$$

$$r_{DN} = 0.0033 \text{ kg oxidized N removed/kg MLVSS.d}$$

$$T = 10^\circ C$$

Comparing this value to data by others (11) as shown in Figure 49, shows that the peak denitrification rate is in the right order of magnitude.

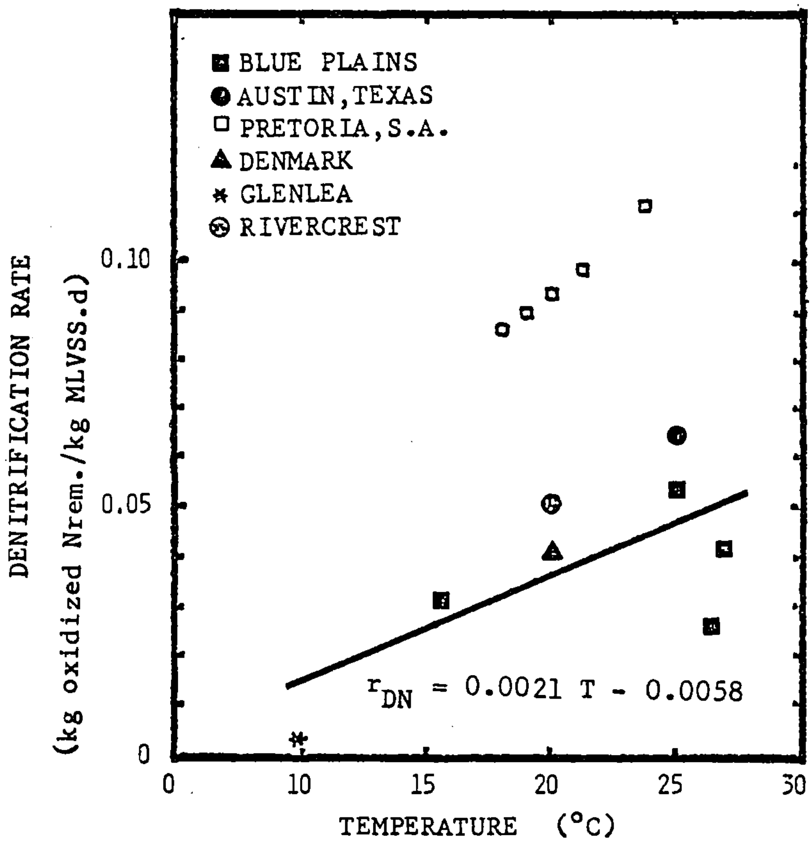

FIGURE 49 EFFECT OF TEMPERATURE ON PEAK DENITRIFICATION RATES WITH WASTEWATER AS A CARBON SOURCE

The data are for combined systems with wastewater as the carbon source. The regressed data fit the equation:

$$r_{DN} = 0.0021\,T - 0.0058 \qquad (26)$$

$$r = 0.667$$

$$10^{\circ}C \leq T \leq 27^{\circ}C$$

where:

T = temperature of liquid, °C

The equation indicates that at a temperature of 3 °C, denitrification ceases.

For denitrification to occur it has been found that a BOD_5/TKN ratio of approximately 3.5 is required (i.e. sufficient carbon must be present). Figure 50 shows that the mean BOD_5/TKN ratio for the Glenlea sewage is 3.5. 90% of the distribution having values equal to or less than 6.9 and 10% equal to or less than 1.85.

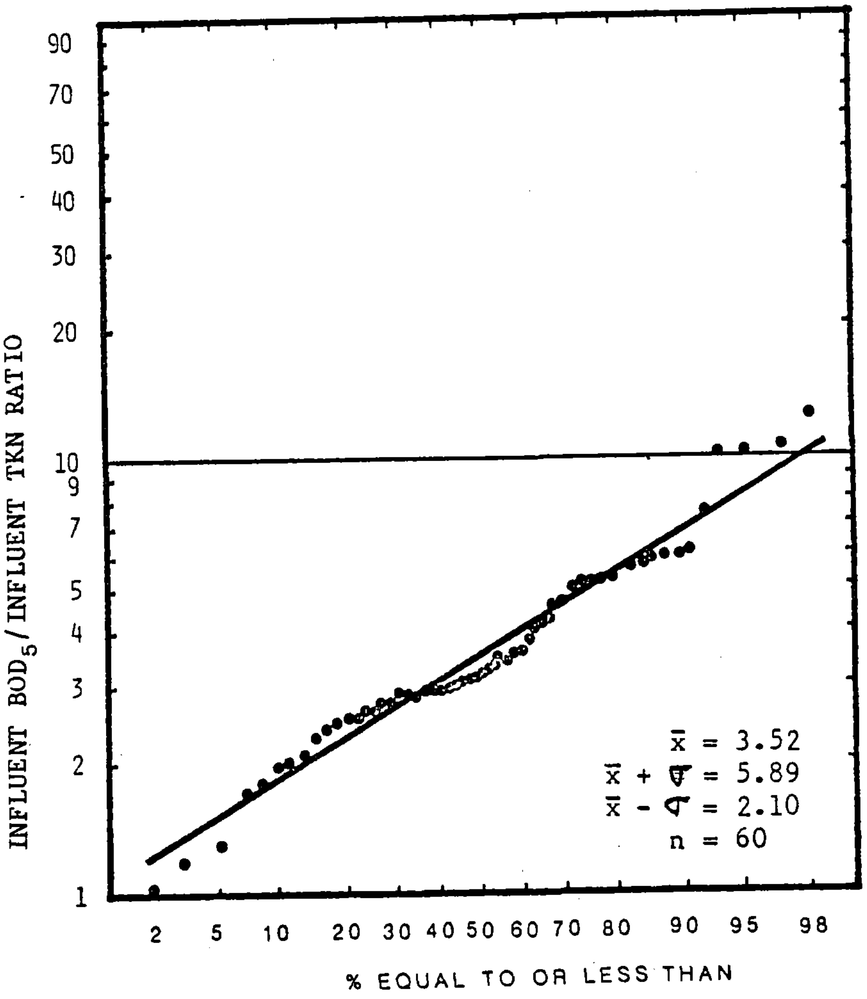

FIGURE 50 BOD_5/TKN RATIO PROBABILITY DISTRIBUTION - GLENLEA

From the analysis of factors involved in biological nitrification and denitrification it is concluded that all process requirements for full nitrification and denitrification are present. All that remains to be done is optimize the operation of the installation by adjusting the fill/react/settle/decant cycle times. It should be noted again that there was no requirement for any process optimization. The analysis of the data merely illustrates that a high degree of both carbon and nitrogen removal can be accomplished. It is important to point out that for nitrification the aeration equipment must be able to satisfy the nitrogenous oxygen demand. As stated earlier the process upgrading objective was to produce a 30/30 effluent. Full denitrification is possible and is only a matter of instituting the appropriate operational strategy. For example, a stir only cycle following the aeration cycle will denitrify the effluent. This again illustrates the desirability of striving for process flexibility by selecting equipment which will permit separation of aeration and mixing so that each may be controlled independently as required. While some of these aspects may be beyond the requirements of very small installations (i.e. < 10 m^3/d) and unnecessarily complicate the operation of those installations, they should be of particular interest to the process design engineer when dealing with larger, domestic installations and industrial applications.

4.3.10 Phosphorus removal

Quite unexpectantly biological phosphorus removal exceeding 50% was observed. As shown in Figure 51 the influent TP average concentration was

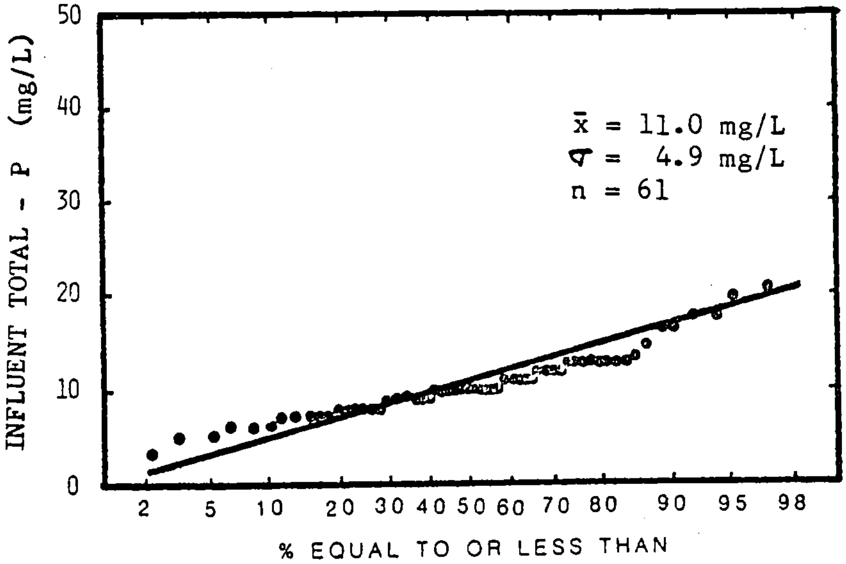

FIGURE 51 INFLUENT TP PROBABILITY DISTRIBUTION - GLENLEA

calculated to be 11 mg/L with 90% of the observations equal to or less than 17 mg/L and 10% equal to or less than 5 mg/L. The effluent TP data distribution indicates an average effluent concentration of 5.4 mg/L. 90% of the observations were equal to or less than 8 mg/L and 10% equal to or less than 3 mg/L (Figure 52).

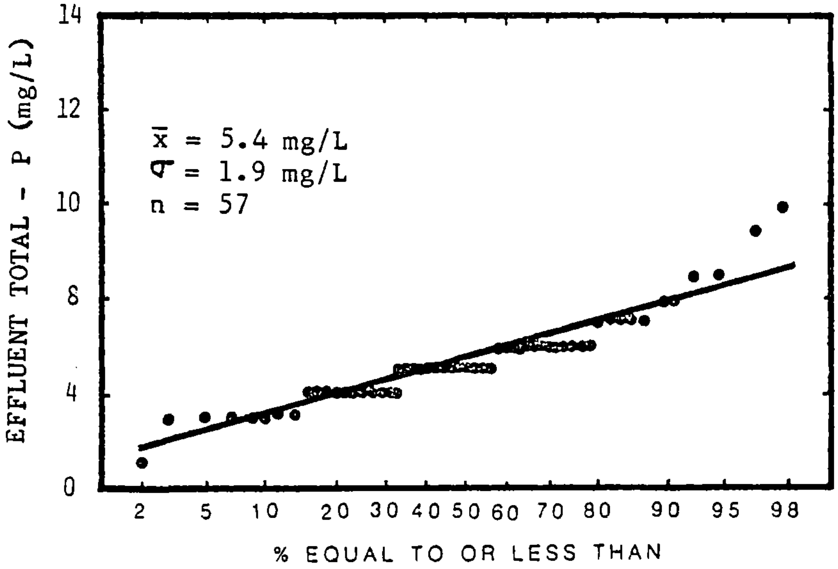

FIGURE 52 EFFLUENT TP PROBABILITY DISTRIBUTION - GLENLEA

The phosphorus concentration decrease due to cell synthesis is calculated from knowing that approximately 5% by weight of phosphorus is required for cell synthesis (15). The biomass production (Figure 19) averaged 570 g/d.

Therefore, mass of P required for cell synthesis = 570 g/d x 0.05
= 29 g/d

The daily P concentration reduction is calculated as:

$$\frac{29\ \text{g/d}}{4.4\ \text{m}^3/\text{d}} = 6\ \text{mg/L}$$

Thus, 6 mg/L TP decrease can be attributed to cell synthesis alone. On a mass balance basis:

$$TP_{in} = TP_{out} + TP_{cells} \qquad (27)$$

$$11\ \text{mg/L} = 5\ \text{mg/L} + 6\ \text{mg/L}$$

(Figure 51) (Figure 52) (calculated)

All of the phosphorus is accounted for.

The influent and effluent TP concentrations during the course of this process assessment program are summarized in Figure 53. The TP concentration in the effluent is extremely stable.

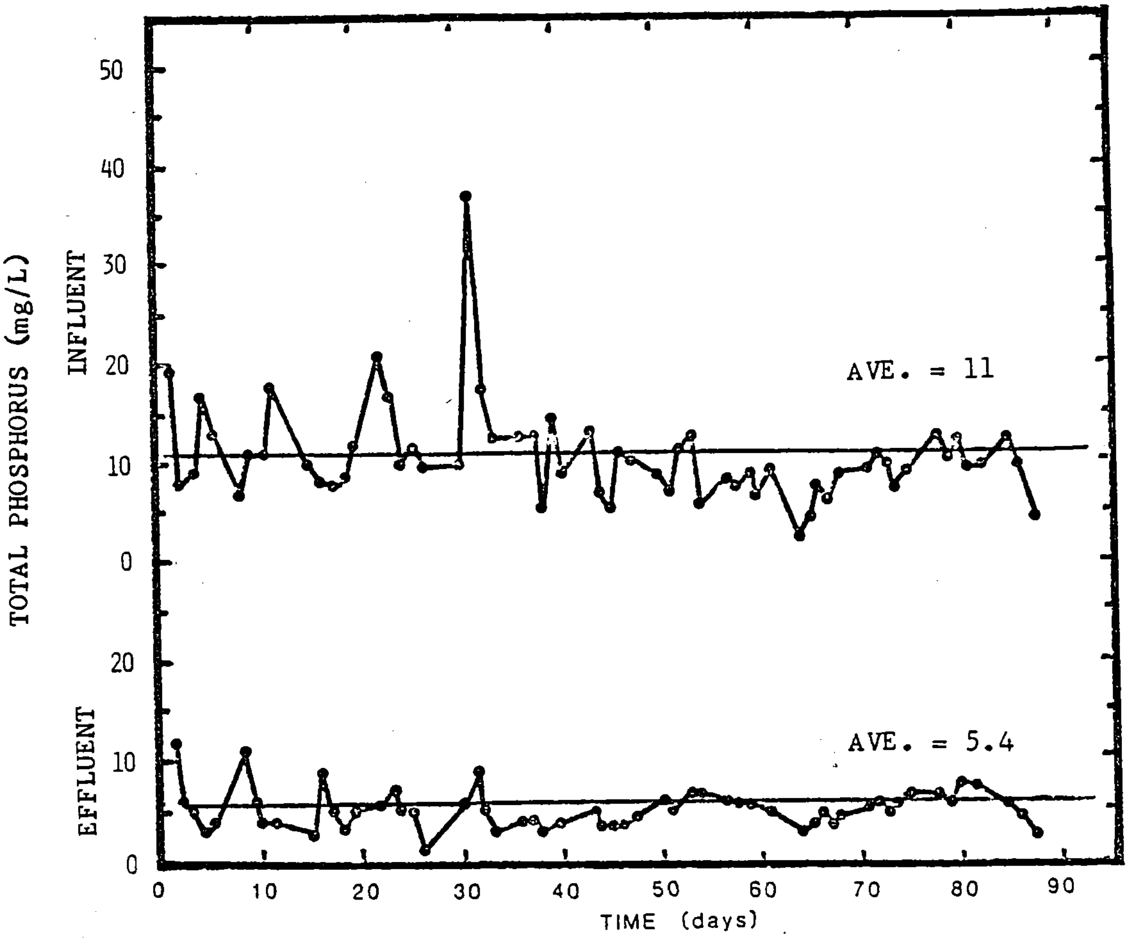

FIGURE 53 INFLUENT AND EFFLUENT TP VARIATIONS - GLENLEA

As with denitrification, more controlled conditions, coupled with a different operating strategy may further enhance biological phosphorus removal.

4.4 Energy & Mixing Requirements

Most waste treatment processes require an external energy input for driving pumps, compressors and rotors. For larger treatment plants these components are sized using conventional design methodology. Small systems usually are designed with excess available motive power. This is governed by two considerations:

1. expectation of large variations in both hydraulic and organic load
2. smallest reasonably sized available unit which is readily available.

It is not surprising therefore that correlations between installed power and hydraulic flow or organic load for small plants are scarce. They are also site specific. In spite of these shortcomings an attempt has been made to at least summarize this information for the Glenlea plant so that it may serve as a reference point.

The following data apply:

Hydraulic load (m^3/d)	4.4
Organic load (kg BOD_5/d)	1.1
Organics removed (kg BOD_5/d)	1.1

Connected power (Appendix C):

Compressor (kW)		1.12
Effluent pumps (kW)		0.25
Sludge pumps (kW)		0.37
	Total	1.74 kW

The total connected power at Glenlea is 1.74 kW. Knowing the running times for the compressor and pumps permits calculation of the daily power use.

Compressor run time per day	22.4 h
Effluent pumping time per day	0.5 h

Correlation of this information with the connected power results in power used as follows:

Compressor (22.4 h x 1.12 kW)	25.1 kWh
Pumps (0.5 h x 0.25 kW)	0.1 kWh
Total daily power drawn	25.2 kWh

(Use of sludge pumps is only once every 20 days, therefore power drawn is negligible)

No allowances for either electrical or mechanical efficiencies of the process components are included.

The above information can be used to express process power requirements on a more standardized basis such as energy per unit organic or volumetric load. This permits comparisons to be made with other, similar systems:

22.9 kWh/kg BOD_5 applied
or 22.9 kWh/kg BOD_5 removed
or 5.73 kWh/m^3 of waste

(No aerobic digestion of waste sludge.)

Another important consideration is how much aeration energy is required per unit of substrate removed. For Glenlea this is calculated at 22.8 kWh/kg BOD_5 removed. This indicates that almost 100% of the total energy requirements are associated with aeration only.

Since the MLSS in the reactor must be kept in suspension and the tank contents should be uniformly mixed, energy input per unit liquid volume has been used as a mixing parameter. From the information for Glenlea it can be calculated that the mixing energy input is 0.12 kW/m^3.

Air supply for diffused aeration systems can also be related to quantity of air supplied per unit substrate removed. Experience has shown that for various process loadings the air requirements are (16):

for $F/M > 0.3$: 30 - 55 m^3 air/kg BOD_5 removed
for $F/M < 0.3$: 75 - 155 m^3 air/kg BOD_5 removed

For Glenlea at an $F/M < 0.3$ the air supplied can be calculated as 875 m^3/kg BOD_5 removed. Clearly, a more than adequate air supply is available.

Air supply can also be expressed on a volumetric basis (waste flow). For domestic waste and diffused aeration systems this generally lies in the range of 3.75 - 15 m^3 air/m^3 of waste. The rule of thumb is 7.5 m^3 air/m^3 waste (17). Generally this is accompanied by a safety factor of 2. Thus setting 15 m^3 air/m^3 waste as a reasonable air supply goal.

For Glenlea the air supply was calculated to be 219 m^3 air/m^3 waste. Again, there will be no lack of process air (219 >> 15).

Since solids must be kept in suspension another way of expressing mixing would be on a quantity of air supplied per unit time per unit mass of MLSS. For Glenlea this parameter is computed to be 1.22 m^3 air/h.kg MLSS. All of the energy and mixing parameters are summarized in Table 4.

4.5 Retrofitting Costs

The retrofitting capital costs associated with the conversion of the original facility can not be assessed. The reason for this is that the Glenlea treatment plant, being small in size, was considered to be an ideal candidate for a demonstration of batch reactor technology. The conversion costs were entirely absorbed by Dr. Topnik, the original proponent of using batch reactors for upgrading existing poorly functioning plants.

Costs will be reported for the other installations discussed in later sections of this report.

TABLE 4 - ENERGY AND MIXING PARAMETER SUMMARY - Glenlea

PARAMETER	UNITS	VALUE
Total Connected Power	kW	1.74
Total Energy Used	kWh/d	25.2
Total Energy Used/Unit Substrate Applied	kWh/ kgBOD$_5$ applied	22.9
Total Energy Used/Unit Substrate Removed	kWh/ kgBOD$_5$ removed	22.9
Total Energy Used/Unit Waste Flow Treated	kWh/ m^{3}waste	5.73
Aeration Engery Used/ Unit Substrate Removed	kWh/ kgBOD$_5$removed	22.8
Mixing Energy Input/ Unit Liquid Volume	kW/m^3	0.12
Air Supplied/Unit Substrate Removed	m^3/kg BOD$_5$ removed	875
Air Supplied/Unit Waste Flow Treated	m^3/m^3	219
Air Flow Rate/Unit MLSS	m^3/h.kg MLSS	1.22

4.6 Operator Requirements

It is well known that all treatment plants require operator attention. The degree of operator attention and skill level requirement can be correlated with process complexity.

Batch reactors are uncomplicated. The whole process is regulated by timers and float actuated switches. Operator attention is only required periodically to check for hot motors, lubrication and tripped fuses. Assessing sludge settleability (SVI) and associated sludge wasting requirements can be done on a twice weekly basis.

Once the operator or person charged with the responsibility of ensuring that the treatment plant operates satisfactorily has become familiar with the operation of the plant, he/she will quickly establish a timetable for performing the various tasks indentified. For example, the sludge settleability (SVI) test would be conducted more frequently as more biomass builds up in the system and a requirement for sludge wasting is approached.

At Glenlea, the operator is not exclusively assigned to plant maintenance duties. He only spends a couple of minutes daily in the plant. Because few problems are ever encountered, there is a great danger that the operator gets lulled into a false sense of security which in an extreme situation can result in forgetting about the plant altogether.

To forestall this, all installations are provided with a brief operations manual describing the particular installation, how the process functions and what maintenance and operational tasks should be performed routinely (Appendix A).

4.7 Operations Problems

Operation problems at Glenlea are directly related to mechanical equipment servicing requirements. Attention must be directed to motor, pumps and electrical components to ensure that they are always in good working order.

The only process concern at Glenlea, as well as the other plants tested, is that sludge wasting be practiced on a regular basis. Without solids wasting control, the process will discharge solids eventually. An SRT of infinity is impossible.

Plant operational problems experienced during the test period include:

1. The air ejector lift station malfunctioned due to a corroded control probe. (One occurence).
2. A manhole located below grade allowed high infiltration flows to enter the plant during spring run-off.
3. The effluent 0.25 kW centrifugal pump clogged with a small piece of plastic (one occurence) and with hair (2 occurences).
4. The absence of pretreatment facilities allowed the entry of trash such as plastic, heavy paper and rubber materials that frequently clogged the sludge pump.
5. Experience has shown that if sludge is not wasted at least once per month mixed liquor solids carry over will occur. At Glenlea a portable pump for sludge removal was used. Sometimes this pump was removed from the plant to be used elsewhere. A permanent convenient sludge pump set-up is mandatory for reliable operation.

4.8 Process Assessment Summary

The various data reported on for the Glenlea installation in the previous sections are summarized in Tables 5 to 7.

The information in the Tables also identifies the number of observations associated with each parameter and the resulting type of data distribution. As well, if one set of data depict more than one distribution, this is noted.

Table 5 summarizes the influent waste characteristics for the Glenlea installation, Table 6 the process parameters and Table 7 the effluent waste characteristics.

TABLE 5 - INFLUENT CHARACTERISTICS - Glenlea

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN 10%	50%	90%	NO. OF OBSERV-ATIONS n	TYPE OF DATA DISTRIBUT.
Flow	m^3/d	1.5	4.4	7.3	60	NP*
Temp.	°C	6.5	8.5	10.5	53	NP
BOD_5(total)	mg/L	134	251	468	61	LNP**
BOD_5(sol.)	mg/L	47	138	246	56	NP[1]
SS	mg/L	96	152	337	62	NP[1]
BOD_{5T}/SS	-	0.95	1.59	2.65	61	LNP
Alkalinity	mg/L	200	314	430	62	NP
BOD_{5T}/TKN	-	1.85	3.50	6.90	60	LNP
TKN	mg/L	32	79	126	61	NP
NH_4-N	mg/L	31	55	80	61	NP
Org-N	mg/L	13	27	53	37	LNP
TP	mg/L	5	11	17	61	NP
pH	-	-	7.7	-	-	-
BOD_5:N:P	-	100:24:4	100:31:4	100:27:4	-	-

* NP = normal probability

** LNP = log normal probability

[1] break in distribution

TABLE 6 - PROCESS PARAMETERS - Glenlea

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN			NO. OF OBSERV-ATIONS	TYPE OF DATA DISTRIBUT.
		10%	50%	90%	n	
MLSS	mg/L	2930	3855	4800	56	NP
VSS	%	79	82.5	86	61	NP
Temp.	°C	8.2	9.75	11.4	52	NP
SVI	ml/g	90	117	145	56	NP
Organic Loading	g BOD_5/kg MLSS.d	12	25	54	55	LNP
Alk_{rem}/ NH_4-N_{rem}	-	3.7	4.8	6.3	58	LNP
Volumetric Loading	g BOD_5/m^3d	-	122	-	-	-
NH_4-Nappl./ MLVSS.d	g NH_4-N/ kg MLVSS.d	2.8	7.8	15.5	55	NP[1]
NH_4-N_{rem}./ MLVSS.d	g NH_4-N/ kg MLVSS.d	3.2	7.8	15.5	49	NP1
Organic Loading (F/M)	g BOD_5/kg MLVSS.d	-	30	-	-	-
Organic Loading (F/M)	g BOD_5/sol kg MLVSS.d	-	16	-	-	-

TABLE 7 - EFFLUENT CHARACTERISTICS - Glenlea

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN 10%	50%	90%	NO. OF OBSERVATIONS n	TYPE OF DATA DISTRIBUT.
BOD_5(total)	mg/L	3	5	7	54	LNP
BOD_5(sol.)	mg/L	0	3	5	57	NP
SS	mg/L	1	6	10	57	NP
Alkalinity	mg/L	22	56	90	57	NP
TKN	mg/L	6	14	22	58	NP
NH_4-N	mg/L	1	2	6	57	NP
Org-N	mg/L	4	8	20	35	LNP
NO_3-N	mg/L	18	31	43	56	NP
TN	mg/L	29	45	60	57	NP
TP	mg/L	3	5	8	57	NP
pH	-	-	6.6	-	-	

5 HUDSON BAY MINING AND SMELTING INSTALLATION

5.1 Process Description

This plant is a retrofitted, enclosed conventional extended aeration package plant sized to handle a flow of 50 m^3/d generated by the mining staff and a cafeteria. The installation is located at the Spruce Point Mine of Hudson Bay Mining & Smelting Company. Plant performance had been erratic. Effluent BOD_5 values varied from 75 to 5 mg/L, and effluent SS values from 120 mg/L to 1 mg/L.

The retrofitting consisted of using the intregral clarifier as a raw sewage transfer tank and the original aeration basin as the batch reactor which was automatically controlled to operate on the conventional fill, aerate, settle and draw cycles. A separate, 4.5m^3 tank, located adjacent to the plant served as the aerobic sludge digestor. Figure 54 is the process schematic (see Appendix C for equipment sizes).

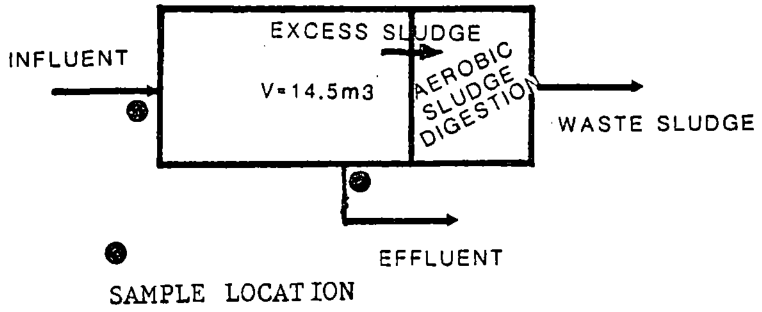

FIGURE 54 HUDSON BAY MINING AND SMELTING BATCH REACTOR INSTALLATION

Originally the sewage was relatively strong (240 mg/L). Later, when the monitoring program started, the cafeteria had been shut down and the sewage now going to the plant was only due to the water from shower use and toilet facilities after each of 3 shifts at the mine. The sewage is equalized.

5.2 Sampling Program

For the purpose of process assessment parameters as summarized in Table 8 were determined from influent, effluent and mixed liquor grab samples.

TABLE 8 - SAMPLES AND PARAMETERS ANALYSED

PARAMETER	SAMPLE		
	Influent	Effluent	Mixed Liquor
BOD_5 (total)	*	*	
SS	*	*	
Alkalinity	*	*	
TKN	*	*	
NH_4-N	*	*	
NO_3-N		*	
TP	*	*	
MLSS			*
% VS			*
Settleable Solids			*

A total of 11 grab samples of the process influent, effluent and mixed liquor were taken. The sampling period extended over 5 months, from June 2 to October 25, 1983. No samples were taken during September.

All analyses were done in accordance with Standard Methods (7).

5.3 Process Observations and Results

The process analyses concern BOD_5 reduction (total and soluble), SS removal effectiveness, nutrient removal and general process stability. Sludge settleability as well as process and aeration energy requirements are also evaluated.

5.3.1 Flow

The major portion of the hydraulic flow for the Hudson Bay Mining and Smelting treatment plant was generated at the end of each of three daily shifts. The major source was shower water. No continuous flow monitoring was conducted. Based on observation of pumping cycles, the flow ranged between 18.2 and 27.2 m^3/d. An average hydraulic load to the plant of 22.7 m^3/d was used for the hydraulic rating of the plant.

5.3.2 Biochemical oxygen demand

Influent BOD_5 concentrations varied from a low of 30 mg/L to a high of 107 mg/L, with a mean concentration of 54 mg/L. These values are characteristic of a grey water sewage where most of the organic load originates with showers taken by the workers at the conclusion of their shift. Figure 55 shows the influent BOD_5 data on a probability distribution basis. 90% of the observations are equal to or less than 91 mg/L and 10% less than or equal to 32 mg/L. As with the Glenlea influent BOD_5 data, this distribution too is log normally distributed.

An attempt was made to determine the influent soluble BOD_5 fraction. As shown in Figure 56 the best fit equation for the data is:

$$BOD_{5in} = 49 + 0.10\ SSi \qquad (28)$$

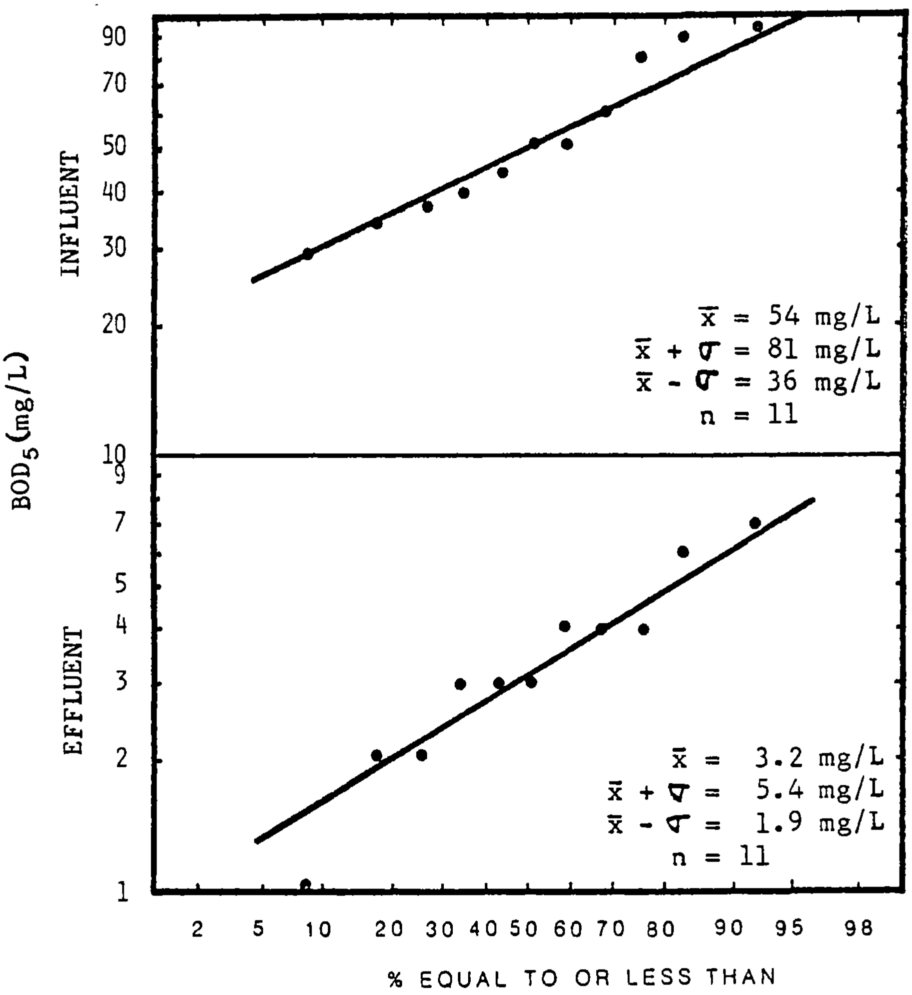

FIGURE 55 INFLUENT AND EFFLUENT BOD$_5$ PROBABILITY DISTRIBUTION - HBM&S

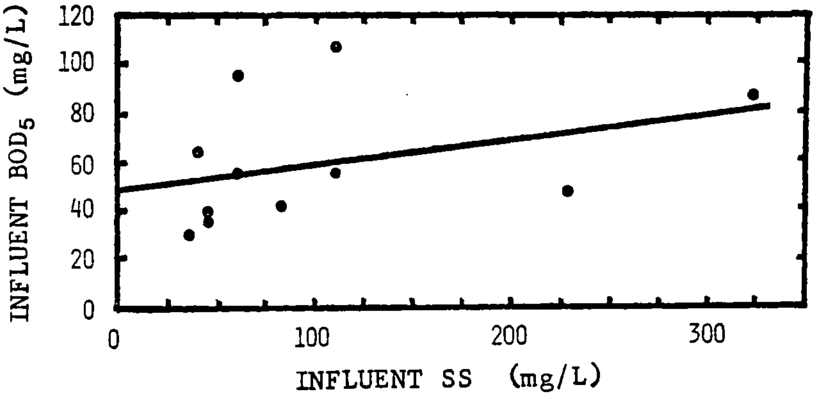

FIGURE 56 INFLUENT BOD$_5$ AND INFLUENT SS CORRELATION - HBM&S

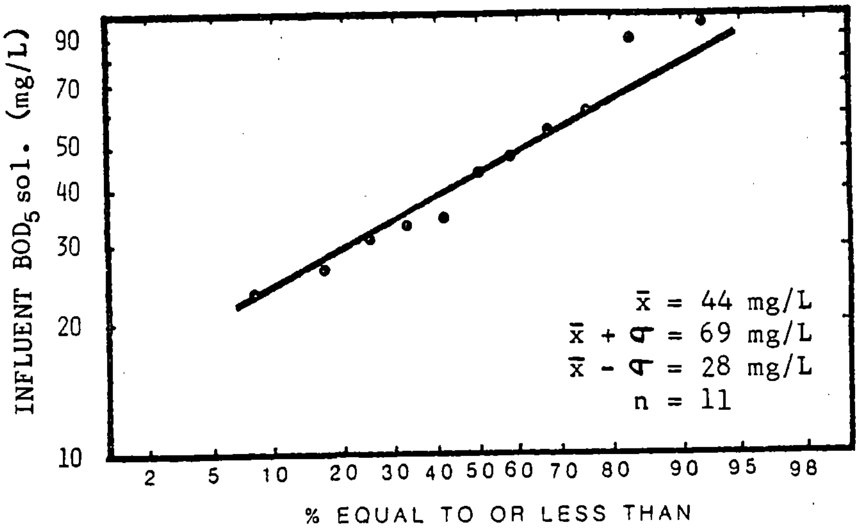

FIGURE 57 INFLUENT SOLUBLE BOD_5 PROBABILITY DISTRIBUTION
- HBM&S

Equation (33) shows that the soluble BOD_5 is 49 mg/L and that approximately only 10% of the influent SS contribute to the total BOD_5. This is not surprising since the influent is a grey water. This information can be used to estimate the soluble BOD_5 fraction of the influent as shown in Figure 57; 90% of the soluble BOD_5 values are less than or equal to 79 mg/L and 10% less than or equal to 24 mg/L. The mean soluble influent BOD_5 is 44 mg/L.

Effluent total BOD_5 concentrations are shown in Figure 55. The mean effluent BOD_5 is approximately 3 mg/L, with 90% of the observations being less than or equal to 6 mg/L and 10% less than or equal to 2 mg/L. Similar to the influent soluble BOD_5 determination the effluent soluble BOD_5 was calculated as shown in Figure 58. The best fit line for the data is described by the equation:

$$BOD_{5e} = 3.0 + 0.12\ SS_e \qquad (29)$$

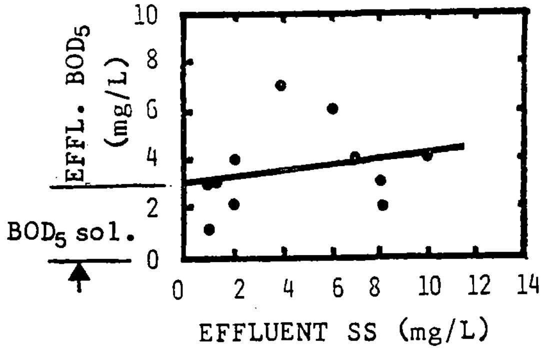

FIGURE 58 EFFLUENT BOD_5 vs EFFLUENT SS
CORRELATION - HBM&S

Equation (34) shows that only 12% of the solids fraction contributes to the effluent BOD_5. It is interesting to note that the solids fraction contributing to the BOD_5 has increased from 10% as noted in the influent to 12% in the effluent. This is explained by the fact that the soluble BOD_5 was converted to biomass thus increasing the organic fraction of the solids. The soluble BOD_5 as shown by equation (34) is 3.0 mg/L. When comparing with the influent soluble BOD_5, this represents a soluble substrate conversion efficiency of 94%. The effluent total BOD_5 and the effluent soluble BOD_5 concentrations are equal (3mg/L). The BOD_5 contribution by the effluent suspended solids is negligible at effluent SS concentrations of less than 4 mg/L.

To check on this substrate conversion calculation and more specifically the value of the effluent soluble BOD_5, equation (3) as noted earlier was used:

$$BOD_5\,\text{sol.} = \frac{BOD_5}{(k_m t + 1)} \qquad (3)$$

For a standard domestic sewage the substrate conversion rate constant (k_m) was assumed to be 15/h. Based on experience it was assumed that for the very dilute sewage k_m will be lower. A value of 7.5/h at 20 C was used.

The average liquid temperature was 22 °C. The reaction rate constant (k_m) must be corrected to the prevailing temperature using equation:

$$k_{mT} = k_{m20}\,(1.072)^{(T - 20)} \qquad (4)$$

Using equations (3) and (4)

$t = 3.4h$

$k_{m20} = 7.5/h$

$BOD_5in = 54$ mg/L

$T = 22°C$

When considering the many assumptions made, the calculated effluent soluble BOD_5 concentration of 1.8 mg/L compares extremely well with the calculated mean effluent soluble BOD_5 of 2.6 mg/L as shown in Figures 58 and 59.

$$\text{EFFLUENT } BOD_5\,\text{sol.} = \frac{54}{(8.6\,(3.4) + 1)} = 1.8\ \text{mg/L}$$

Figure 59 shows the distribution of calculated soluble effluent BOD_5 concentrations. The mean value is 2.6 mg/L, with 90% of the values being equal to or less than 5 mg/L and 10% of the values being equal to or less than 1 mg/L.

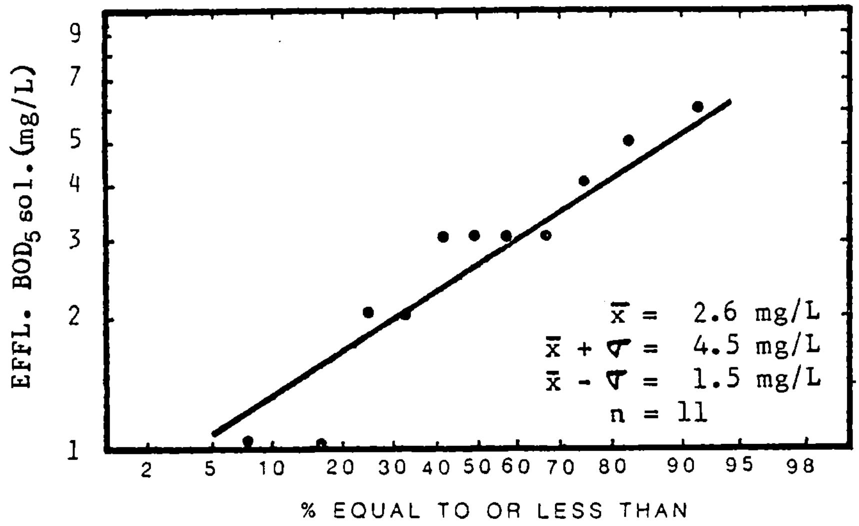

FIGURE 59 EFFLUENT SOLUBLE BOD_5 PROBABILITY DISTRIBUTION - HBM&S

The variations in influent and effluent BOD_5 concentrations over the investigative period are shown in Figure 60. The effluent BOD_5 stability in spite of 3 fold variations in influent BOD_5 concentrations is well illustrated.

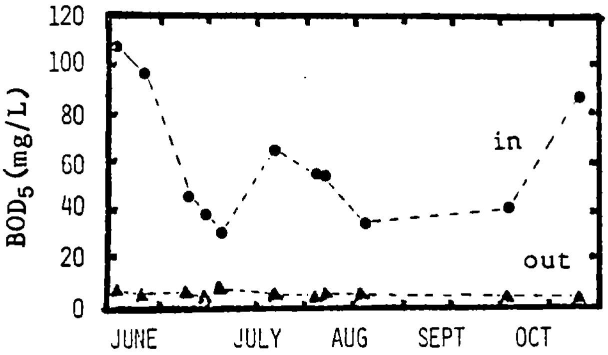

FIGURE 60 BOD_5 CONCENTRATIONS - INFLUENT AND EFFLUENT - HBM&S

5.3.3 Process loading

As shown in Figure 61 the calculated mean F/M value (g BOD_5 applied/kg MLVSS.d) is 52. Ninety percent of the F/M observations are equal to or less than 72 and 10% equal to or less than 37. The organic loading is typical for extended aeration plants.

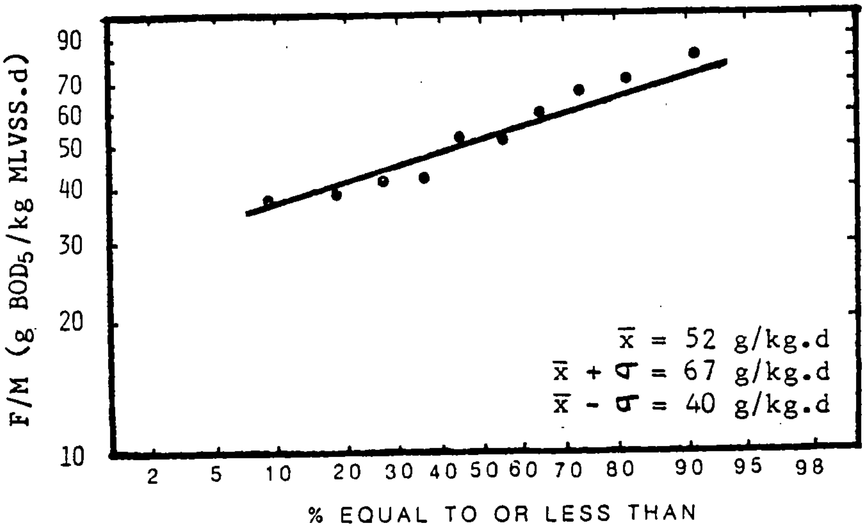

FIGURE 61 F/M PROBABILITY DISTRIBUTION - HBM&S

5.3.4 Sludge growth

Figure 62 shows the history of the MLSS concentration over the sampling period. Of interest is the observation that a very large inert sludge solids load was carried at the beginning.

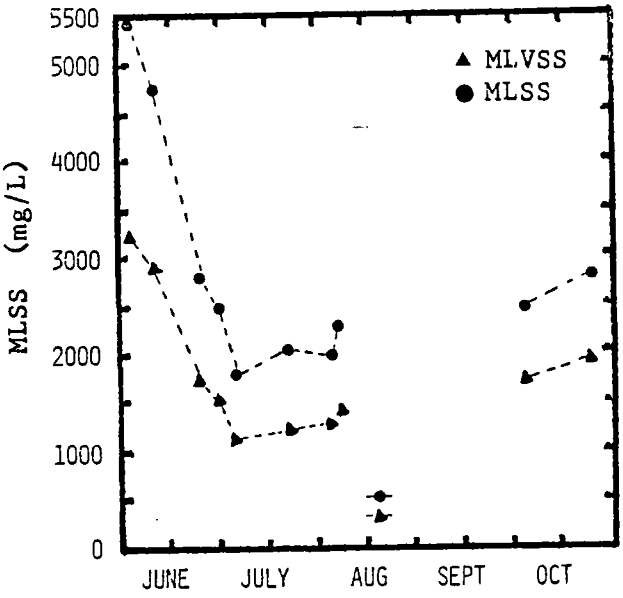

FIGURE 62 MLSS CONCENTRATIONS - HBM&S

Over the month of June the MLSS decreased from almost 5500 mg/L to 2500 mg/L. This decrease when looking at the MLVSS only can be described by a function as determined from the data shown in Figure 63:

$$\frac{dX_v}{dt} = 85.5 - 0.013\ X_v \qquad (30)$$

where:

$\frac{dX_v}{dt}$ = rate of decrease of MLVSS, mg/L.d

X_v = MLVSS concentration in reactor, mg/L

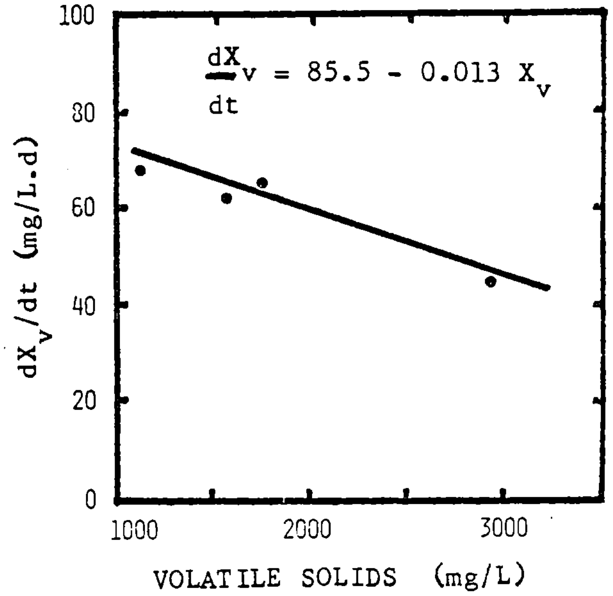

FIGURE 63 BIOMASS ENDOGENOUS DECAY - HBM&S

The constant of 0.013 in equation (35) represents the decay constant for net volatile sludge reduction. As shown in Figure 64 of the MLSS concentration distribution, the average MLSS concentration was 2344 mg/L. 90% of the time values are equal to or less than 2780 mg/L and 10% equal to or less than 1890 mg/L. The process operational objective was to maintain an average MLSS concentration of 2500 mg/L.

The volatile fraction of the MLSS averaged 0.630, with 90% being equal to or less than 0.660 and 10% equal to or less than 0.600 (Figure 65). The low MLVSS fraction is typical of biological processes with grey water as the influent substrate. It also lends support to the assumption made in the selection of a substrate conversion rate constant, k_m, at 50% of its value for conventional domestic sewage.

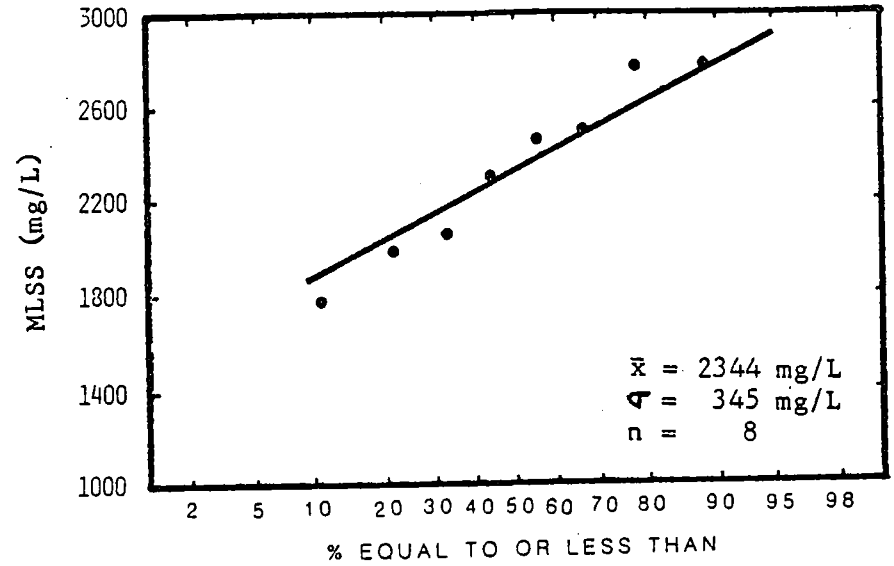

FIGURE 64 MLSS PROBABILITY DISTRIBUTION - HBM&S

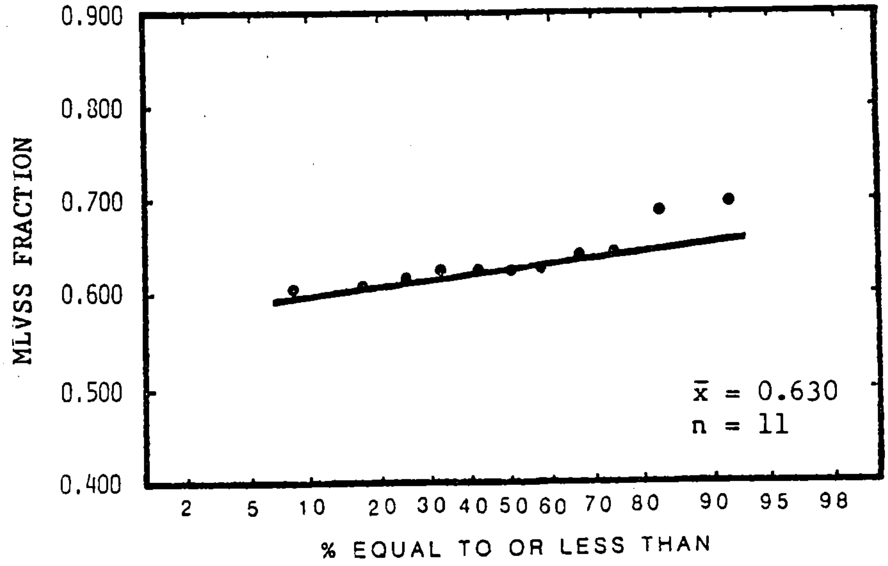

FIGURE 65 FRACTION VS IN MLSS PROBABILITY DISTRIBUTION
- HBM&S

5.3.5 Sludge settleability

The variation of the SVI over the period during which samples were taken is illustrated in Figure 66. A probability analysis of the SVI data indicates a mean value of 120, with 90% of the data being equal to or less than 176 and 10% equal to or less than 64 (Figure 67).

The sludge at the Hudson Bay Mining & Smelting treatment plant exhibited excellent settling characteristics.

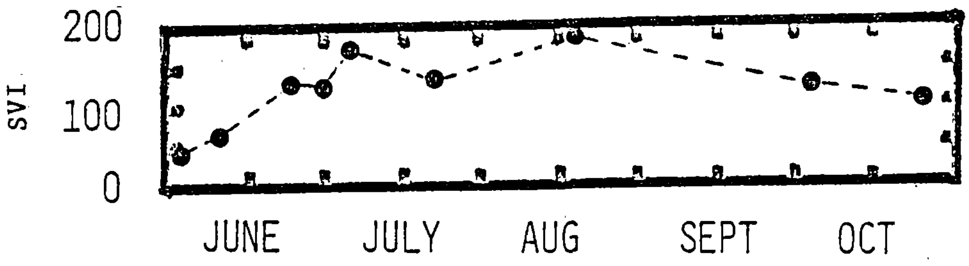

FIGURE 66 SVI HISTORY AT HBM&S

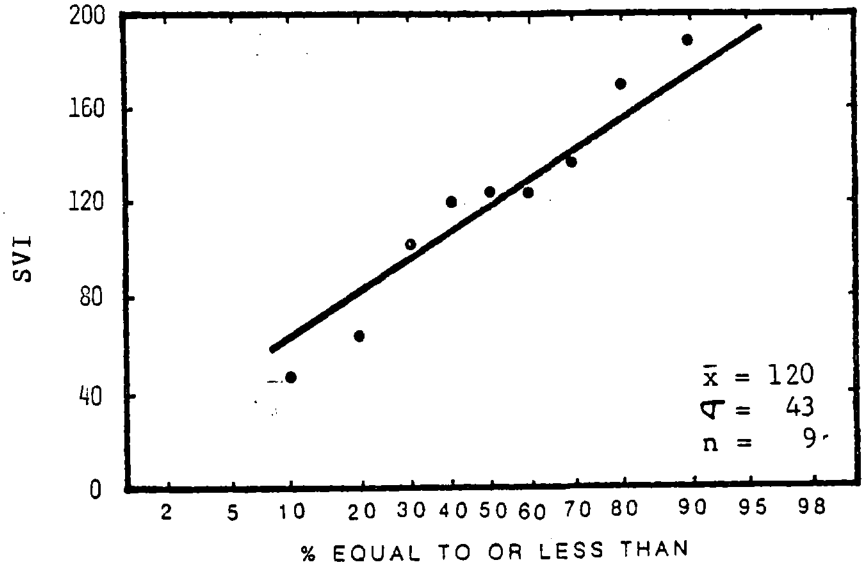

FIGURE 67 SVI PROBABILITY DISTRIBUTION - HBM&S

5.3.6 Sludge wasting

During the period of process monitoring no sludge was wasted. As indicated in Figure 62 operator error (unfamiliar with system) resulted in pumping out the reactor contents. Nevertheless, the process was quickly reestablished.

5.3.7 Suspended solids

The distribution of influent suspended solids (SS) to the system is illustrated in Figure 68. Two distinct distributions were observed; as well, the distribution is not normal. From Figure 68 a mean influent SS concentration of 67 mg/L was determined with 90% of the values equal to or less than 280 mg/L and 10% equal to or less than 37 mg/L. The solids concentrations are highly variable. This is not surprising since, as noted earlier, this is a grey water waste.

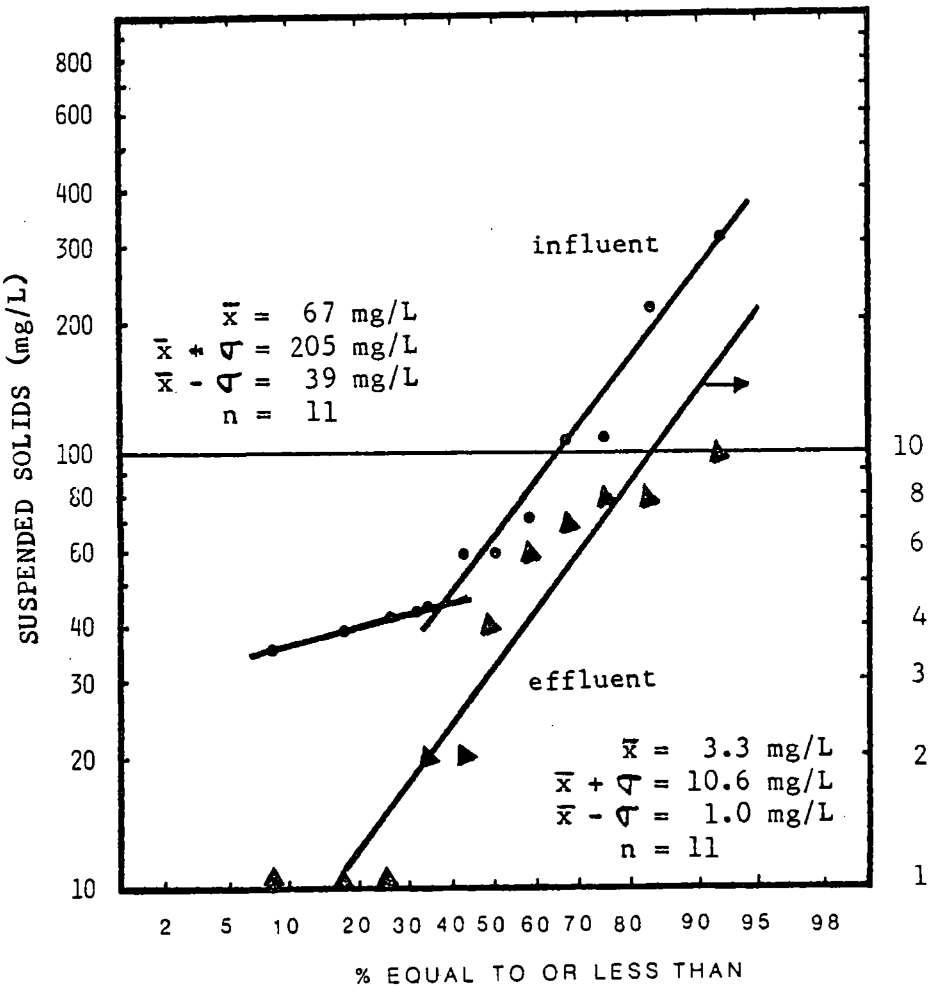

FIGURE 68 INFLUENT AND EFFLUENT SS PROBABILITY DISTRIBUTIONS - HBM&S

The influent BOD_5 to SS ratio was determined to have a mean value of 0.7 with 90% of the values equal to or less than 1.53 and 10% equal to or less than 0.32 (Figure 69). For normal domestic sewage the ratio is close to 1.0.

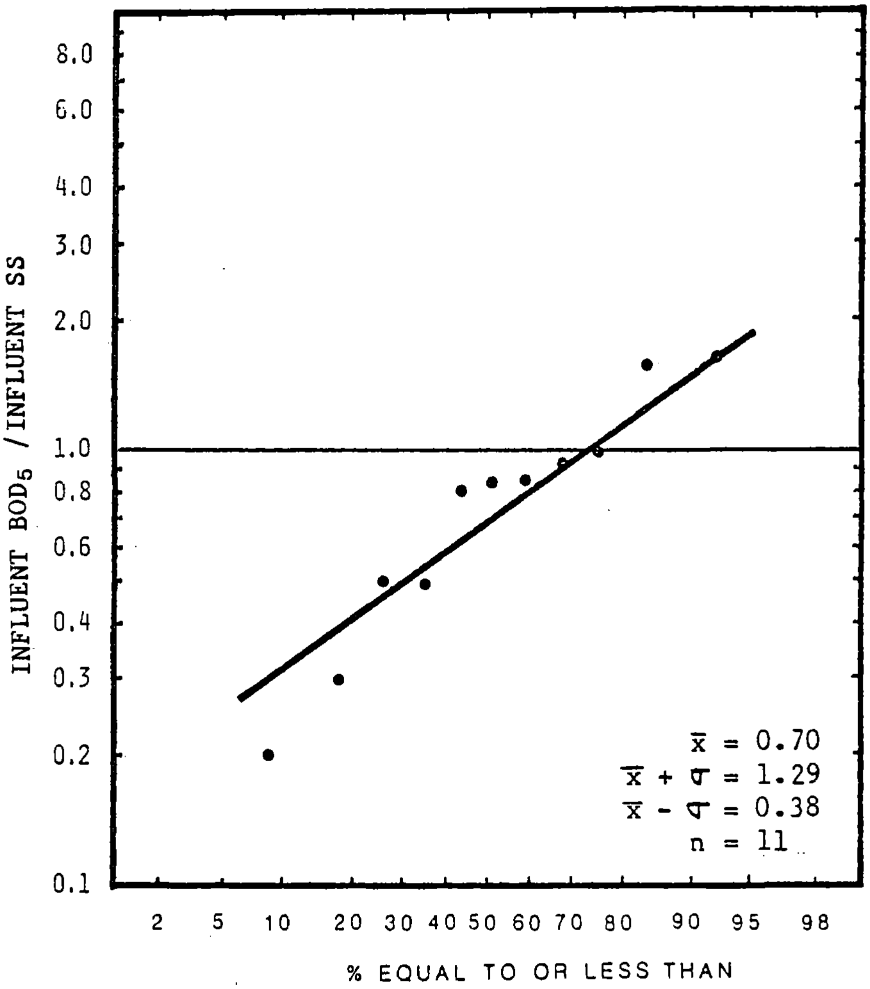

FIGURE 69 INFLUENT BOD_5/SS RATIO PROBABILITY DISTRIBUTION - HBM&S

The effluent SS distribution is shown in Figure 68. The distribution is log normal, with a mean value of approximately 3 mg/L with 90% of the concentrations equal to or less than 15 mg/L and 25% equal to 1 mg/L.

Similar to the Glenlea installation, reported on in the previous section, the effluent SS solids concentrations are consistently very low. This further reinforces the excellent liquid/solid performance which one can expect from batch reactor processes.

The influent and effluent SS concentrations determined during this program phase are illustrated in Figure 70.

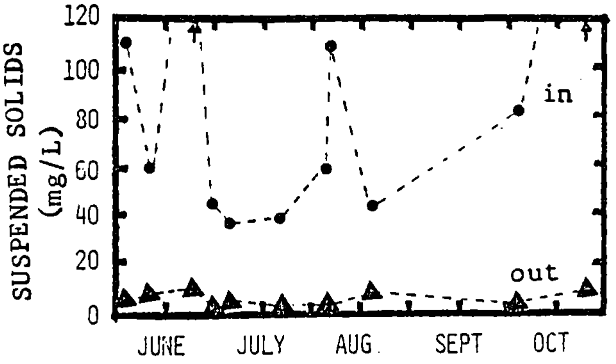

FIGURE 70 INFLUENT AND EFFLUENT SS VARIATIONS - HBM&S

5.3.8 Nitrification/denitrification

The water supply source at Hudson Bay Mining and Smelting is from a surface water. Hence the alkalinity of the wastewater is not particularly high. As shown in Figure 71, the mean influent alkalinity is 122 mg/L with 90% of the observations equal to or less than 147 mg/L and 10% equal to or less than 102 mg/L.

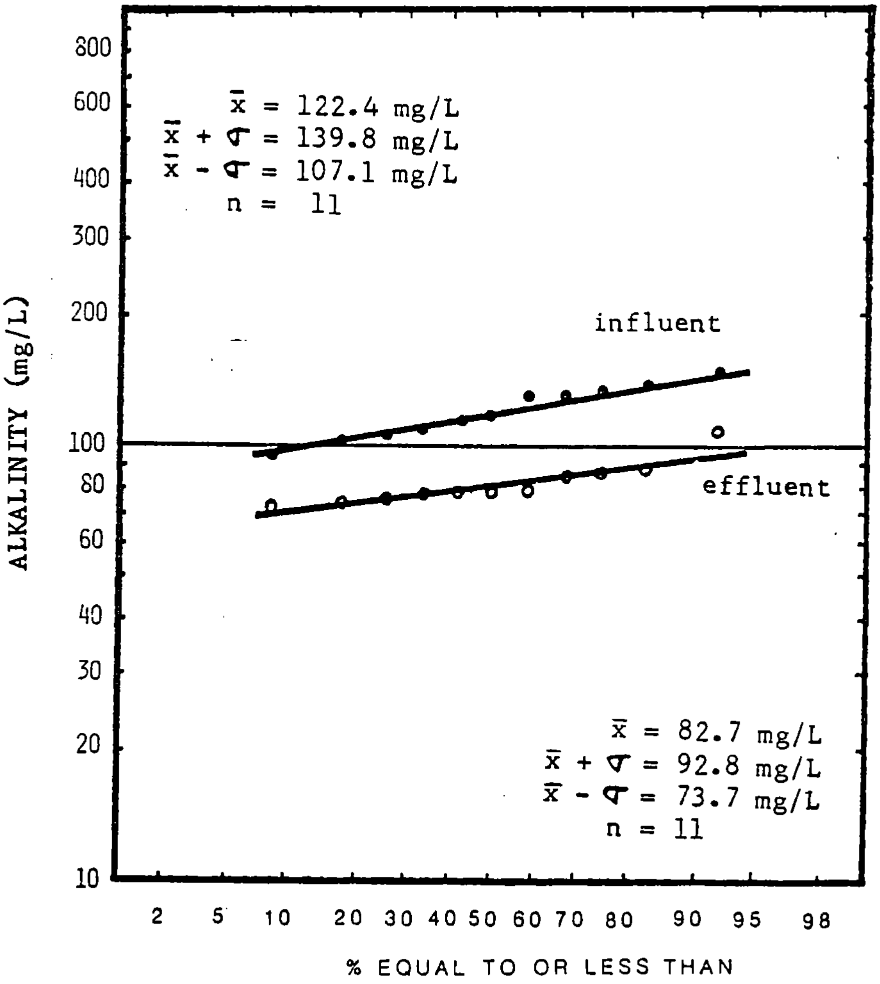

FIGURE 71 INFLUENT AND EFFLUENT ALKALINITY PROBABILITY DISTRIBUTIONS - HBM&S

The influent NH_4-N concentrations summarized in Figure 72 shows a mean of only 8.4 mg/L with 90% of the values equal to or less than 13 mg/L and 10% equal sto or less than 5 mg/L.

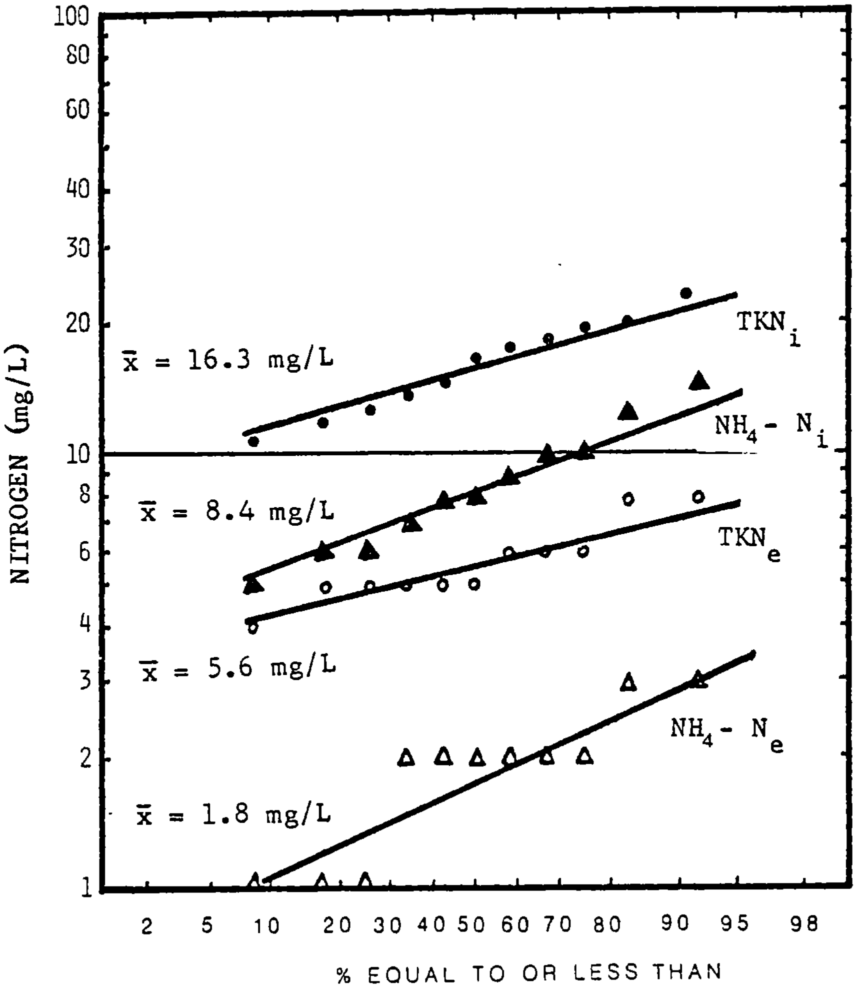

FIGURE 72 INFLUENT AND EFFLUENT NH_4- N AND TKN PROBABILITY DISTRIBUTIONS - HBM&S

Effluent NH_4-N concentrations shown in Figure 72 indicate a mean value of 1.8 mg/L with 90% of the observations being equal to or less than 3 mg/L and 25% equal to or less than 1 mg/L. This represents 78% NH_4-N removal.

The effluent aklalinity concentrations shown in Figure 71 indicate a mean value of 83 mg/L with 90% of the values equal to or less than 96 mg/L and 10% equal to or less than 71 mg/L. Clearly, sufficient alkalinity for nitrification of this weak sewage was available.

The alkalinity used to NH_4-N oxidized ratio, while stoichiometrically is 7.14, was determined to average 5.7 (Figure 73) with 90% of the calculated ratios equal to or less than 7.0 and 10% equal to or less than 4.4.

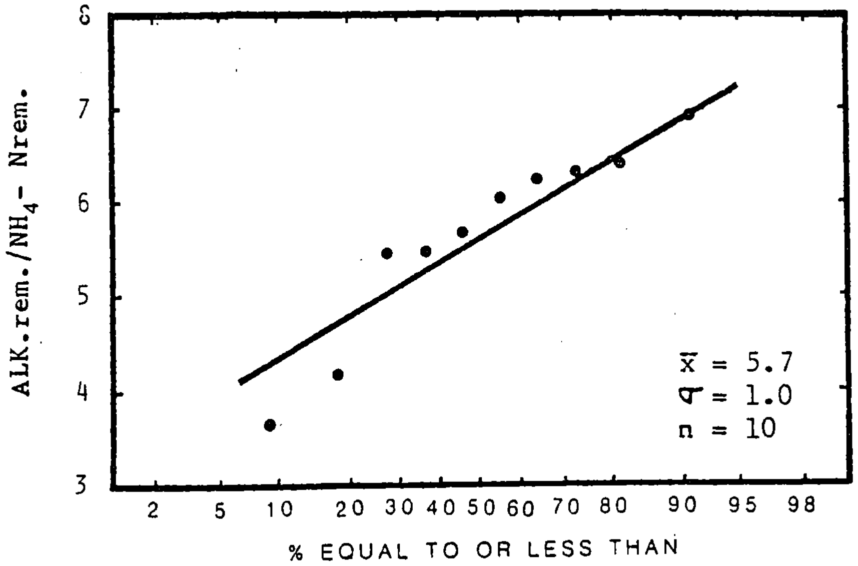

FIGURE 73 RATIO OF ALKALINITY REMOVED TO NH_4- N OXIDIZED PROBABILITY DISTRIBUTION - HBM&S

The minimum SRT required for nitrification, was determined using equation (21) (see section 4.3.8).

$$\mu = (0.392 \text{ pH} - 2.35) e^{0.098(T - 15)} \qquad (21)$$

The average pH of the mixed liquor was 6.5 and the average temperature 22 °C (Figure 74). The net growth rate for the nitrifiers under these conditions is:

$$\mu = (0.392 (6.5) - 2.35) e^{0.098(22 - 15)}$$

$$\mu = 0.393/\text{day}$$

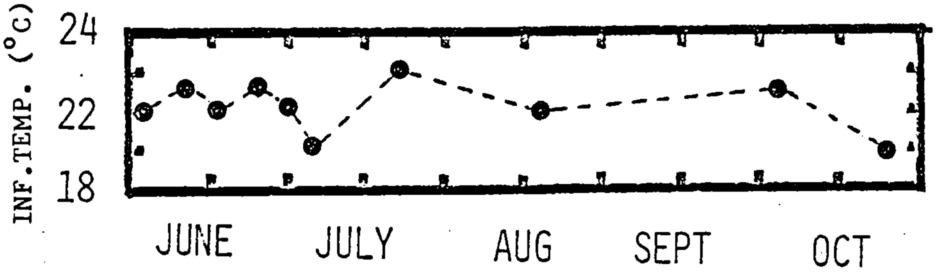

FIGURE 74 MIXED LIQUOR TEMPERATURE VARIATIONS - HBM&S

Under these conditions the minimum required SRT at Hudson Bay Mining and Smelting for nitrification to occur is:

$$SRT = \frac{1}{\mu} = \frac{1}{0.393} = 2.5 \text{ days}$$

Since no sludge was wasted during the period of observation, the SRT was very much greater than 2.5 days. Hence, conditions for nitrification were always present.

The NH_4-N load to the plant can also be expressed on the basis of g of NH_4-N applied/kg MLVSS.d. Figure 75 shows the distribution of these data. The average value is 8.6 g NH_4-N applied/kg MLVSS.d and ranged between 12.5 and 4.7 for 90% and 10% of the values being equal to or less than those stated, respectively.

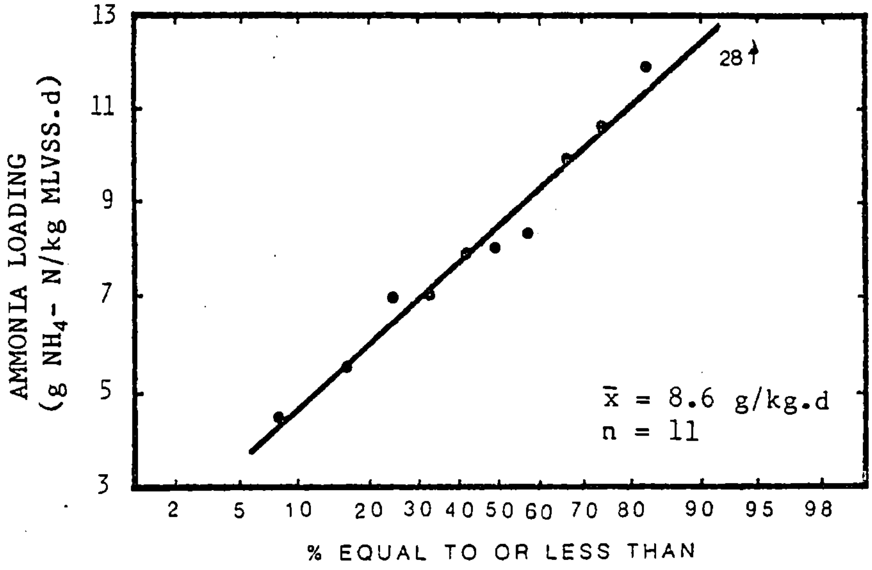

FIGURE 75 NH_4- N PROCESS LOADING PROBABILITY DISTRIBUTION - HBM&S

Another way of stating NH_4-N removal efficiency is based on the mass of NH_4-N removed per day per unit mass of MLVSS. Figure 76 illustrates this concept. The average rate is 6.1 g NH_4-N removed/kg MLVSS.d with 90% of the values equal to or less than 9.6 and 10% equal to or less than 2.5.

For normal domestic sewage the nitrification rate could be predicted by equation (23):

$$n_{rT} = 0.0071 \, T^{2.89} \qquad (22)$$

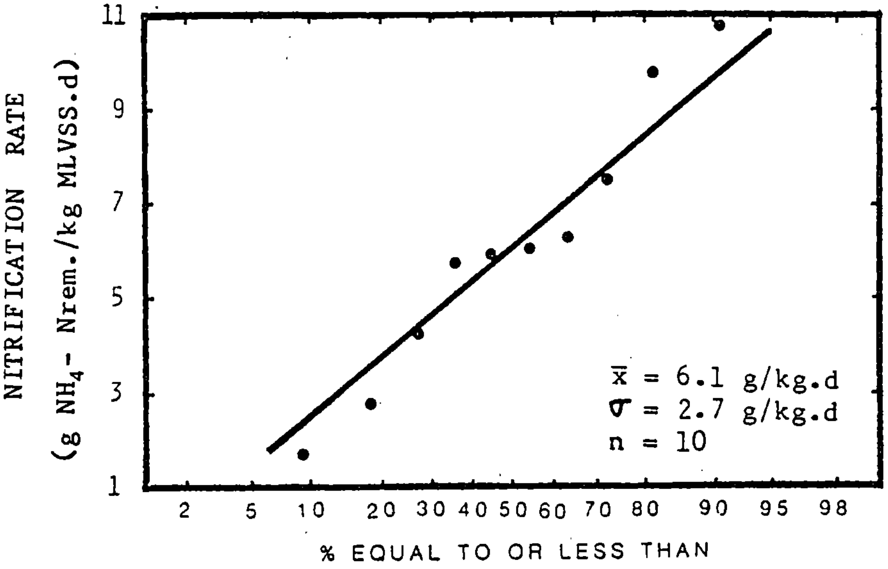

FIGURE 76 NH_4- N REMOVED PER UNIT MLVSS PROBABILITY DISTRIBUTION - HBM&S

For Hudson Bay Mining and Smelting at a mixed liquor operating temperature of 22°C, the nitrification rate should be 54 g NH_4-N removed/kg MLVSS.d. In actual fact, it is only 11% of that rate. This is really not surprising since the waste water is a grey water.

Figure 77 illustrates the variability of the influent and effluent NH_4-N data over the entire monitoring period. Even though the influent NH_4-N varied considerably, the effluent concentration is stable.

The NO_3-N concentration distributions are shown in Figure 78. The data are normally distributed with an average value of 4 mg/L with 90% of the observations equal to or less than 6 mg/L and 10% equal to or less than 2 mg/L.

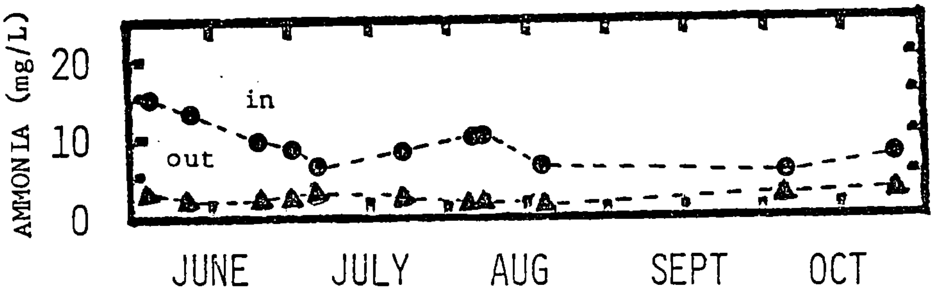

FIGURE 77 INFLUENT AND EFFLUENT NH_4- N VARIATIONS - HBM&S

Figure 79 shows the relationship between the NO_3-N generated and NH_4-N oxidized. The relationship can be described by the function:

$$NO_3 - N_g = 2.27 + 0.28\ NH_4 - N_o \qquad (31)$$

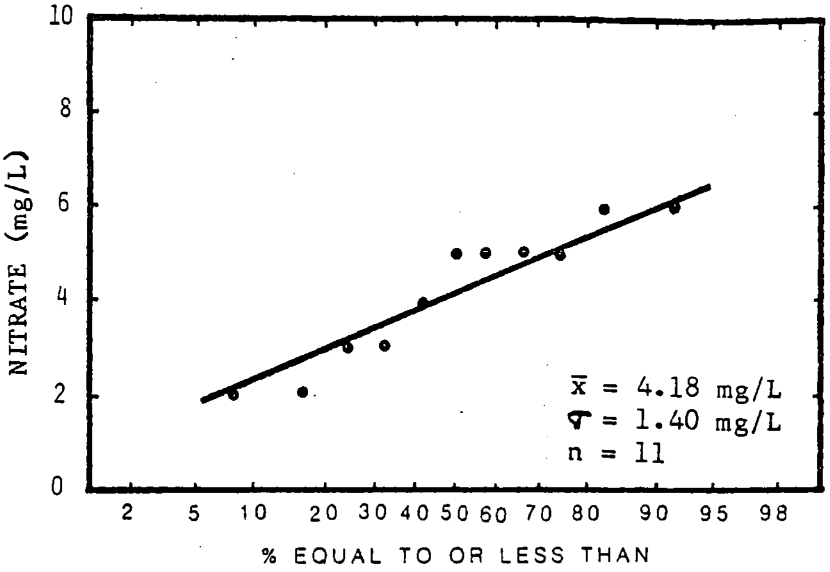

FIGURE 78 NO_3- N PROBABILITY DISTRIBUTION - HBM&S

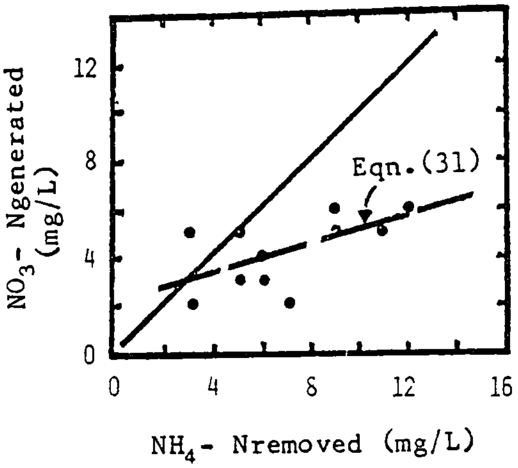

FIGURE 79 NO_3- N GENERATED TO NH_4- N OXIDIZED RELATION - HBM&S

The data illustrate that more NH_4-N was oxidized than NO_3-N measured in the effluent. This leads to the conclusion that a significant degree of denitrification occured.

5.3.9 Nitrogen removal

Examination of the influent and effluent organic nitrogen data (Figure 80) indicates that a significant amount of organic nitrogen has been removed. The influent mean organic nitrogen concentration was 7.5 mg/L with 90% of the values equal to or less than 11 mg/L and 10% equal to or less than 5 mg/L.

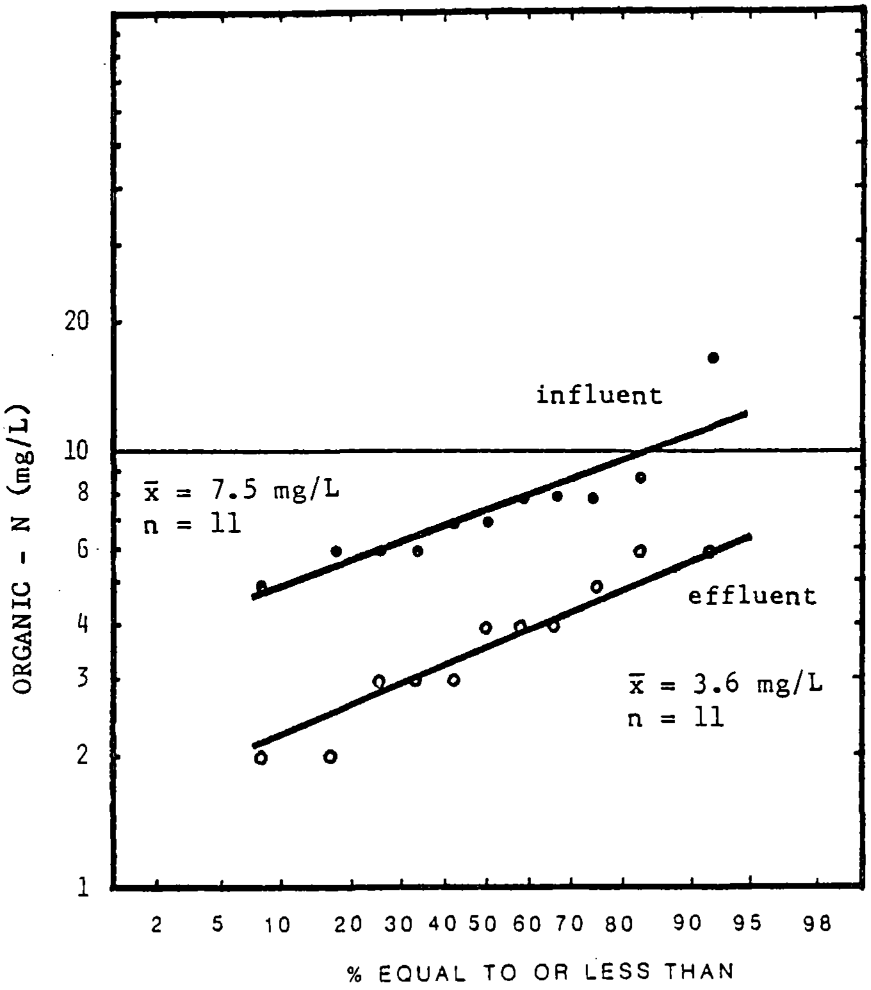

FIGURE 80 INFLUENT AND EFFLUENT ORGANIC - N PROBABILITY DISTRIBUTION - HBM&S

Effluent organic nitrogen had a mean concentration of 3.6 mg/L with 90% of the concentrations being equal to or less than 6 mg/L and 10% equal to or less than 2 mg/L. This represents an average reduction in organic nitrogen of 52%.

On a total Kjeldahl nitrogen (TKN) basis the mean influent concentration was determined to be 16 mg/L (Figure 72). Ninety percent of the distribution has values equal to or less than 22 mg/L and 10% equal to or less than 12 mg/L.

The effluent mean TKN concentration was calculated to be 6 mg/L (Figure 72) with 90% of the values equal to or less than 7 mg/L and 10% equal to or less than 4 mg/L.

TKN removal averaged 63%.

Examining the removal of total nitrogen (TN), the influent TN is represented by the influent TKN. The effluent TN is equal to:

$$\text{EFFLUENT TN} = (\text{TKN}) + (NO_3 - N) + (NO_2 - N) \qquad (24)$$

Nitrite-N was not determined and because of its instability anyway, was for practical considerations taken as zero. The effluent TN is therefore the sum of the effluent TKN and the NO_3-N. Figure 81 shows the effluent TN concentration distribution. The average value was calculated to be 10 mg/L with 90% of the values being equal to or less than 13 mg/L and 10% being equal to or less than 7 mg/L.

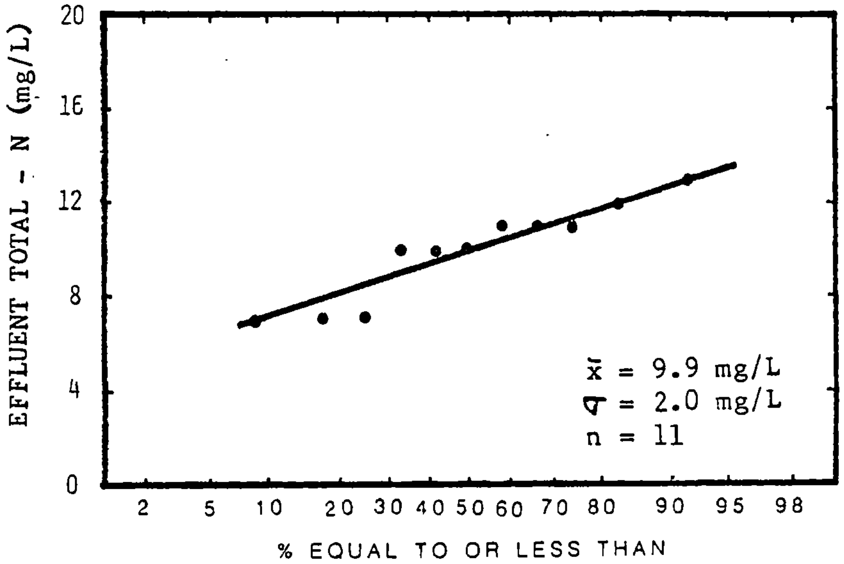

FIGURE 81 EFFLUENT TN PROBABILITY DISTRIBUTION - HBM&S

Total nitrogen removal at Hudson Bay Mining and Smelting was therefore 60%. For denitrification to occur a minimum BOD_5/TKN ratio of 3.5 is required. Figure 82 shows that the average BOD_5/TKN ratio for the Hudson Bay Mining and Smelting installation is 3.5. Ninety percent of the distribution has values equal to or less than 4.9 and 10% equal to or less than 1.6.

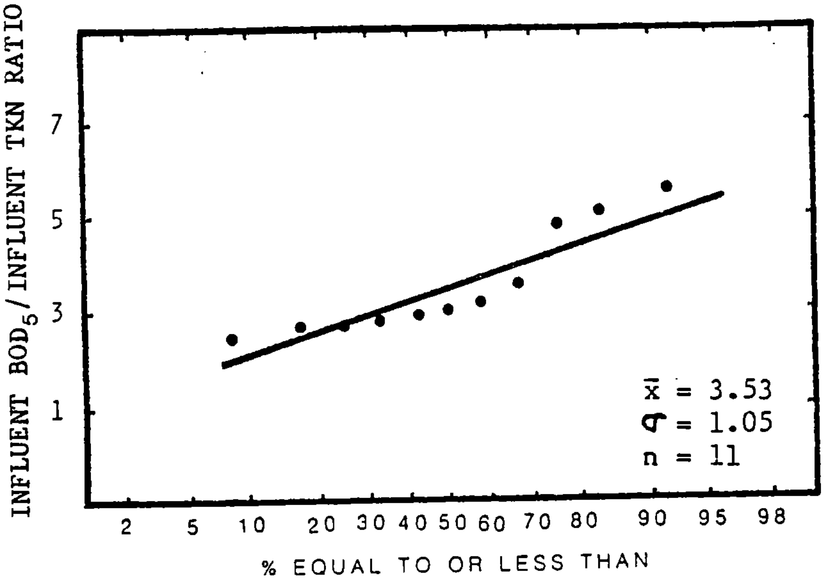

FIGURE 82 BOD_5/TKN RATIO PROBABILITY DISTRIBUTION - HBM&S

As for the Glenlea installations all requirements for full nitrification and denitrification are present. Process optimization could attain full nitrogen removal.

This data analysis has illustrated that both a high degree of carbon and nitrogen removal can be accomplished.

5.3.10 Phosphorus removal

The influent total phosphorus data distribution shows a mean value of 2 mg/L with 90% of the values equal to or less than 4 mg/L and 25% equal to or less than 1 mg/L. (Figure 83) The influent total phosphorus concentrations during the time of process assessment are shown in Figure 84.

Effluent total phosphorus concentrations were on average less or equal to 0.2 mg/L.

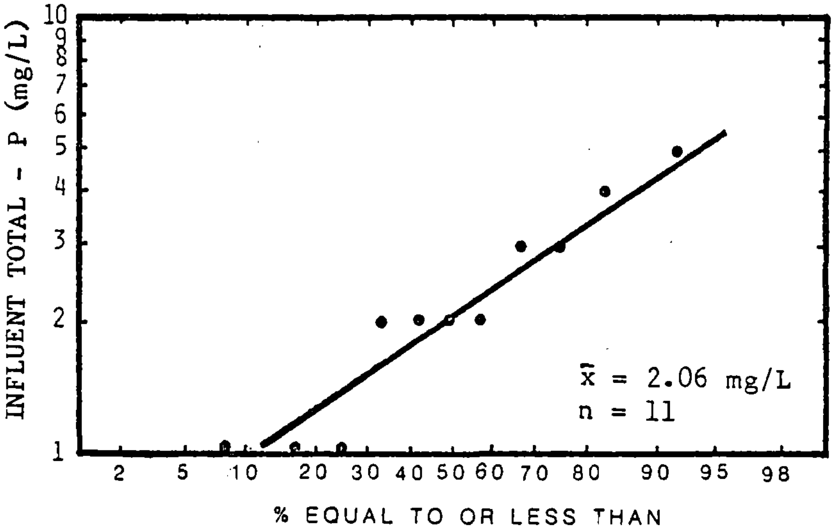

FIGURE 83 INFLUENT TP PROBABILITY DISTRIBUTION - HBM&S

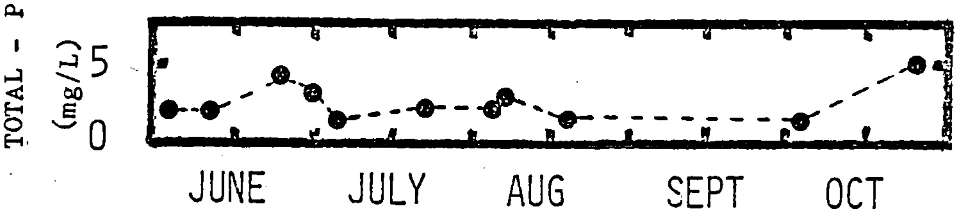

FIGURE 84 INFLUENT TP VARIATIONS - HBM&S

5.4 Energy & Mixing Requirements

Process energy and mixing energy requirements are summarized by the following data:

Hydraulic load (m^3/d)	22.7
Organic load (kg BOD_5/d)	1.2
Organics removed (kg BOD_5/d)	1.2
Connected power (Appendix C):	
Compressor (kW)	1.12
Effluent pumps (kW)	0.25
Sludge pumps (kW)	0.37
Transfer pumps (kW)	0.37
Total	2.11 kW

The total connected power at Hudson Bay Mining and Smelting is 2.11 kW. Knowing the running times for the compressor and pumps permits calculation of the daily power use.

Compressor run time per day	14.1 h
Effluent pumping time per day	2.5 h
Transfer pumps running time per day	2.5 h

Correlating this information with the connected power results in calculated power used as follows:

Compressor	(14.1 h x 1.12 kW)	15.8 kWh
Effluent Pumps	(2.5 h x 2.25 kW)	0.6 kWh
Transfer Pumps	(2.5 h x 0.37 kW)	0.9 kWh
(Use of sludge pumps is negligible)		
Total power drawn daily		17.3 kWh

No allowances for either electrical or mechanical efficiencies of the process components are included.

The above information can be used to express process power requirements on a more standardized basis. However, since aerobic digestion of the sludge is practised at this installation and 50% of the air-flow is diverted from the compressor, an appropriate power correction will be made so that the power requirements for the systems reported on in this report can be compared.

By making the appropriate adjustment in power drawn by the compressor the process energy per unit organic and volumetric load parameters are:

7.8 kWh/kg BOD_5 applied
or 7.8 kWh/kg BOD_5 removed
or 0.414 kWh/m^3 of waste

Another important consideration is how much aeration energy is required per unit of substrate removed. For this installation it is calculated to be 6.6 kWh/kg BOD_5 removed. This indicates that approximately 85% of the process energy requirements (excluding aerobic sludge digestion) are associated with aeration only.

The mixing energy input is calculated to be 0.04 kW/m^3.

Air supply when based on quantity of substrate removed was calculated to be 269 m^3/kg BOD_5 removed. For an $F/M < 0.3$ the air supply range for design purposes is taken as 75 - 155 m^3/kg BOD_5 removed. The available air supply is more than adequate.

When air supply is expressed on a volumetric basis (waste flow) it can be calculated that for this installation this parameter is 21.4 m^3 air/m^3 waste. The rule of thumb quantity when multiplied by a safety factor of 2 is 15 m^3 air/m^3 waste. As before there will be no lack of process air ($21.4 > 15$). On a MLSS basis, the air supply is calculated to be 0.65 m^3 air/h.kg MLSS. The energy and mixing parameters are summarized in Table 9.

5.5 Retrofitting Costs (1982)

The retrofitting costs were $18,500 and consisted of approximately $6,000 for hardware, $2,500 engineering and $10,000 labour.

The costs associated with this project may well have been considerably higher if the mine personnel had not been involved and the work would have had to be done by a general contractor.

The upgrading costs can be put on a dollar per kg BOD_5 applied basis. For this installation, because of the extremely low BOD_5 (grey water) the cost is calculated to be $15,400 per kg BOD_5 applied. On a per unit waste flow basis the cost is $815.- /$m^3$.d.

No information on operating costs were available.

TABLE 9 - ENERGY AND MIXING PARAMETER SUMMARY - Glenlea

PARAMETER	UNITS	VALUE
Total Connected Power	kW	2.11
Total Energy Used	kWh/d	17.3
Total Energy Used/Unit Substrate Applied	kWh/ kgBOD_5 applied	7.8
Total Energy Used/Unit Substrate Removed	kWh/ kgBOD_5 removed	7.8
Total Energy Used/Unit Waste Flow Treated	kWh/ m^3waste	0.414
Aeration Energy Used/ Unit Substrate Removed	kWh/ kgBOD_5removed	6.6
Mixing Energy Input/ Unit Liquid Volume	kW/m^3	0.04
Air Supplied/Unit Substrate Removed	m^3/kg BOD_5 removed	269
Air Supplied/Unit Waste Flow Treated	m^3/m^3	21.4
Air Flow Rate/Unit MLSS	m^3/h.kg MLSS	0.65

5.6 Operator Requirements

As with the Glenlea installation, reported on in the previous section, no regular operator is exclusively associated with this installation.

A good example of what can happen to an installation with an unfamiliar operator was a complete pump out of the reactor contents in error.

The robustness of the process though, led to quick re-establishment of the complete biological process.

An operations and maintenance manual similar to the example in Appendix A is provided to the operator.

5.7 Operations Problems

Operational concerns at the Hudson Bay Mining and Smelting installation include mechanical system service checks as well as a regular sludge waste program.

Particular problems observed or reported at the site throughout this test program included:

1. Power Fluctations

   Power for the mine operations is diesel generated on site. When fire destroyed part of the the power generating system, the entire mine site operation was seriously affected.

   Significant voltage fluctuations occured causing the control panel to malfunction with electric contactor flutter. This affected process control and undue wear on the contractors. In spite of this, changes in effluent quality and/or equipment serviceability, although expected, were not noted. Normal operation resumed when normal power generation was restored.

2. Control probe shorting

   Although the shorting out of the liquid control probe was not a problem during the test period, it was reported that when the cafeteria was in use occasional problems were experienced with fibrous material attaching itself to the low level liquid probe (insulated except for the tip). This prevented the effluent pump from being shut off. Daily plant maintenance includes observation of the control rods for fouling.

3. Effluent pump clogging

   On several occasions the impeller of the 0.25 kW centrifugal pump clogged. The main cause was hair. Particulate matter, such as plastic, can also effectively put the pump out of service. Regular checks for debris in the pump case is recommended.

4. Process control

   Process control was achieved using a sludge wasting program based on sludge volume index. The mine personnel prepared a chart that indicated the sludge pumping time required to transfer the appropriate amount of mixed liquor to the digester so as to maintain a relatively stable MLSS concentration in the reactor. This was based on the percent volume occupied by settled sludge in a 2 liter beaker after 1 hour. During the monitoring period sludge wasting from the aerotic digestor was not required.

5.8 Process Assessment Summary

The various data reported on for the Hudson Bay Mining and Smelting installation in the previous sections are summarized in Tables 10 to 12.

The information in the Tables also identifies the number of observations associated with each parameter and the resulting type of data distribution. As well, if one set of data depict more than one distribution, this is noted.

Table 10 summarizes the influent waste characteristics, Table 11 the process parameters and Table 12 the effluent waste characteristics.

TABLE 10 - INFLUENT CHARACTERISTICS - HBM&S

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN			NO. OF OBSERVATIONS	TYPE OF DATA DISTRIBUT.
		10%	50%	90%	n	
Flow	m^3/d	-	22.7	-	-	-
Temp.	°C	-	22	-	-	-
BOD_5(total)	mg/L	32	54	91	11	LNP
BOD_5(sol.)	mg/L	24	44	79	11	LNP
SS	mg/L	37	67	280	11	LNP[1]
BOD_{5T}/SS	-	0.32	0.70	1.53	11	LNP
Alkalinity	mg/L	102	122	147	11	LNP
BOD_{5T}/TKN	-	1.6	3.5	4.9	11	NP
TKN	mg/L	12	16	22	11	LNP
NH_4-N	mg/L	5	8	13	11	LNP
Org-N	mg/L	5	8	11	11	LNP
TP	mg/L	1	2	4	11	LNP
pH	-	-	6.4	-	-	-
BOD_5:N:P	-	100:38:3	100:30:4	100:24:5	-	-

[1] break in distribution

TABLE 11 - PROCESS PARAMETERS - HBM&S

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN			NO. OF OBSERVATIONS	TYPE OF DATA DISTRIBUT.
		10%	50%	90%	n	
MLSS	mg/L	1890	2344	2780	8	NP
VSS	%	60	63	66	11	NP
SVI	ml/g	64	120	176	9	NP
Organic Loading	g BOD_5/kg MLSS.d	22	33	48		
Alk_{rem}/ NH_4-N_{rem}	-	4.4	5.7	7.0	10	NP
Volumetric Loading	g BOD_5/m^3d	-	85	-	-	-
NH_4-Nappl./ MLVSS.d	g NH_4-N/ kg MLVSS.d	4.7	8.6	12.5	10	NP
NH_4-N_{rem}./ MLVSS.d	g NH_4-N/ kg MLVSS.d	2.5	6.1	9.6	10	NP
Organic Loading (F/M)	g BOD_5/kg MLVSS.d	37	52	72	10	LNP
	g BOD_5/sol kg MLVSS.d	-	42	-	-	-

TABLE 12 - EFFLUENT CHARACTERISTICS - HBM&S

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN 10%	50%	90%	NO. OF OBSERVATIONS n	TYPE OF DATA DISTRIBUT.
BOD_5(total)	mg/L	2	3	6	11	LNP
BOD_5(sol.)	mg/L	1	3	5	11	LNP
SS	mg/L	1	3	15	11	LNP
Alkalinity	mg/L	71	83	96	11	LNP
TKN	mg/L	4	6	7	11	LNP
NH_4-N	mg/L	1	2	3	11	LNP
Org-N	mg/L	2	4	6	11	LNP
NO_3-N	mg/L	2	4	6	11	NP
TN	mg/L	7	10	13	11	NP
TP	mg/L	-	0.2	-	8	-
pH	-	-	6.5	-	-	-

6 RIVERCREST INSTALLATION

6.1 Process Description

The original two septic tank system at Rivercrest was converted to a sequencing batch reactor. The flow schematic, Figure 85, shows that a portion of one septic tank is used to store and equalize the raw sewage while the other portion is used for aerobic digestion of the waste sludge. The settled sewage is pumped to the second septic tank structure, retrofitted to operate as a batch reactor. The complete cycles of fill, aerate, settle and draw are fully automated. The plant is enclosed and heated by thermostatically controlled baseboard heaters (Appendix C).

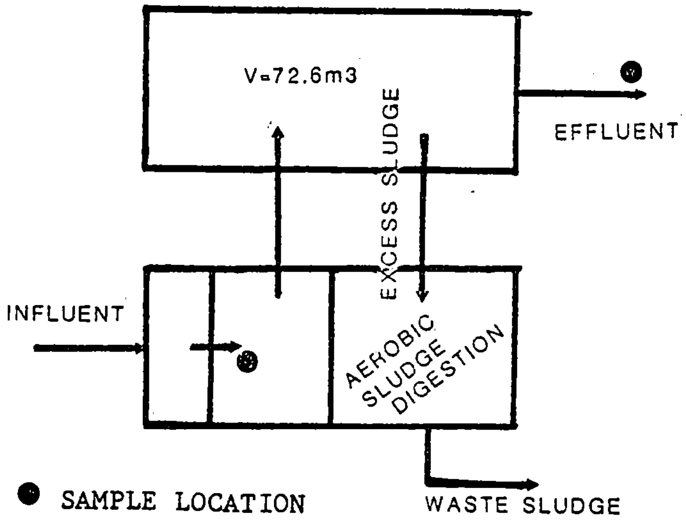

FIGURE 85 RIVERCREST BATCH REACTOR INSTALLATION

6.2 Sampling Program

For the purpose of process assessment parameters as summarized in Table 13 were determined from influent, effluent and mixed liquor grab samples.

TABLE 13 - SAMPLES AND PARAMETERS ANALYSED

PARAMETER	SAMPLE		
	Influent	Effluent	Mixed Liquor
BOD_5 (total)	*	*	
SS	*	*	
Alkalinity	*	*	
TKN	*	*	
NH_4-N	*	*	
NO_3-N		*	
TP	*	*	
MLSS			*
% VSS			*
Settleable Solids			*

A total of 18 grab samples of the process influent, effluent and mixed liquor were taken. The sampling period lasted from October 3 - December 28, 1983.

All analyses were done in accordance with Standard Methods (7).

6.3 Process Observations and Results

The process analyses concern BOD_5 reduction (total and soluble), SS removal efficiencies, nutrient removal and general process stability. Sludge settleability, as well as process and aeration energy requirements are also evaluated.

6.3.1 Flow

The raw sewage flow to the Rivercrest batch reactor plant is generated by a subdivision consisting of 142 homes with approximately 426 inhabitants. The flow varied between 204 and 249 m^3/d. The average flow was 227 m^3/d or 532 L/capita.d. This was the hydraulic load used in all process evaluation calculations.

6.3.2 Biochemical oxygen demand

The equalized influent BOD_5 concentrations varied from a low of 115 mg/L to a high of 356 mg/L, with an average concentration of 236 mg/L. These values are representative of a normal domestic sewage. Figure 86 shows the influent BOD_5 data on a probability distribution basis with 90% of the observations equal to or less than 330 mg/L and 10% less than or equal to 142 mg/L.

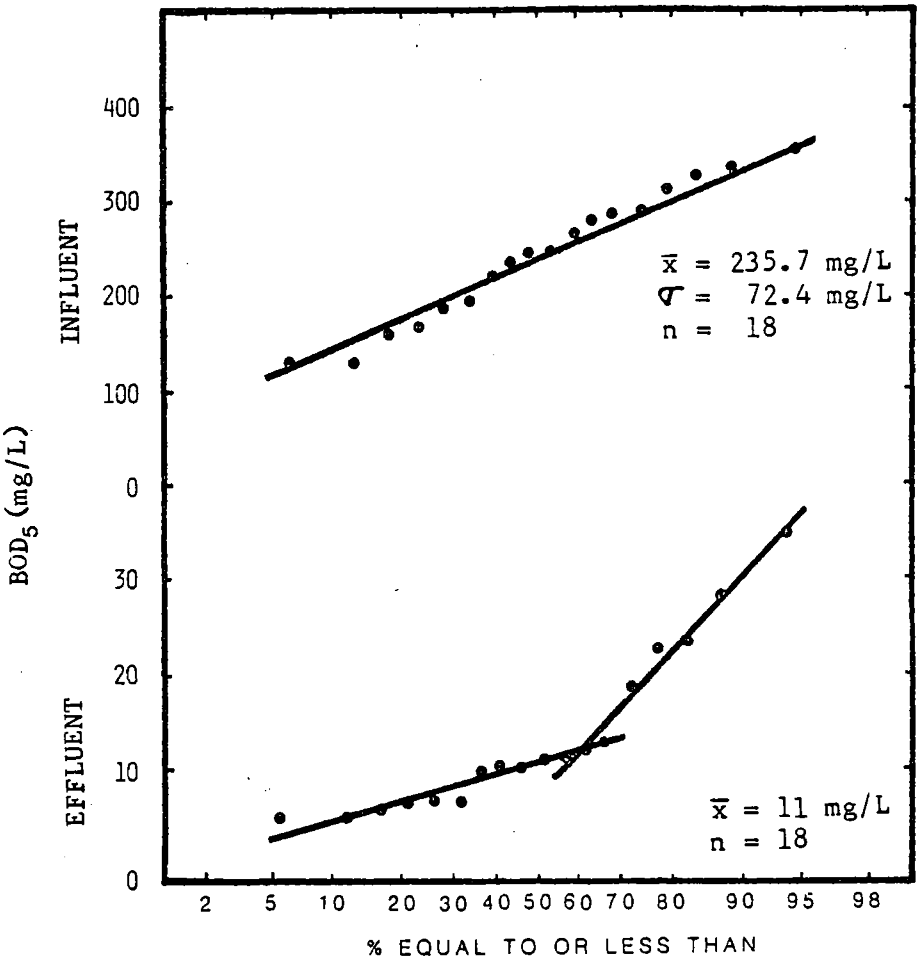

FIGURE 86 INFLUENT AND EFFLUENT BOD_5 PROBABILITY DISTRIBUTION - RIVERCREST

An attempt was made to determine the influent soluble BOD_5 fraction. As shown in Figure 87 the best fit equation for the data is:

$$BOD_{5in} = 160 + 0.286\ SSi \qquad (32)$$

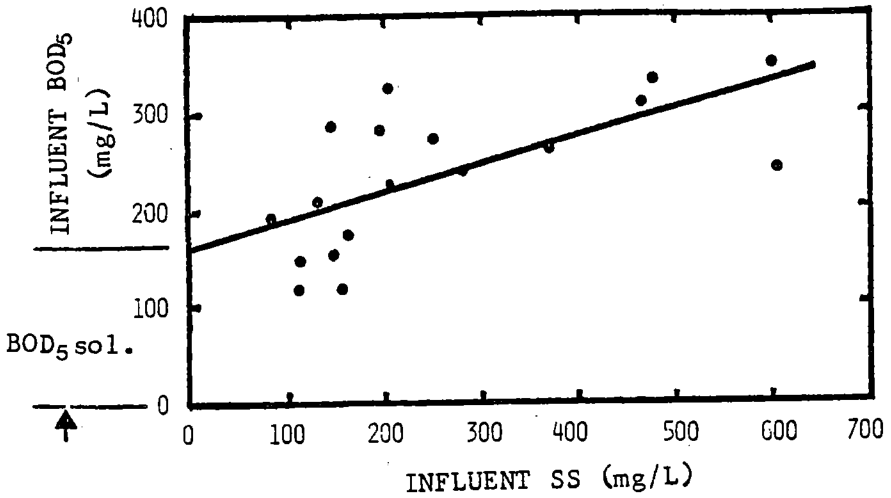

FIGURE 87 INFLUENT BOD$_5$ vs INFLUENT SS CORRELATION - RIVERCREST

Equation (37) shows that the soluble BOD$_5$ is 160 mg/L and that approximately 29% of the influent SS contribute to the total BOD$_5$. This information can be used to estimate the soluble BOD$_5$ fraction of the influent as shown in Figure 88; 90% of the soluble BOD$_5$ values are less than or equal to 230 mg/L and 10% less than or equal to 88 mg/L. The mean soluble influent BOD$_5$ is 160 mg/L.

Effluent total BOD$_5$ concentrations are shown in Figure 86. There are two distinct distributions. The average effluent BOD$_5$ is approximately 11 mg/L, with 90% of the observations being less than or equal to 31 mg/L and 10% less than or equal to 5 mg/L. Similar to the influent soluble BOD$_5$ determination the effluent soluble BOD$_5$ was calculated as shown in Figure 89. The best fit line for the data is described by the equation:

$$BOD_{5e} = 9.0 + 0.28\ SS_e \qquad (33)$$

Equation (38) shows that approximately 28% of the solids fraction contributes to the effluent BOD$_5$. The soluble BOD$_5$ as shown by equation (38) is 9.0 mg/L. When comparing effluent with the influent soluble BOD$_5$, this represents a soluble substrate conversion efficiency of 94%. The BOD$_5$ contribution by the effluent suspended solids is approximately 3 mg/L on average.

To check on this substrate conversion calculation and more specifically the value of the effluent soluble BOD$_5$, equation (3) as noted earlier was used:

$$BOD_5\ sol. = \frac{BOD_5}{(k_m t + 1)} \qquad (3)$$

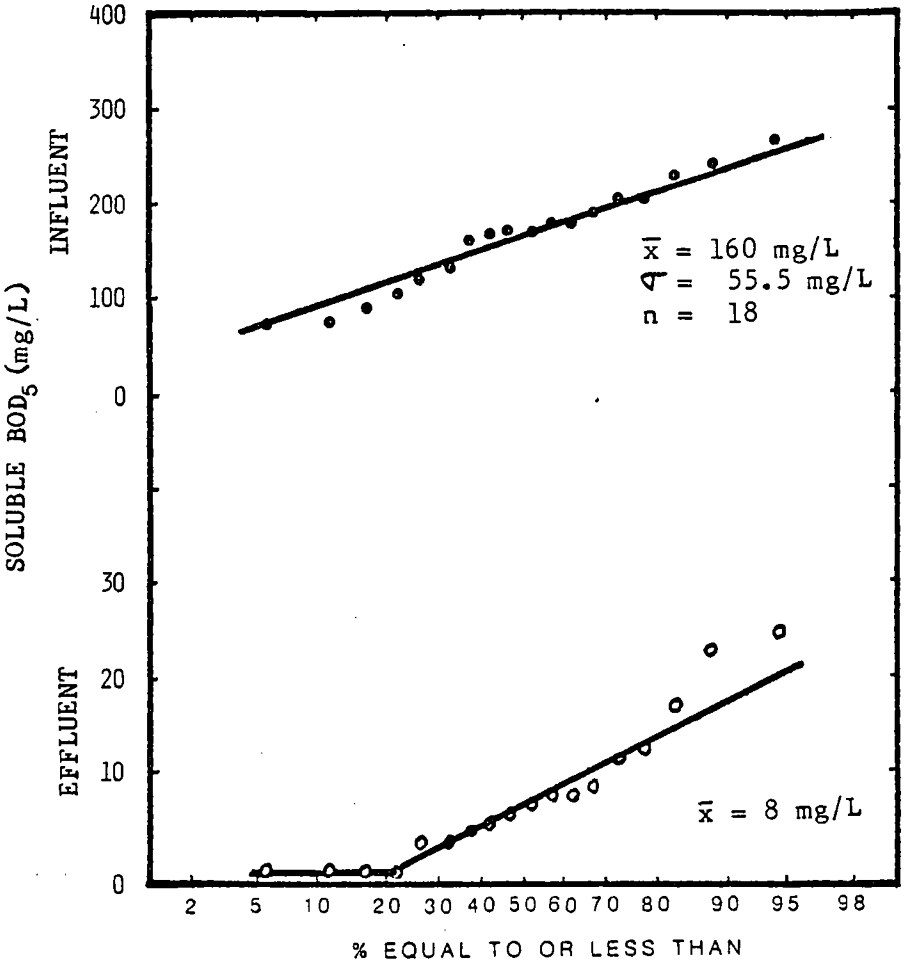

FIGURE 88 INFLUENT AND EFFLUENT SOLUBLE BOD_5 PROBABILITY DISTRIBUTION - RIVERCREST

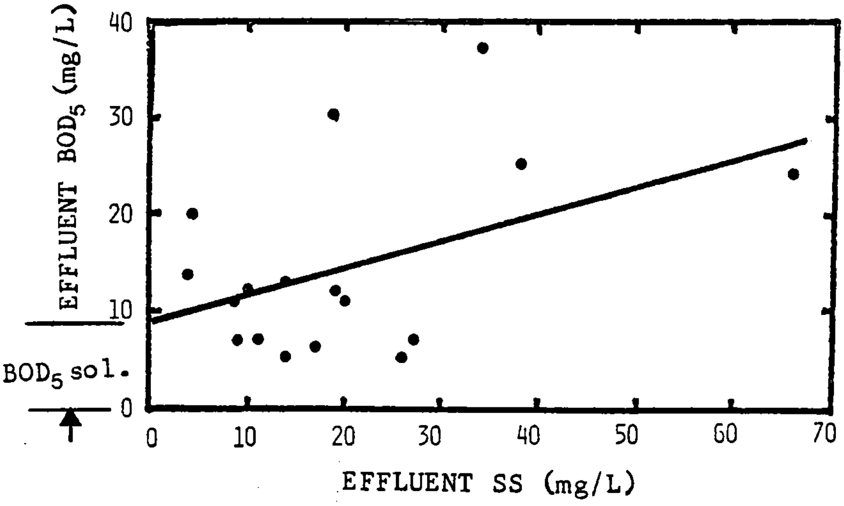

FIGURE 89 EFFLUENT BOD_5 vs EFFLUENT SS CORRELATION - RIVERCREST

For a standard domestic sewage the substrate conversion rate constant (k_m) was assumed to be 15/h.

The average liquid temperature was estimated to be 22 °C. The reaction rate constant (k_m) must be corrected to prevailing temperature using equation:

$$k_{mT} = k_{m20} \, (1.072)^{(T - 20)} \qquad (4)$$

Using equations (3) and (4)

$t = 1.5\text{h}$

$k_{m20} = 15 \ /\text{h}$

$BOD_5 in = 236 \text{ mg/L}$

$T = 20°\text{C}$

$$\text{EFFLUENT } BOD_5 \text{ sol.} = \frac{236}{(15 (1.5) + 1)} = 10 \text{ mg/L}$$

When considering the many assumptions made, the calculated effluent soluble BOD_5 concentration of 10 mg/L compares extremely well with the calculated mean effluent soluble BOD_5 of 8 mg/L as shown in Figures 88 and 9 mg/L in Figure 89.

Figure 88 shows the distribution of calculated soluble effluent BOD_5 concentrations. The mean value is 8.0 mg/L, with 90% of the values being equal to or less than 19 mg/L and 10% of the values being equal to or less than 2 mg/L.

The variations in influent and effluent BOD_5 concentrations over the investigative period are shown in Figure 90. The effluent BOD_5 stability in spite of 3 fold variations in influent BOD_5 concentrations is well illustrated.

6.3.3 Process loading

As shown in Figure 91 the calculated mean F/M value (g BOD_5 applied/kg MLVSS.d) is 323. 90% of the F/M observations are equal to or less than 430 and 10% equal to or less than 218. This loading is typical of a conventional activated sludge plant. The variation in F/M over the period of process monitoring is shown in Figure 92.

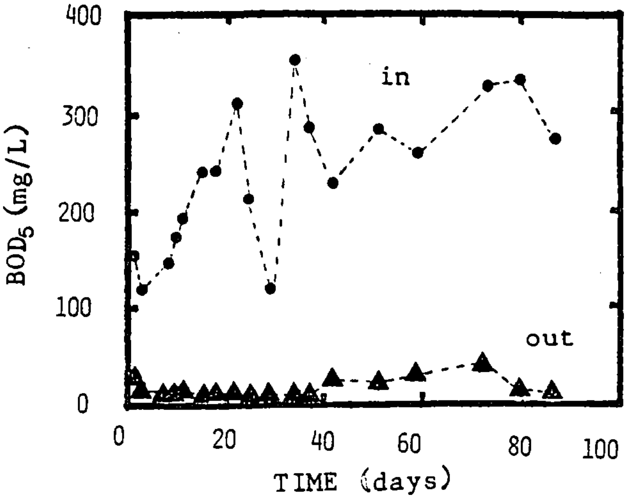

FIGURE 90 BOD_5 CONCENTRATIONS - INFLUENT AND EFFLUENT - RIVERCREST

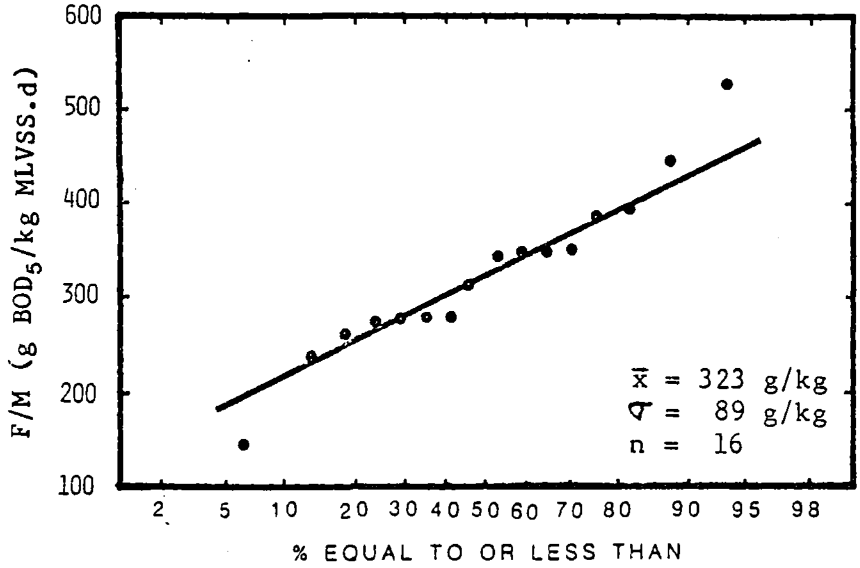

FIGURE 91 F/M PROBABILITY DISTRIBUTION - RIVERCREST

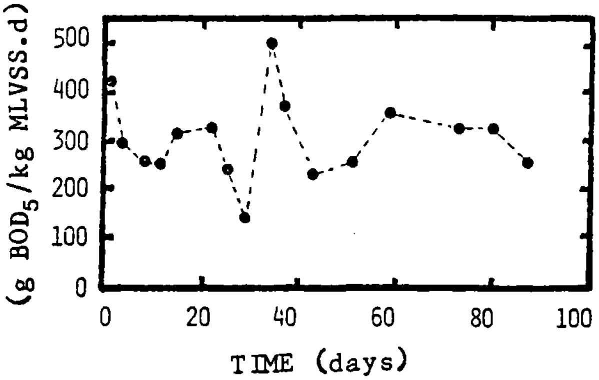

FIGURE 92 F/M VARIABILITY - RIVERCREST

6.3.4 Sludge growth

Sludge growth is the net result of substrate conversion and endogenous respiration. This is of prime interest in that it establishes the sludge management requirements for the process. Figure 93 shows the net increase in sludge concentration for 3 distinct periods over the monitoring period. As indicated by the decrease in sludge concentration, sludge was wasted every 20 to 30 days. This was done with the objective of operating in a MLSS concentration range of 2500 - 4500 mg/L. A steady-state sludge wasting program had still not been established at the time of this investigation. As shown in Figure 94, the distribution of MLSS, the average MLSS concentration was 2958 mg/L with 90% of the time values equal to or less than 4000 mg/L and 10% equal to or less than 1900 mg/L.

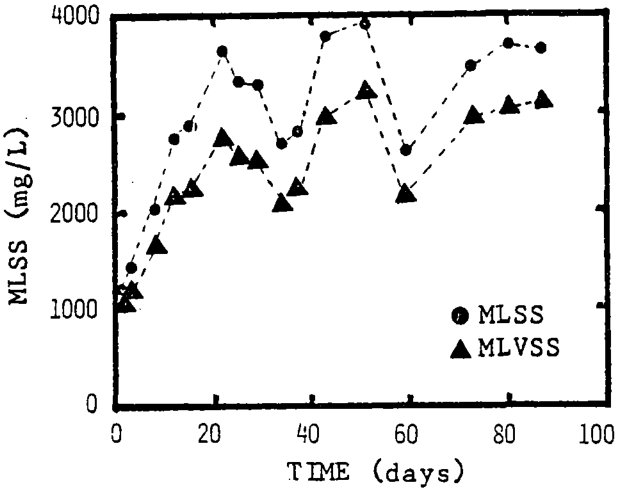

FIGURE 93 MLSS CONCENTRATIONS - RIVERCREST

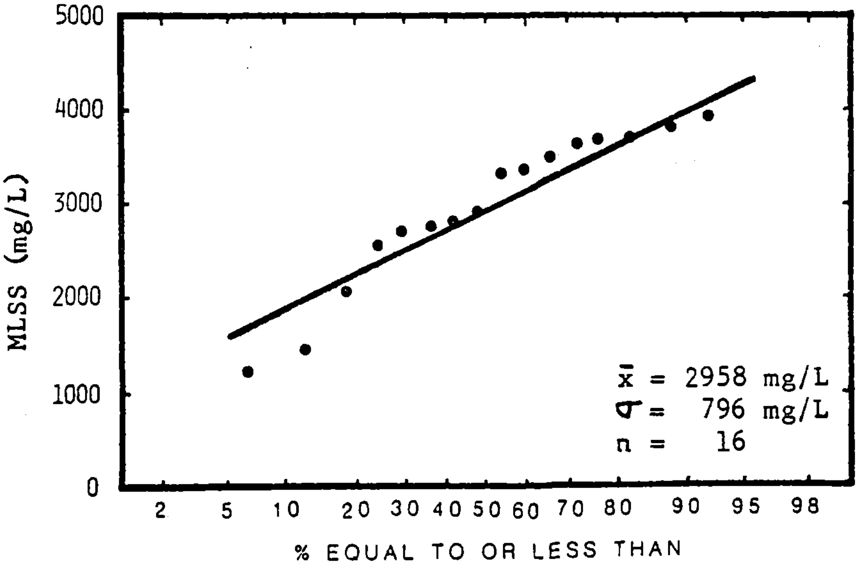

FIGURE 94 MLSS PROBABILITY DISTRIBUTION - RIVERCREST

The volatile solids fraction of the MLSS averaged 0.807, with 90% being less than or equal to 0.848 and 10% being less than or equal to 0.762 (Figure 95).

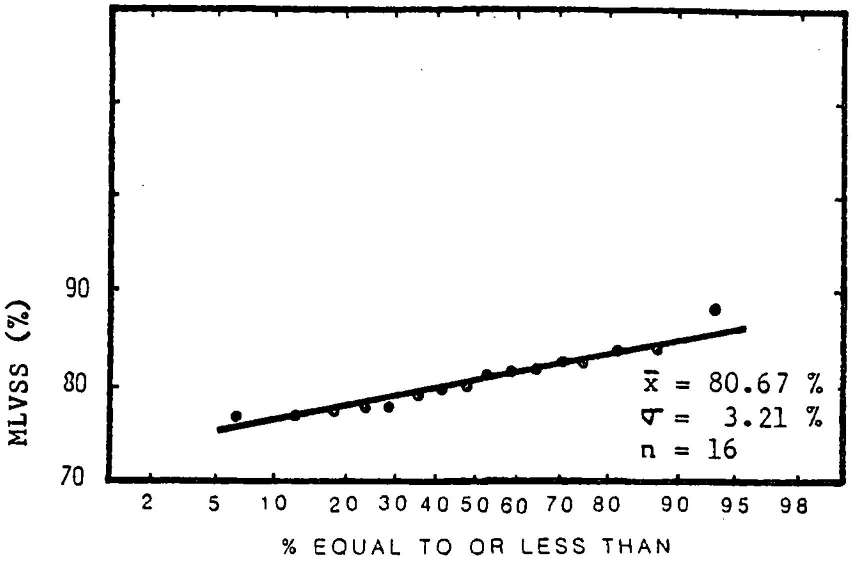

FIGURE 95 PERCENT VS IN MLSS PROBABILITY DISTRIBUTION - RIVERCREST

Analysis of the MLVSS data results in the following regression equations for the respective periods between sludge wasting:

Period day	No. of data n	Equation		Regression Coeff. r
1 - 22	6	MLVSS = 1018 + 83.8t	(34)	0.982
34 - 51	4	MLVSS = 2077 + 69.9t	(35)	0.941
59 - 87	4	MLVSS = 2207 + 35.6t	(36)	0.932

From equations (34 to (36) the rate of change in MLVSS can be determined by differentiating the equations with respect to time. Therefore; for equation (34):

$$\frac{dC_v}{dt} = 83.8 \text{ mg/L.d}$$

multiplying the concentration change with the liquid volume of the reactor V, changes the values to a mass basis.

$$V \frac{dC_v}{dt} = \frac{dX_v}{dt} \qquad (10)$$

For Glenlea:

$$72.6\ m^3 \left(\frac{83.8\ g}{m^3 \cdot d} \right) = 6.08\ kg/d = \frac{dX_v}{dt}$$

Values for dXv/dt and Xv are calculated and summarized in Table 14. Plotting dXv/dt versus Xv as shown in Figure 96 and calculating the best fit line for the data yields the equation:

$$\frac{dX_v}{dt} = 8.42 - 0.030\ X_v \qquad (37)$$

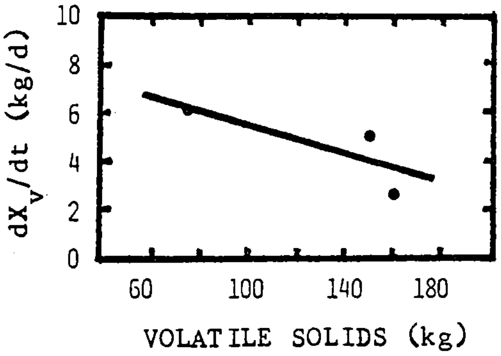

FIGURE 96 BIOMASS GROWTH RATE - RIVERCREST

TABLE 14 - BIOMASS GENERATION SUMMARY

$-\frac{dCv}{dt}$	V	Cv	Xv	$\frac{dXv}{dt}$
mg/L.d	m^3	mg/L	kg	kg/d
83.8	72.6	1018	73.9	6.08
69.9		2077	150.8	5.07
35.6		2207	160.2	2.58

From equation (42) the specific growth rate μ, is determined to be 0.030/day. This means that the average minimum SRT should be:

$$SRT = \frac{1}{\mu} = \frac{1}{0.030} = 33 \text{ days} \qquad (15)$$

The minimum SRT during the monitoring period was 43 days.

Figure 97 shows the distribution of volatile solids production per day. The average net volatile solids production is 4.58 kg/d with 90% of the values equal to or less than 6.50 kg/d and 10% equal to or less than 2.60 kg/d.

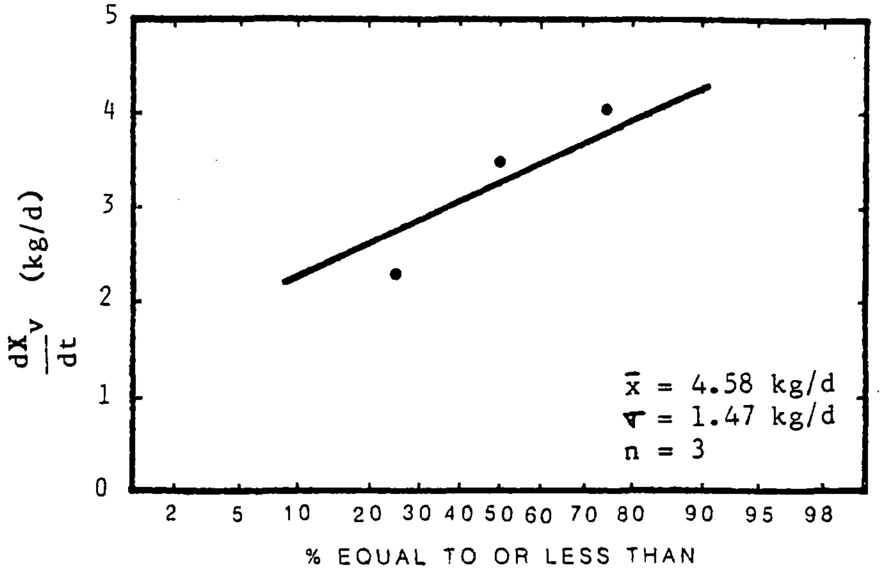

FIGURE 97 BIOMASS GROWTH RATE PROBABILITY DISTRIBUTION - RIVERCREST

Comparing sludge production (VS) with the soluble BOD_5 converted:

$$\frac{(\text{INFLUENT BOD}_5\text{sol.} - \text{EFFLUENT BOD}_5\text{sol.})\ (Q)}{1000} = \text{BOD}_5\,\text{sol.(kg/d)} \qquad (16)$$

$$\frac{(\ 160 - 8\ )(\ 227\ )}{1000} = 34.5 \text{ kg BOD}_5\,\text{sol./d}$$

one can calculate the amount of biomass produced per unit of soluble substrate removed as:

$$\frac{4.58 \text{ kg VS/d}}{34.5 \text{ kg BOD}_5\,\text{sol./d}} = 0.13 \text{ kg VS/kg BOD}_5\,\text{sol.}$$

The extremely low net mass of VS produced per day would lead one to conclude that much of the volatile suspended solids are aerobically digested because of the long cell residence time in the system.

It must be remembered that the process substrate is a settled domestic sewage.

Insofar as sludge production for the whole installation is concerned, this is the total of the solids removed through presettling plus the solids increase in the reactor. This has been calculated as follows:

SSin = 200 mg/L
SSsettl = $\underline{31}$ mg/L
169 mg/L = primary sludge (SSps)
MLSS increase = 115 mg/L.d
MLSS = 115 mg/L.d x 72.6 m^3 = 8.35 kg/d
SSps = 169 mg/L x 227 m^3/d = 38.36 kg/d
Total sludge production 46.71 kg/d

Total amount of BOD_5 removed = 236 - 11 = 225 mg/L
225 mg/L x 227 m^3/d = 51.08 kg/d

Therefore sludge production = $\frac{46.71}{51.08}$ = 0.91 kg sludge/kg BOD_5 removed

This value is remarkably close to the rule of thumb value of 1 kg of sludge produced per kg of substrate removed.

6.3.5 Sludge settleability

The variation of the SVI over the period during which samples were taken is illustrated in Figure 98. A probability analysis of the SVI data indicates a mean value of 120, with 90% of the data being equal to or less than 180 and 10% equal to or less than 78 (Figure 99).

The sludge at the Rivercrest treatment plant exhibited excellent settling characteristics.

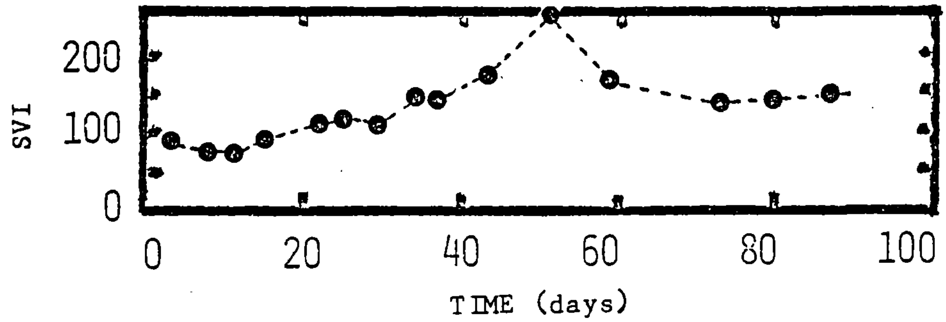

FIGURE 98 SVI HISTORY AT RIVERCREST

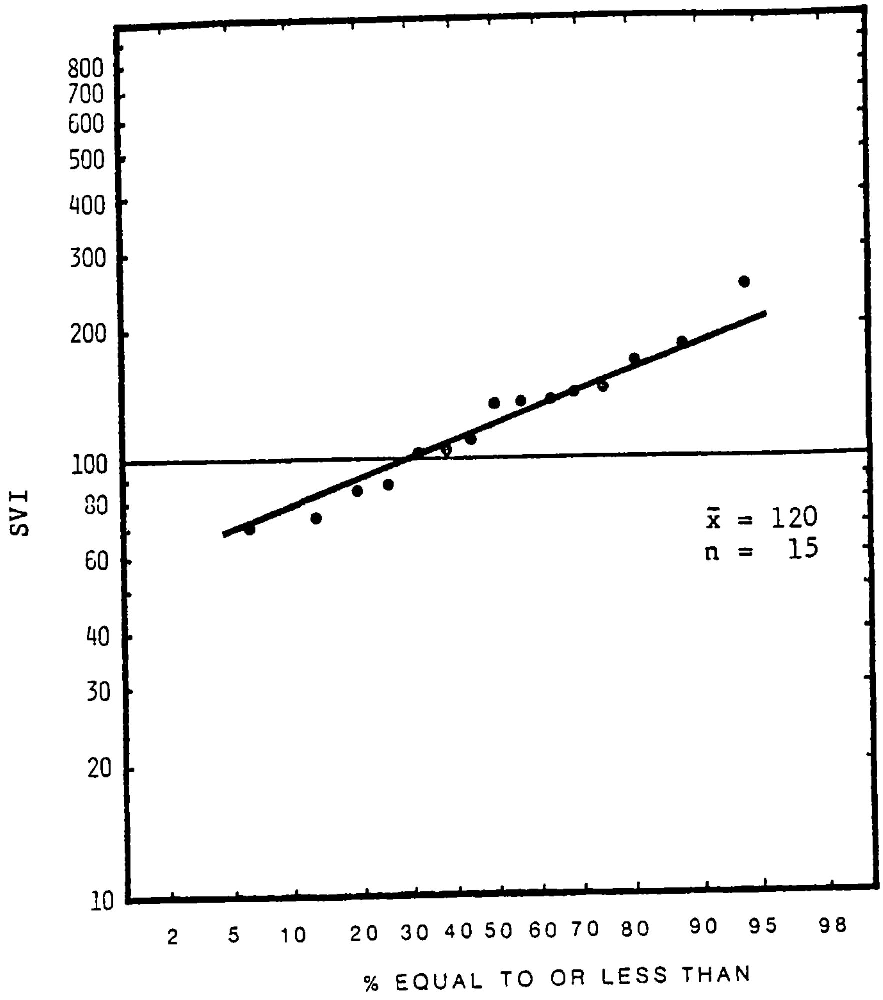

FIGURE 99 SVI PROBABILITY DISTRIBUTION - RIVERCREST

6.3.6 Sludge wasting

During the process monitoring period sludge was wasted periodically as shown in Figure 93. Sludge bulking was experienced toward the end of the test period. At that time 9 m^3 of sludge were wasted on six separate occasions. The settleable solids had increased to 500 ml/L. Sludge wasting presented no particular problem since the sludge was pumped to the aerobic digester. During the monitoring period no sludge had to be wasted from the aerobic digestor.

6.3.7 Suspended solids

It should be noted that the process influent is a settled sewage. Calculations indicate that 84% removal of SS occured in the settling section. The SS concentration to the bioreactor was calculated to be 32 mg/L.

The distribution of the unsettled influent suspended solids (SS) is illustrated in Figure 100. Two distinct distributions were observed; as well, the distribution is not normal. From Figure 100 a mean influent SS concentration of 200 mg/L was determined with 90% of the values equal to or less than 660 mg/L and 10% equal to or less than 106 mg/L. The solids concentrations are highly variable.

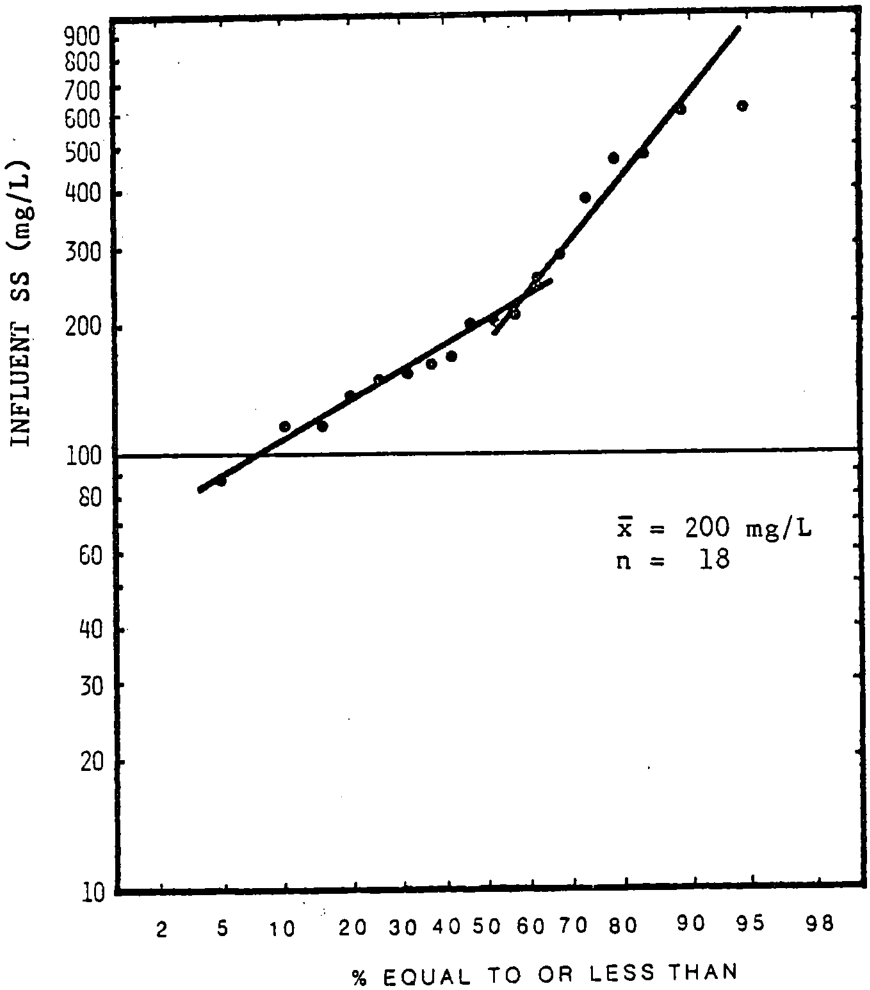

FIGURE 100 INFLUENT SS PROBABILITY DISTRIBUTION - RIVERCREST

The influent BOD_5 to SS ratio was determined to have an average value of 0.95. Ninety percent of the values are equal to or less than 1.85 and 10% equal to or less than 0.55 (Figure 101). For normal domestic sewage the ratio is close to 1.0.

The effluent SS distribution is shown in Figure 102. The distribution is log normal, with a mean value of approximately 15 mg/L with 90% of the concentrations equal to or less than 41 mg/L and 25% equal to 9 mg/L.

The influent and effluent SS concentrations determined during this program phase are illustrated in Figure 103.

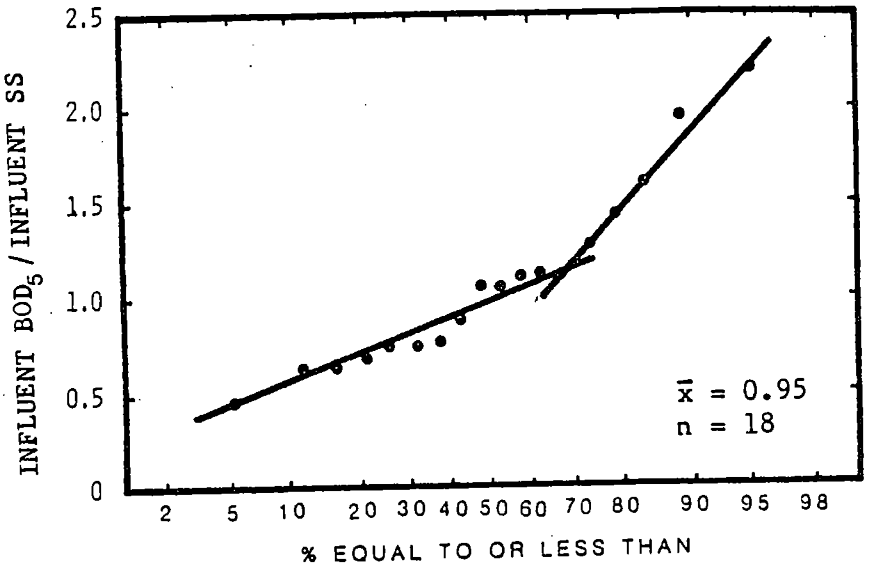

FIGURE 101 INFLUENT BOD$_5$/SS RATIO PROBABILITY DISTRIBUTION - RIVERCREST

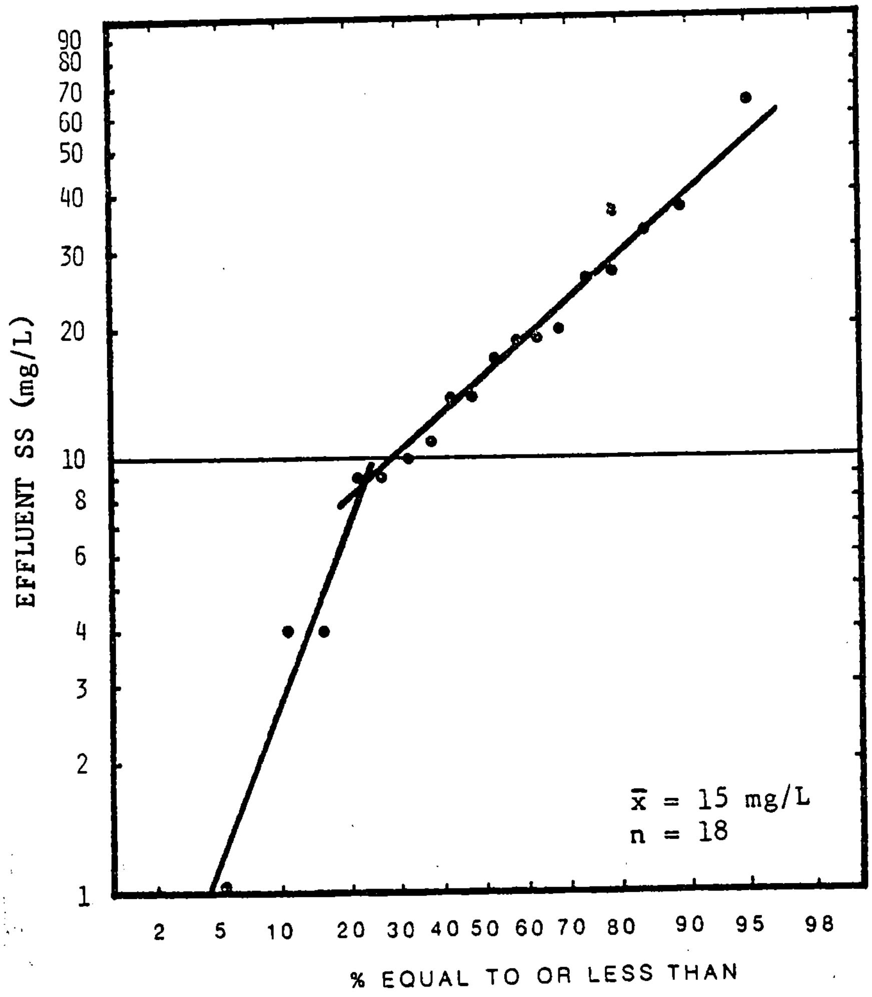

FIGURE 102 EFFLUENT SS PROBABILITY DISTRIBUTION - RIVERCREST

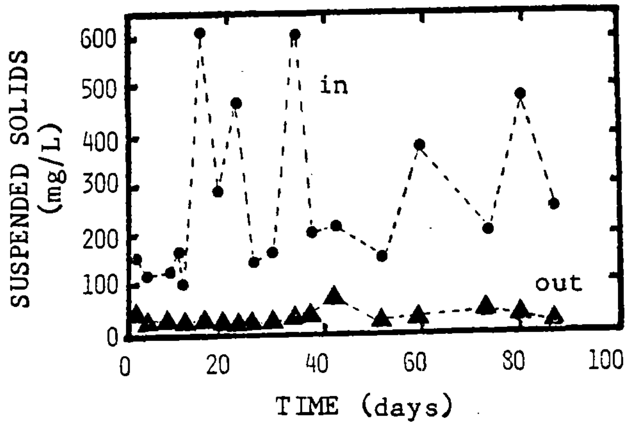

FIGURE 103 INFLUENT AND EFFLUENT SS VARIATIONS - RIVERCREST

The reason for the high mean SS effluent concentration of 15 mg/L is unknown. This high effluent SS also contributes approximately 4 mg/L of BOD_5 to the total effluent BOD_5 measured at 11 mg/L.

6.3.8 Nitrification/denitrification

The water supply source at Rivercrest is from a ground water source. Hence the alkalinity of the wastewater is relatively high. As shown in Figure 104, the mean influent alkalinity is 545 mg/L. Ninety percent of the observations are equal to or less than 575 mg/L and 10% equal to or less than 520 mg/L.

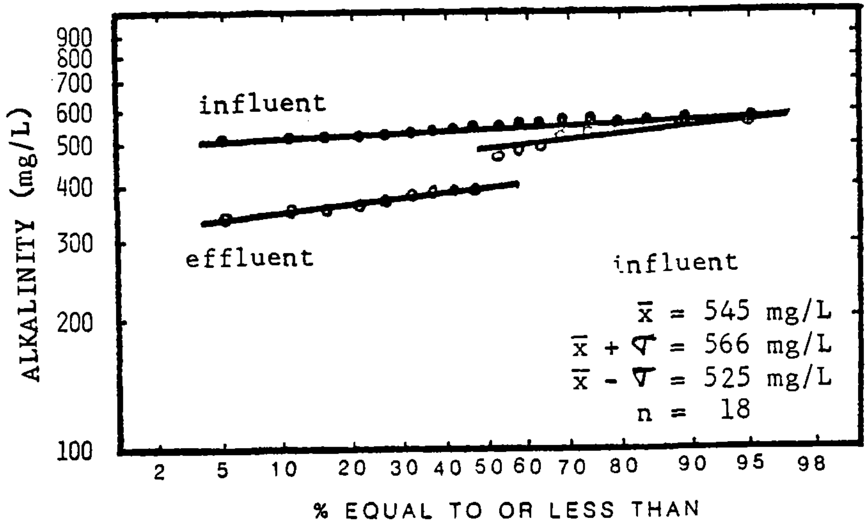

FIGURE 104 INFLUENT AND EFFLUENT ALKALINITY PROBABILITY DISTRIBUTION - RIVERCREST

The influent NH_4-N concentrations summarized in Figure 105 show a mean of only 37 mg/L with 90% of the values equal to or less than 46 mg/L and 10% equal to or less than 29 mg/L.

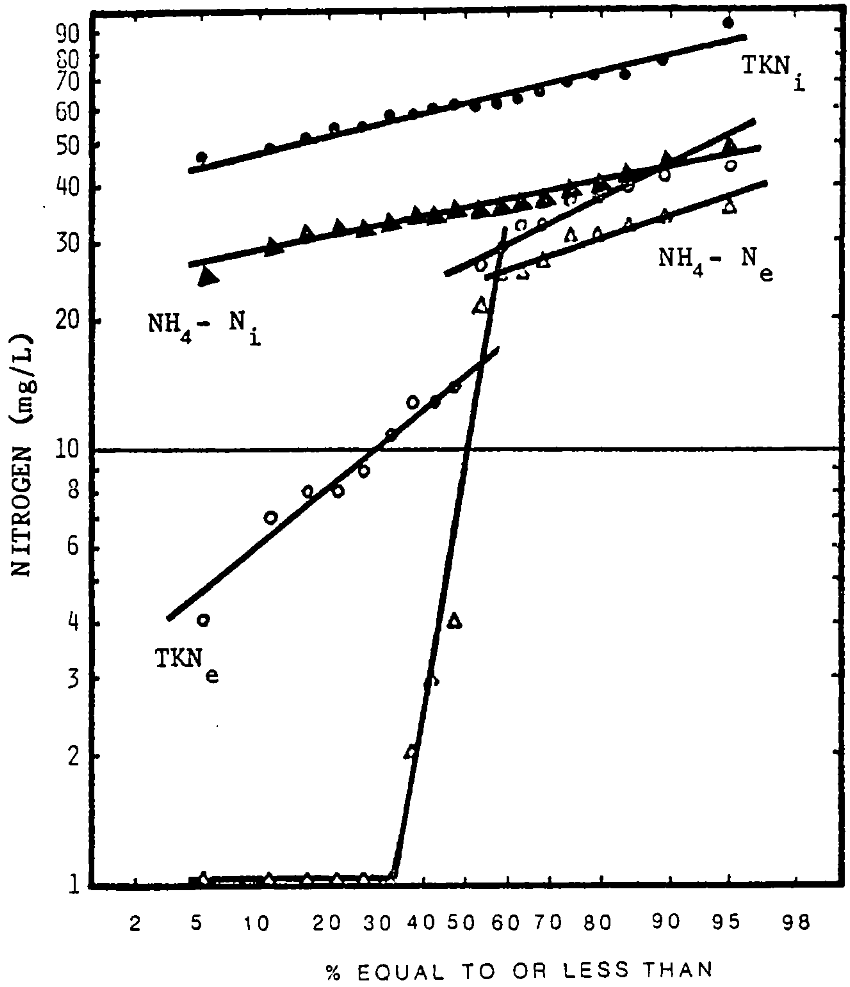

FIGURE 105 INFLUENT AND EFFLUENT NH_4- N AND TKN PROBABILITY DISTRIBUTION - RIVERCREST

Effluent NH_4-N concentrations shown in Figure 105 indicate a mean value of 10 mg/L with 90% of the observations being equal to or less than 35 mg/L and 35% equal to or less than 1 mg/L. This represents 73% NH_4-N removal. It should be noted from Figure 103 that when nitrification ceased, the effluent NH_4-N concentration increased substantially.

The effluent alkalinity concentrations shown in Figure 104 indicate a mean value of 400 mg/L. Ninety percent of the values are equal to or less than 550 mg/L and 10% equal to or less than 350 mg/L. Clearly, sufficient alkalinity for nitrification was available.

The alkalinity used to NH_4-N oxidized ratio, while stoichiometrically is 7.6, was determined to average 4.7 (Figure 106) with 90% of the calculated ratios equal to or less than 5.6 and 10% equal to or less than 3.5.

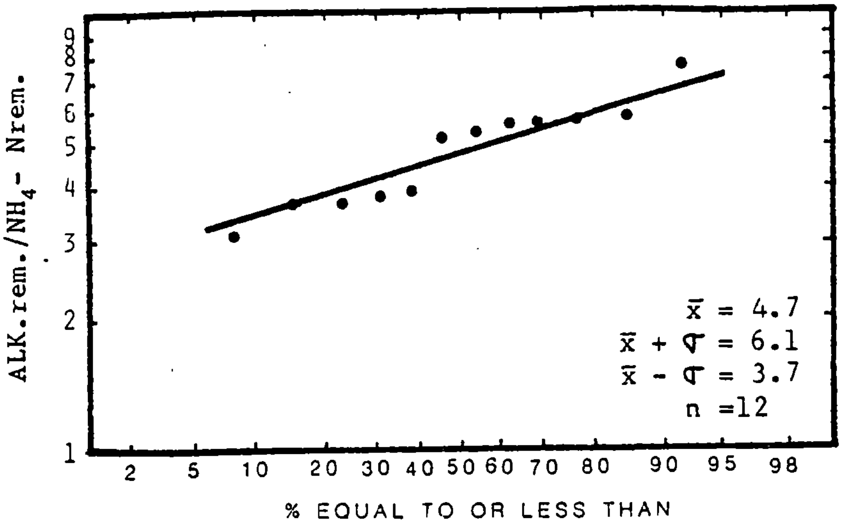

FIGURE 106 ALKALINITY REMOVED TO NH_4- N OXIDIZED PROBABILITY DISTRIBUTION - RIVERCREST

The minimum SRT required for nitrification, was determined using equation (21) (see Section 4.4.8).

$$\mu = (0.392 \text{ pH} - 2.35) e^{0.098 (T - 15)} \qquad (21)$$

The average pH of the mixed liquor was 6.5 and the average temperature 20 °C. The net growth rate for the nitrifiers under these conditions is:

$$\mu = (0.392 (6.9) - 2.35) e^{0.098 (20 - 15)}$$

$$\mu = 0.579 \ / \ \text{day}$$

Under these conditions the minimum required SRT at Rivercrest for nitrification to occur is:

$$\text{SRT} = \frac{1}{\mu} = \frac{1}{0.579} = 1.7 \text{ days}$$

The SRT was calculated to be 45 to 54 days. Hence, conditions for nitrification were always present.

The NH_4-N load to the plant can also be expressed on the basis of g of NH_4-N applied/kg MLVSS.d. Figure 107 shows the distribution of these data. The mean value is 43 g NH_4-N applied/kg MLVSS.d and ranged between 55 and 33 for 90% and 10% of the values being equal to or less than those stated, respectively.

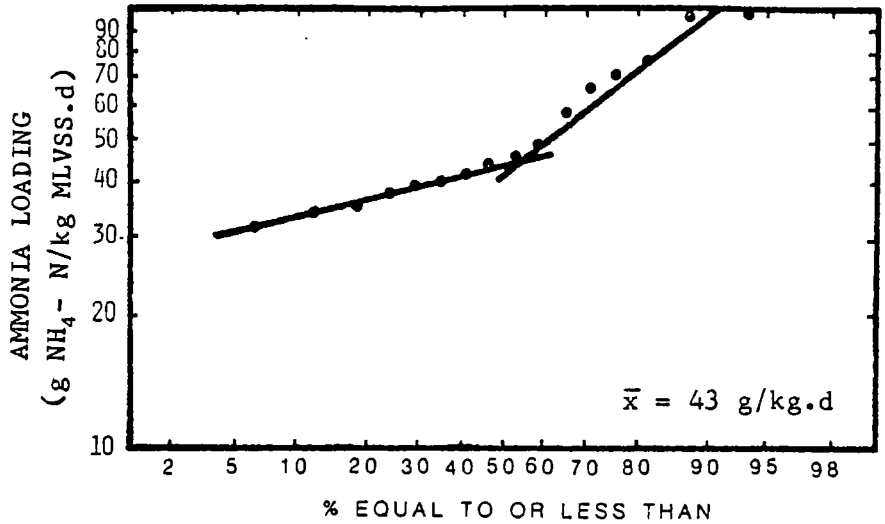

FIGURE 107 NH_4- N PROCESS LOADING PROBABILITY DISTRIBUTION - RIVERCREST

Another way of stating NH_4-N removal efficiency is based on the mass of NH_4-N removed per day per unit mass of MLVSS. Figure 108 illustrates this concept. The mean rate is 44 g NH_4-N removed/kg MLVSS.d. Ninety percent of the values are equal to or less than 57 and 10% are equal to or less than 30.

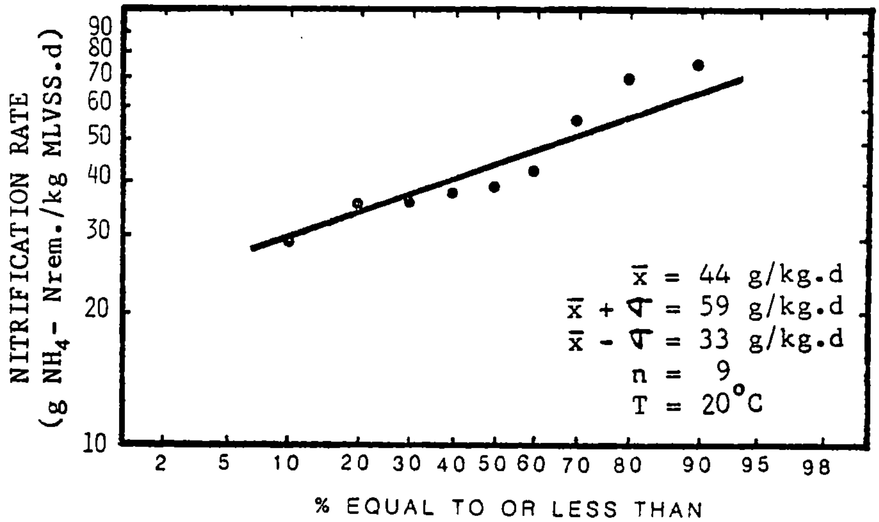

FIGURE 108 NH_4- N REMOVED PER UNIT MLVSS PROBABILITY DISTRIBUTION - RIVERCREST

For normal domestic sewage the nitrification rate could be predicted by equation:

$$n_{rT} = 0.0071\ T^{2.89} \qquad (22)$$

For the Rivercrest installation at a mixed liquor operating temperature of 20 °C, the nitrification rate should be 41 g NH_4-N removed/kg MLVSS.d. This compares extremely well to the relationship shown in Figure 36.

Figure 109 illustrates the variability of the influent and effluent NH_4-N data over the entire monitoring period. The time when nitrification occured is clearly defined by the data.

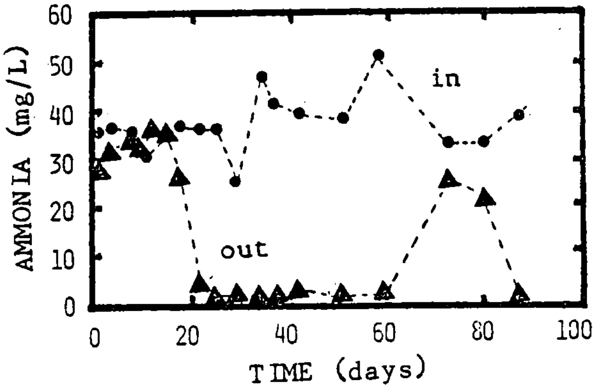

FIGURE 109 INFLUENT AND EFFLUENT NH_4- N VARIATIONS - RIVERCREST

The NO_3-N concentration distributions are shown in Figure 110. The data are log normally distributed with an average value of 2.5 mg/L with 90% of the observations equal to or less than 26 mg/L and 40% equal to or less than 1 mg/L. Nitrification and lack thereof are clearly indicated.

Figure 111 shows the relationship between the NO_3-N generated and NH_4-N oxidized.

The data illustrate that more NH_4-N was oxidized than NO_3-N measured in the effluent. This leads to the conclusion that a significant degree of denitrification occured.

6.3.9 Nitrogen removal

Examination of the influent and effluent organic nitrogen data (Figure 112) indicates that a significant amount of organic nitrogen has been removed. The influent mean organic nitrogen concentration was 26 mg/L with 90% of the values equal to or less than 35 mg/L and 10% equal to or less than 19 mg/L.

Effluent organic nitrogen had a mean concentration of 8 mg/L with 90% of the concentrations being equal to or less than 11 mg/L and 10% equal to or less than 4 mg/L. This represents an average reduction in organic nitrogen of 69%.

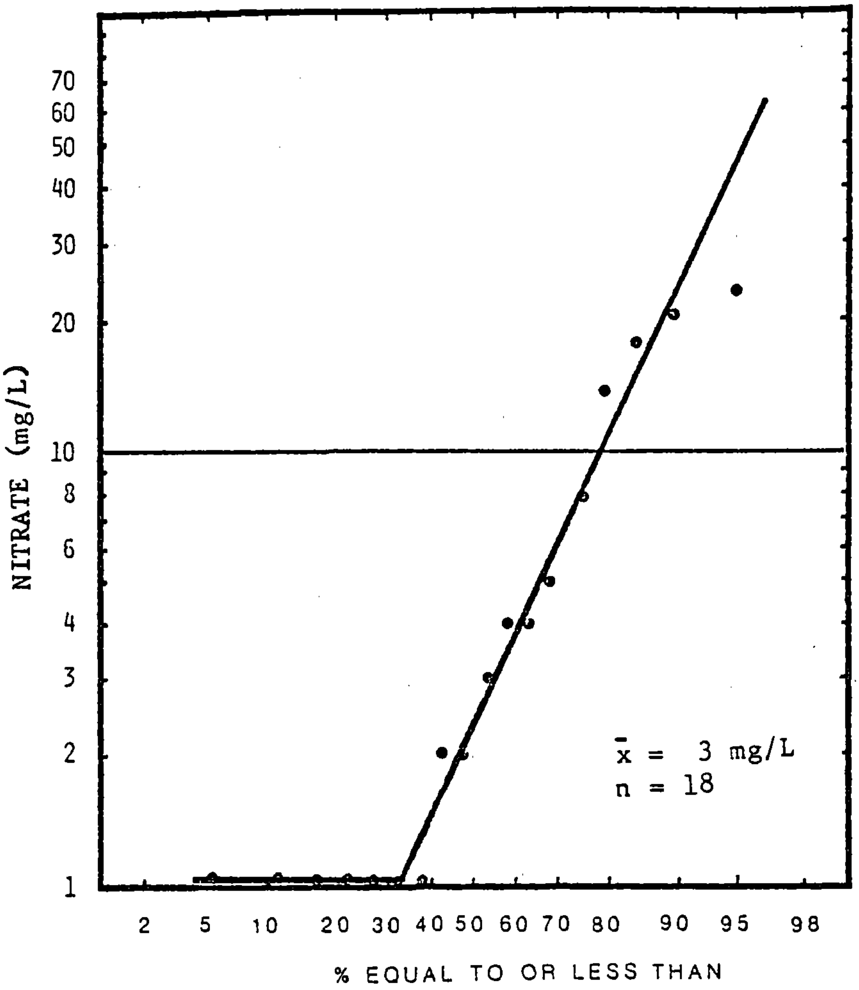

FIGURE 110 NO_3- N PROBABILITY DISTRIBUTION - RIVERCREST

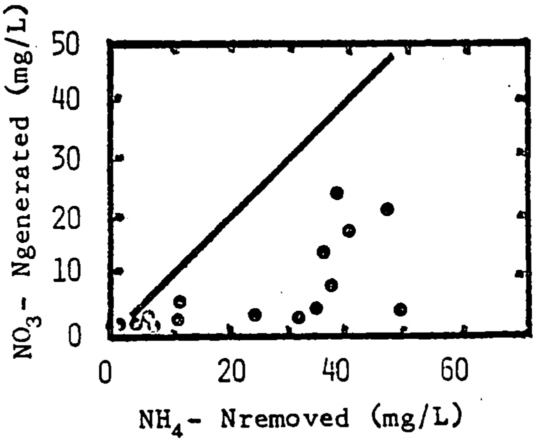

FIGURE 111 NO_3- N GENERATED TO NH_4- N OXIDIZED RELATION - RIVERCREST

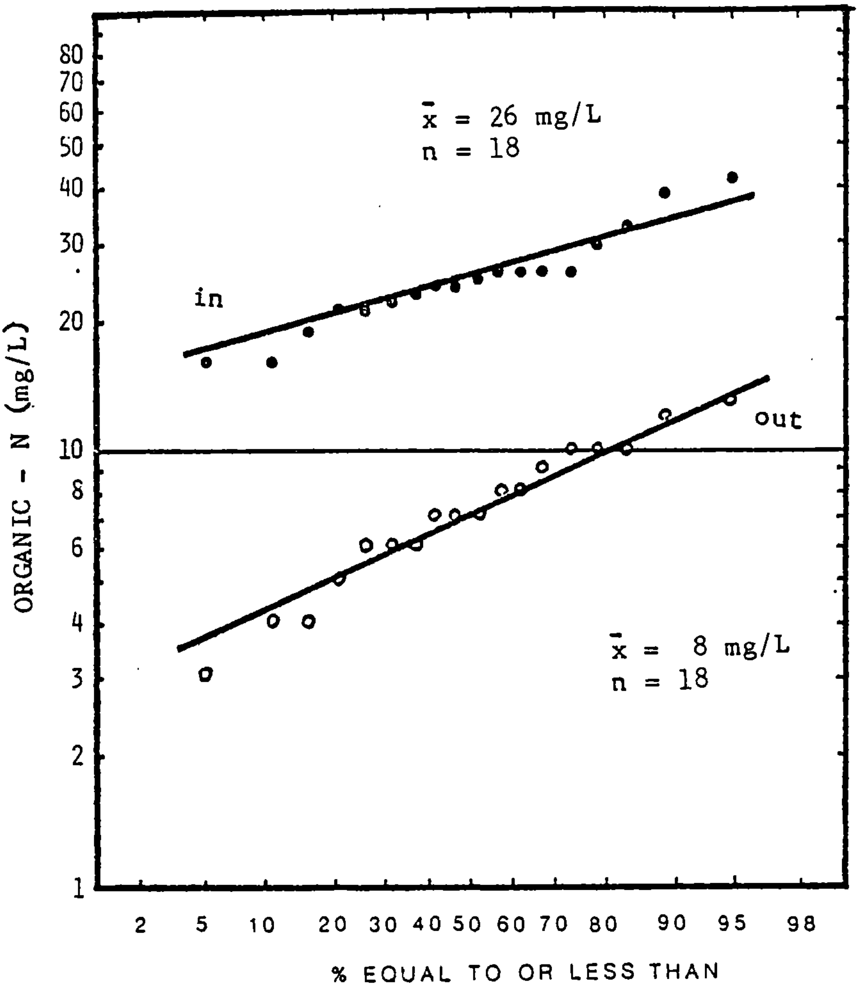

FIGURE 112 INFLUENT AND EFFLUENT ORGANIC - N PROBABILITY DISTRIBUTION - RIVERCREST

On a total Kjeldahl nitrogen (TKN) basis the mean influent concentration was determined to be 62 mg/L (Figure 105). Ninety percent of the distribution has values equal to or less than 80 mg/L and 10% equal to or less than 47 mg/L.

The effluent mean TKN concentration was calculated to be 27 mg/L (Figure 105) with 90% of the values equal to or less than 46 mg/L and 10% equal to or less than 6 mg/L. TKN removal averaged 56%.

Examining the removal of total nitrogen (TN), the influent TN is represented by the influent TKN. The effluent TN is equal to:

$$\text{EFFLUENT TN} = (\text{TKN}) + (NO_3 - N) + (NO_2 - N) \qquad (24)$$

Figure 113 shows the effluent TN concentration distribution. The mean value was calculated to be 33 mg/L with 90% of the values being equal to or less than 43 mg/L and 10% being equal to or less than 9 mg/L. Total nitrogen removal was therefore 47%.

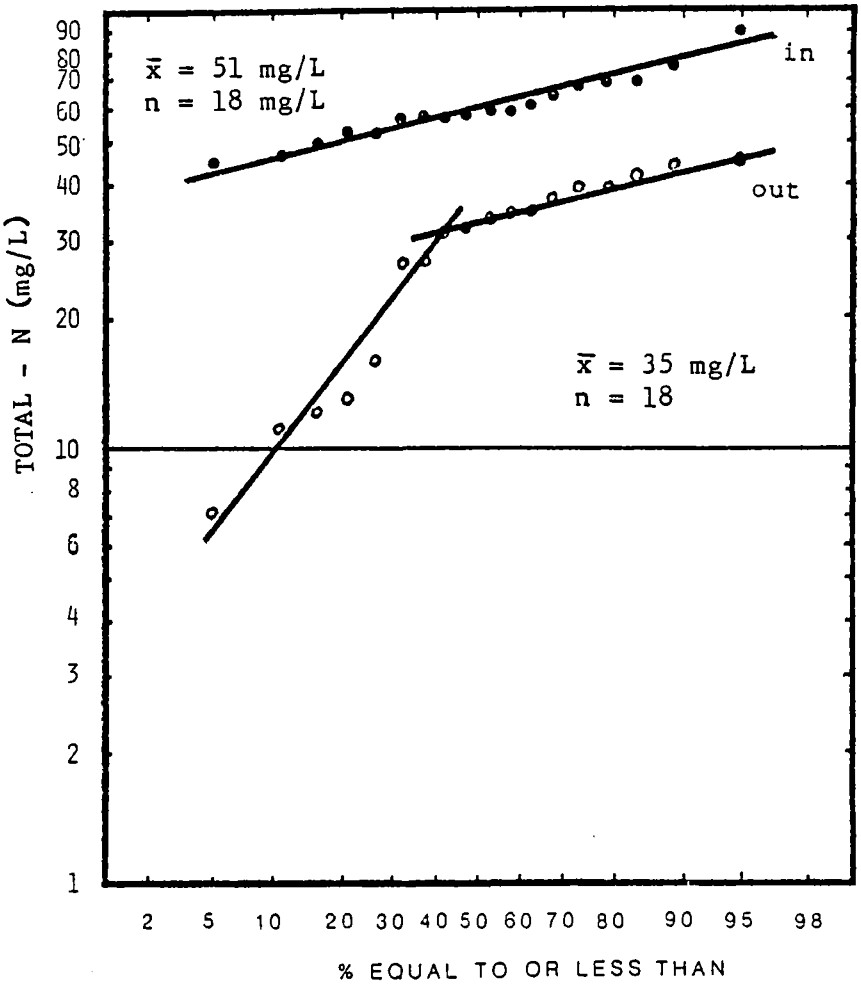

FIGURE 113 INFLUENT AND EFFLUENT TN PROBABILITY DISTRIBUTION - RIVERCREST

From nitrogen balance analyses for the system (Appendix D) it was established that:

nitrification efficiency = 67 %
denitrification efficiency = 93 %

It was calculated that the NO_3-N lost due to denitrification was 39 mg/L. The calculated NO_3-N concentration decrease due to denitrification can be used to obtain an estimate of the peak denitrification rate, expressed as kg NO_3-N removed per kg MLVSS per day (r_{DN}).

$$r_{DN} = \frac{(NO_3-N_r)(Q)}{(MLSS)(\%VS)(V)} \tag{25}$$

where:

$NO_3\text{-}N_r$ = oxidized nitrogen concentration decrease, mg/L
Q = average waste flow, m^3/d
MLSS = average mixed liquor suspended solids concentration in reactor, mg/L
% VS = percent volatile solids in reactor, fraction
V = liquid volume in reactor, m^3

substituting the appropriate values into equation (31)

$$r_{DN} = \frac{(39)(227)}{(2958)(0.807)(72.6)}$$

$$= 0.051 \text{ kg oxidized N removed/ kg MLVSS.d}$$

$$T = 20^\circ C$$

The peak denitrification rate of 0.051 compares with the data for combined systems with wastewater as the carbon source as shown in Figure 49.

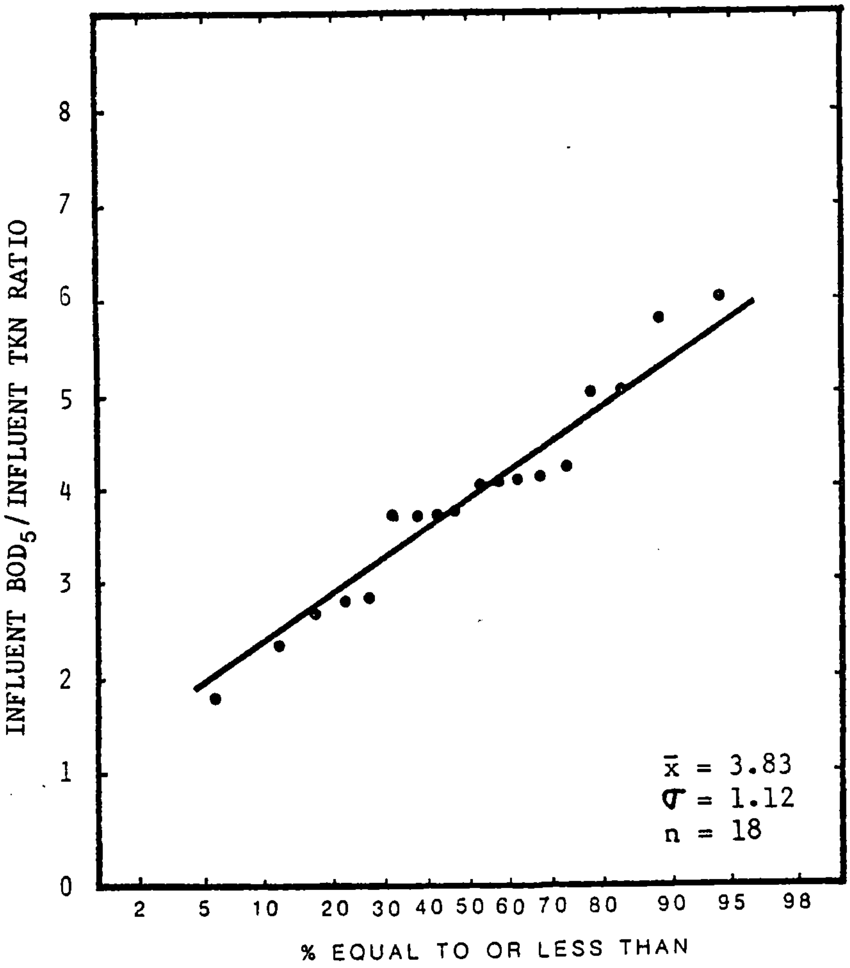

FIGURE 114 BOD_5/TKN PROBABILITY DISTRIBUTION - RIVERCREST

For denitrification to occur a minimum BOD_5/TKN ratio of 3.5 is required. Figure 114 shows that the average BOD_5/TKN ratio for the Rivercrest installation is 3.83. Ninety percent of the distribution has values equal to or less than 5.30 and 10% equal to or less than 2.35.

Similar to both the Glenlea and the Hudson Bay Mining and Smelting installations all requirements for full nitrification and denitrification are present at Rivercrest. Process optimization could attain full nitrogen removal.

This data analysis has illustrated that both a high degree of carbon and nitrogen removal can be accomplished. However the high leakage of soluble BOD_5 (8 mg/L) could be reduced by making appropriate process operating changes.

6.3.10 Phosphorus removal

The influent total phosphorus data distribution shows a mean value of 9 mg/L with 90% of the values equal to or less than 11 mg/L and 10% equal to or less than 7 mg/L. (Figure 115)

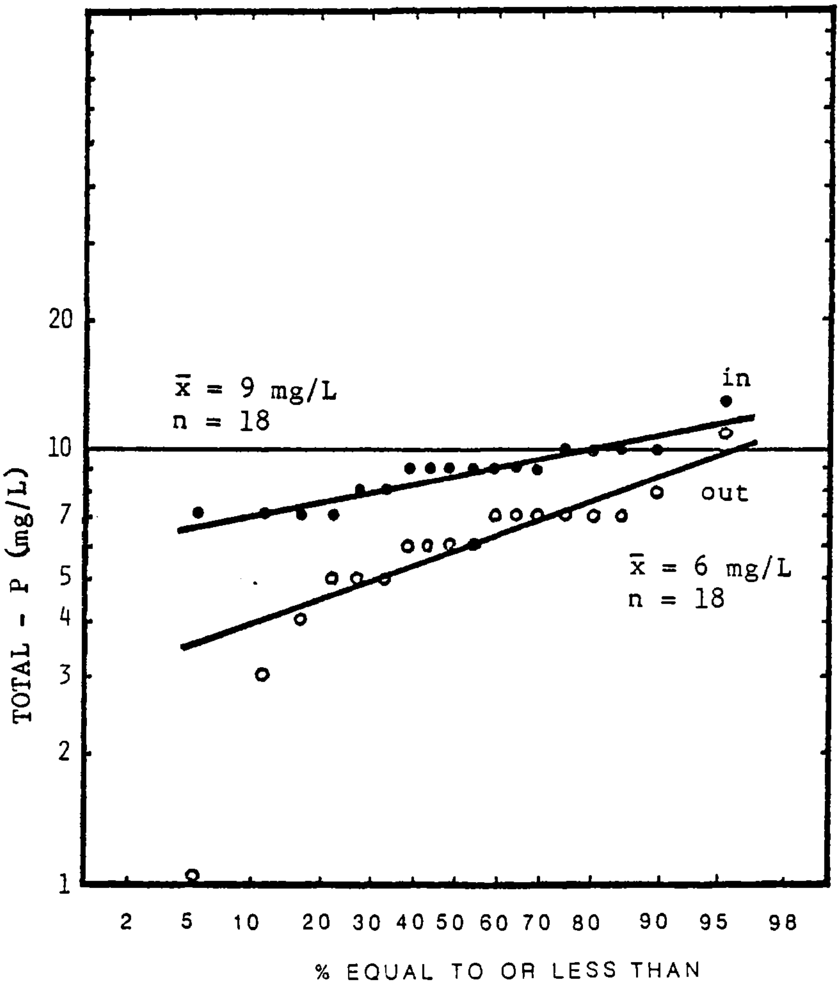

FIGURE 115 INFLUENT AND EFFLUENT TP PROBABILITY DISTRIBUTION - RIVERCREST

Effluent total phosphorus concentrations as shown in Figure 112 have a mean value of 6 mg/L. Ninety percent of the distribution has values equal to or less than 9 mg/L and 10% equal to or less than 4 mg/L.

The influent and effluent total phosphorus concentrations during the time of process assessment are shown in Figure 116.

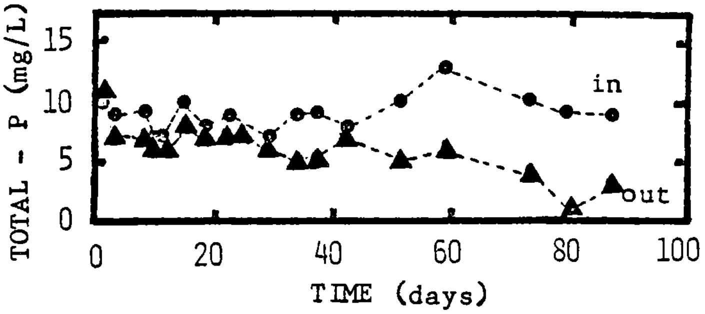

FIGURE 116 INFLUENT AND EFFLUENT TP VARIATIONS - RIVERCREST

6.4 Energy & Mixing Requirements

Process energy and mixing energy requirements are summarized by the following data:

Hydraulic load (m^3/d)	227
Organic load (kg BOD_5/d)	53.5
Organics removed (kg BOD_5/d)	51.1
Connected power (Appendix C):	
Compressor (kW)	4.62
Effluent pumps (kW)	0.33
Sludge pumps (kW)	0.75
Transfer pumps (kW)	0.75
Total	6.45 kW

The total connected power at Rivercrest is 6.45 kW. Knowing the running times for the compressor and pumps permits calculation of the daily power use.

Compressor run time per day	10.2 h
Effluent pumping time per day	8.9 h
Transfer pumps running time per day	8.9 h

Correlating this information with the connected power results in calculated power used as follows:

Compressor	(10.2 h x 4.62 kW)	47.1 kWh
Effluent Pumps	(8.9 h x 0.33 kW)	2.9 kWh
Transfer Pumps	(8.9 h x 0.75 kW)	6.7 kWh
(Use of sludge pumps is negligible)		
Total power drawn daily		56.7 kWh

No allowances for either electrical or mechanical efficiencies of the process components are included.

The above information can be used to express process power requirements on a more standardized basis. However, since aerobic digestion of sludge is practised at this installation and 10% of the air-flow is diverted from the compressor, an appropriate power correction must be made so that the power requirements for the systems reported on in this report can be compared.

By making the appropriate adjustment in power drawn by the compressor, the process energy per unit organic and volumetric load parameters are:

1.38 kWh/kg BOD_5 applied
or 1.45 kWh/kg BOD_5 removed
or 0.414 kWh/m^3 of waste

Another important consideration is how much aeration energy is required per unit of substrate removed. For this installation it is calculated to be 1.18 kWh/kg BOD_5 removed. This indicates that approximately 82% of the process energy requirements (excluding aerobic sludge digestion) are associated with aeration only.

The mixing energy input is calculated to be 0.06 kW/m^3.

Air supply when based on quantity of substrate removed was calculated to be 91 m^3/kg BOD_5 removed. For an $F/M > 0.3$ the air supply range for design purposes is taken as 30 - 55 m^3/kg BOD_5 removed. The available air supply is more than adequate.

When air supply is expressed on a volumetric basis (waste flow) it can be calculated that for this installation this parameter is 13.7 m^3 air/m^3 waste. The rule of thumb quantity when multiplied by a safety factor of 2 is 15 m^3 air/m^3 waste. As before, the air supply just meets this criterion. On a MLSS basis, the air supply is calculated to be 1.42 m^3 air/h.kg MLSS. All energy and mixing parameters are summarized in Table 15.

It is to be expected that should the organic loading to this installation increase, additional process air will have to be supplied.

TABLE 15 - ENERGY AND MIXING PARAMETER SUMMARY - Rivercrest

PARAMETER	UNITS	VALUE
Total Connected Power	kW	6.45
Total Energy Used	kWh/d	56.7
Total Energy Used/Unit Substrate Applied	kWh/ kgBOD_5 applied	1.38
Total Energy Used/Unit Substarte Removed	kWh/ kgBOD_5 removed	1.45
Total Energy Used/Unit Waste Flow Treated	kWh/ m^3waste	0.229
Aeration Energy Used/ Unit Substrate Removed	kWh/ kgBOD_5removed	1.18
Mixing Energy Input/ Unit Liquid Volume	kW/m^3	0.06
Air Supplied/Unit Substrate Removed	m^3/kg BOD_5 removed	91
Air Supplied/Unit Waste Flow Treated	m^3/m^3	13.7
Air Flow Rate/Unit MLSS	m^3/h.kg MLSS	1.42

6.5 Retrofitting Costs

The retrofitting costs were $62,900 and consisted of approximately $25,000 for hardware, $10,000 engineering and $27,900 labour.

The cost can be put on a dollar per kg BOD_5 applied basis. For this installation, the cost is calculated to be $1,175 per kg BOD_5 applied. On a per unit waste flow basis the cost is $275.- /$m^3$.d. It can not be over-emphasized that these retrofitting costs are highly variable and depend on local circumstances, such as accessibility availability of local labor and materials, 1983 costs.

Based on power charges alone, the daily operating cost is calculated to be $2.61. This represents a cost of 5¢ per kg. BOD_5 removed.

6.6 Operator Requirements

The Rivercrest installation has regular operators assigned to maintaining the facility. Daily inspections (5 days/week) are made to ensure proper control in accordance with an operations manual as shown in Appendix A.

The monitoring period for this plant reported on here was from the plant start-up date. Considerable operator time was spent on this plant during that period for operator familiarization and fine tuning of the mechanical equipment. While the time requirements during this period varied between 10 - 15 man hours per week, it is expected that this will decrease to about 5 hours per week.

All installations have an absolute minimum requirement of 2 man hours per week for operator attention for general housekeeping and process monitoring.

6.7 Operations Problems

During the start-up phase of this installation operational problems were both of the mechanical and process managment type. A brief description of these operational start-up problems is as follows:

1. The Raw sewage enters the equalizing raw sewage transfer tank by gravity. There is no break up of solid materials as would be the case in a pumping station. The trash and debris has a tendency to clog even sewage pumps designed to pass 50 mm solids. A trash trap consisting of separated stop logs and aluminum mesh has solved the problem. The raw sewage pumps must still be checked regularly for clogging. As in all sewage systems, materials include plastics, paper and rubber goods. The raw sewage pumps clogged once during the test period.
2. Liquid level probes, although insulated, present a concern for fibrous material to adhere and artificially extend the low level rod, thus preventing the effluent pumps from shutting off. This ultimately results in emergency overflow conditions. A daily check by the operator must include washing down the probes. Control rod fouling occured twice during the test period.

3. Effluent pump clogging with hair and debris occured on at least 2 occasions. Regular pump maintenance is essential. Larger, more expensive pumps would reduce although not necessarily eliminate the problem.
4. The operation of Rivercrest in the conventional activated sludge F/M mode requires careful attention to settling tests and sludge wasting. Pumping is a manual operation and should be automated for reduced operator attention. This becomes increasingly significant for larger, highly loaded plants like Rivercrest.
5. Large aeration basins housed in air tight enclosures result in high humidity which will attack and deteriorate interior finishes and freeze doors in the winter. The piping access part was covered with a polyethylene sheet and an electric heater was installed to reduce the humidity.
6. Blower sound levels can be of significance in residential areas. This is especially true when high speed (greater than 2500 rpm) blowers are used. Noise levels will increase with increasing horsepower.
   Although the blower mounting and silencers at Rivercrest have resulted in an acceptable installation with respect to sound; it is recommended that low speed units be specified where noise may be objectionable.

6.8 Process Assessment Summary

The various data reported on for the Rivercrest installation in the previous sections are summarized in Tables 16 to 18.

The information in the Tables also identifies the number of observations associated with each parameter and the resulting type of data distribution. As well, if one set of data depict more than one distribution, this is noted.

Table 16 summarizes the influent waste characteristics, Table 17 the process parameters and Table 18 the effluent waste characteristics.

TABLE 16 - INFLUENT CHARACTERISTICS - RIVERCREST

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN			NO. OF OBSERV-ATIONS	TYPE OF DATA DISTRIBUT.
		10%	50%	90%	n	
Flow	m^3/d	-	227	-	-	-
Temp.	°C	-	20*	-	-	-
BOD$_5$(total)	mg/L	142	236	330	18	NP
BOD$_5$(sol.)	mg/L	88	160	230	18	NP
SS	mg/L	106	200	660	18	LNP[1]
BOD$_{5T}$/SS	-	0.55	0.95	1.85	18	NP[1]
Alkalinity	mg/L	520	545	575	18	LNP
BOD$_{5T}$/TKN	-	2.35	3.83	5.30	18	NP
TKN	mg/L	47	62	80	18	LNP
NH$_4$-N	mg/L	29	37	46	18	LNP
Org-N	mg/L	19	26	35	18	LNP
TP	mg/L	7	9	11	18	LNP
pH	-	-	7.2	-	-	-
BOD$_5$:N:P	-	100:33:5	100:26:4	100:24:3	-	-

* assumed

TABLE 17 - PROCESS PARAMETERS - RIVERCREST

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN 10%	50%	90%	NO. OF OBSERV-ATIONS n	TYPE OF DATA DISTRIBUT.
MLSS	mg/L	1900	2958	4000	16	NP
VSS	%	76.2	80.7	84.8	16	NP
SVI	ml/g	78	120	180	15	LNP
Organic Loading	g BOD_5/kg MLSS.d	117	183	256	16	NP
Alk_{rem}/ NH_4-N_{rem}	-	3.5	4.7	5.6	12	LNP
Volumetric Loading	g BOD_5/m^3d	-	738	-	-	-
NH_4-Nappl./ MLVSS.d	g NH_4-N/ kg MLVSS.d	33	43	95	16	LNP[1]
NH_4-N_{rem}./ MLVSS.d	g NH_4-N/ kg MLVSS.d	30	44	57	9	LNP
Organic (F/M) Loading	g BOD_5/kg MLVSS.d	153	227	302	16	NP
	g BOD_5/sol kg MLVSS.d	-	219	-	-	-

TABLE 18 - EFFLUENT CHARACTERISTICS - RIVERCREST

PARAMETER	UNITS	VALUE FOR OBSERVATION EQUAL TO OR LESS THAN 10%	50%	90%	NO. OF OBSERVATIONS n	TYPE OF DATA DISTRIBUT.
BOD_5(total)	mg/L	5	11	31	18	NP^1
BOD_5(sol.)	mg/L	2	8	19	18	NP
SS	mg/L	3	15	41	18	LNP^1
Alkalinity	mg/L	350	400	550	18	LNP^1
TKN	mg/L	6	27	46	18	LNP^1
NH_4-N	mg/L	1*	10	35	18	LNP^1
Org-N	mg/L	4	8	11	18	LNP^1
NO_3-N	mg/L	1	3	26	18	LNP^1
TN	mg/L	9*	33	43	18	LNP^1
TP	mg/L	4	6	9	18	LNP
pH	-	-	6.9	-	-	-

* nitrification

7 PROCESS PERFORMANCE COMPARISON

A summary comparing process performances between the three installations is presented in Tables 19 to 22, and Figure 117.

This summary is briefly discussed as follows:

7.1 Biochemical Oxygen Demand

The raw waste total BOD_5 varied from 54 mg/L for the grey water at Hudson Bay Mining and Smelting to 236 mg/L for Rivercrest and 250 mg/L for Glenlea which are typical for domestic sewage. It should be noted though that at Rivercrest, the sewage going to the batch reactor is a settled sewage. The calculated influent total BOD_5 to the reactor was 169 mg/L.

For the three installations total BOD_5 removal ranged from 94 to 98%.

It is more appropriate to relate biological process efficiency to the degree of soluble substrate conversion. As Table 19 indicates, the effluent soluble BOD_5 concentrations were 3 mg/L for both Glenlea and HBM&S. The Rivercrest effluent soluble BOD_5 was 8 mg/L. The Rivercrest plant is not operating under optimum soluble substrate conversion conditions.

7.2 Suspended Solids

The influent SS concentrations for the three installations varied from a low of 32 mg/L (calculated) for Rivercrest which is a settled sewage, to 67 mg/L at HBM&S which is a grey water to 152 mg/L at Glenlea which is a conventional domestic sewage (Table 19).

Suspended solids removal process efficiency is really a meaningless parameter for biological processes. What is important are the effluent suspended solids which indicate the efficiency of the liquid/solid separation step.

TABLE 19 - PROCESS PERFORMANCE SUMMARY
(50% of values are equal to or less than value shown)

PARAMETER		UNITS		INSTALLATION		
				GLENLEA	HBM&S	RIVERC.
TOTAL BOD_5		mg/L	in	251	54	236(169)
		mg/L	out	5	3	11
	removal	%		98	94	- (95)
SOLUBLE BOD_5		mg/L	in	138	44	160
		mg/L	out	3	3	8
	removal	%		98	93	95
SS		mg/L	in	152	67	200(32)
		mg/L	out	6	3	15
	removal	%		96	96	- (53)
TOTAL BOD_5/SS		-	in	1.59	0.70	0.95
		-	out	0.83^c	1.00^c	1.38^c
TOTAL BOD_5/TKN		-	in	3.5	3.5	3.8
		-	out	0.36^c	0.50^c	0.41^c
ALKALINITY		mg/L	in	314	122	545
		mg/L	out	56	83	400
	removal	%		82	32	27
TKN		mg/L	in	79	16	62
		mg/L	out	14	6	27
	removal	%		82	63	56
NH_4-N		mg/L	in	55	8	37
		mg/L	out	2	2	10
	removal	%		96	75	73
ORGANIC-N		mg/L	in	27	8	26
		mg/L	out	8	4	8
	removal	%		70	50	69
NO_3-N		mg/L	out	31	4	3
TN		mg/L	in	79	16	62
		mg/L	out	45	10	33
	removal	%		43	38	47
TP		mg/L	in	11	2	9
		mg/L	out	5	0.2	6
	removal	%		55	-	33
pH		-	in	7.7	6.4	7.2
		-	out	6.6	6.5	6.9
	change			-1.0	+0.1	-0.3

( ) calculated for settled sewage

c calculated

Since settling in a batch reactor system occurs under nearly perfect conditions, it is not surprising that the effluent SS concentrations for HBM&S and Glenlea were 3 and 6 mg/L respectively.

The 15 mg/L effluent SS concentration for the Rivercrest installation can be attributed to higher daily process cycle frequency and shorter aeration and settling times.

It would appear, from examining Table 22, that changes in operating cycle times could be made in order to enhance overall process efficiency of the Rivercrest plant (i.e. decrease draw time and increase fill/react time).

Generally, the BOD_5/SS ratio is near unity for domestic sewage. As indicated in Table 19 this varied from 0.70 for HBM&S (grey water) to 0.95 for Rivercrest (conventional domestic sewage) to 1.59 at Glenlea (a settled sewage).

7.3 Alkalinity

The influent alkalinity is indicative of the source of potable water supply. For example, at Rivercrest the water supply is from wells, hence the high alkalinity. The HBM&S potable water supply is from surface water. As indicated in Table 19, Glenlea shows the highest drop in alkalinity. This of course is due to nitrification as discussed earlier and as indicated by the effluent NO_3-N concentration of 31 mg/L and low NH_4-N effluent concentration of 2 mg/L.

As shown by the data in Table 20 the ratio of alkalinity used per unit NH_4-N removed, varies from 4.7 at Rivercrest to 4.8 at Glenlea to 5.7 at HBM&S. It should be remembered though that a certain degree of denitrification occured at Glenlea (Figure 43) Hudson Bay Mining and Smelting (Figure 79) and Rivercrest (Figure 111).

7.4 Total Kjeldahl Nitrogen

The data in Table 19 indicate that the TKN removal varied from 56 - 82% between the three installations. The low removal value of 56% for Rivercrest can again be attributed to less than optimum process operation (effluent TKN = 27 mg/L). On the other hand the HBM&S and Glenlea TKN effluents were 6 and 14 mg/L respectively. The low TKN influent concentration of 16 mg/L is characteristic of grey water.

7.5 Ammonia

Influent NH_4-N concentrations varied from 8 mg/L (HBM&S) to 27 and 55 mg/L for the Rivercrest and Glenlea installations respectively (Table 19). With the exception of the Rivercrest installation where the effluent NH_4-N concentration was 10 mg/L, the other two installations had extremely low NH_4-N effluent concentrations (2 mg/L). Considering that the processes were not optimized, especially with respect to NH_4-N conversion, the 96% conversion achieved at Glenlea is remarkable.

7.6 Organic Nitrogen

The organic nitrogen concentrations were determined by calculating the difference between individual TKN and NH_4-N observations and then plotting the distribution of these values.

From these data it is evident that during the biological process a significant amount of organic nitrogen (urea for example) was hydrolyzed to NH_4-N. The effluent organic nitrogen concentrations for the 3 plants were 8 mg/L for both Glenlea and Rivercrest and 4 mg/L for HBM&S (Table 19).

7.7 Nitrate

As stated earlier, the degree of nitrification is rather difficult to assess since denitrification also occured. The data of Table 19 show that when examining both the effluent NH_4-N concentration and the NO_3-N concentration, for Glenlea nitrification was complete, but denitrification was incomplete. The effluent NO_3-N concentration was 31 mg/L and the NH_4-N ammonia concentration was 2 mg/L. As well, the alkalinity removed was high and the pH dropped by one whole unit. Had denitrification occured to a higher degree, alkalinity would have been returned to the system with a concurrent increase in pH.

Effluent NO_3-N concentrations of 4 and 3 mg/L for HBM&S and Rivercrest respectively with 2 and 10 mg/L NH_4-N do indicate two things. One, it is doubtful that a higher degree of process efficiency for HBM&S is attainable and two, that the Rivercrest process bears further optimization. The provisal is that adequate process hardware and flexibility is available.

7.8 Total Nitrogen

By examining the influent and effluent TN concentrations, the total nitrogen removal efficiency of a process can be assessed. In spite of the difficulties experienced in attaining a total nitrogen balance the data show that around 40% of the TN is removed (Table 19).

7.9 Total Phosphorus

Rather surprisingly TP removal varied from 33 to 55% (Table 19). These differences can be attributed to differences in cell synthesis and metabolic rates as well as adsorption phenomena.

7.10 Hydraulic Load

The average hydraulic loads for the three systems are 4.4, 22.7 and 227 m^3/d for Glenlea, HBM&S and Rivercrest respectively (Table 20). Daily flow data was only collected for the Glenlea installation as shown in Figure 3.

7.11 Organic Load

Table 20 summarizes the observed organic load to the three treatment plants. The organic load has been expressed in a number of different ways as noted. The data show that of the three plants the Rivercrest plant was subjected to a loading normally associated with conventional activated sludge plants, whereas the other two plants were loaded at rates used for extended aeration plants. (323 vs 52 , 30 g BOD_5/kg MLVSS.d).

7.12 Nitrogen Load and Nitrification Rate

Nitrogen load expressed as g NH_4-N applied per kgMLVSS.d varied from 43 for Rivercrest to approximately 8 for both Glenlea and HBM&S (Table 20).

TABLE 20 - PROCESS DATA SUMMARY

PARAMETER	UNITS	INSTALLATION		
		GLENLEA	HBM&S	RIVERC.
Hydraulic Load	m3/d	4.4	22.7	227
Organic Load (F/M)	g BOD5/kg MLVSS.d	30	52	323(227)
	g BOD5/kg MLSS.d	25	33	260(183)
	g BOD5sol./kg MLVSS.d	16	42	219
Nitrogen Load	g NH4-N/kg MLVSS.d	7.8	8.6	43
Nitrification Rate	g NH4-Nrem./kg MLVSS.d	7.8	6.1	44
Volumetric Loading	g BOD5/m3.d	122	85	738(528)
Alkalinity Required	g Alk.rem/g NH4-Nrem	4.8	5.7	4.7
Nutrient Availability	BOD_5:N:P	100:31:4	100:30:4	100:26:4
MLSS	mg/L	3855	2344	2958
MLVSS	%	82.5	63.0	80.7
SVI	ml/g	117	120	120
Temperature	°C	9.75	22	20

( ) based on settled sewage

The nitrification rate for the 3 installations was calculated as 44, 7.8 and 6.1 g NH_4-Nremoved per kg MLVSS.d for Rivercrest, HBM&S and Glenlea respectively. The corresponding temperatures were 20 °C, 22 °C and approximately 10 °C. The HBM&S nitrification rate data applies to a grey water and does not fit the nitrification rate function:

$$n_{rT} = 0.0071\ T^{2.89} \qquad (22)$$

The other two data, for Rivercrest and Glenlea, show excellent agreement with the data in the literature (Figure 36).

7.13 Volumetric Loading

Another way of expressing the organic load to a treatment plant is through g BOD_5 applied per day per m^3 of liquid volume. The loadings vary from 85 to 738 g BOD_5/m^3.d (Table 20). The low loading is for HBM&S with the grew water and the high loading for Rivercrest with the domestic sewage. The loading of 738 g BOD_5/m^3.d is not entirely correct because it must be adjusted on the basis of dealing with a settled sewage. Making the appropriate correction results in a volumetric loading of 528 g BOD_5/m^3.d.

7.14 Nutrient Availability

Nutrient availability for the three installations is compared in Table 20. The average nutrient ratio for the raw sewage approximates 100:30:4. When making the correction for using settled sewage at Rivercrest, that ratio increases to 100:36:6. Clearly, no nutrient deficiency will be experienced.

7.15 Mixed Liquor

The mean ML concentration varied from approximately 2300 mg/L at HBM&S to 3000 mg/L for Rivercrest to 3900 mg/L at Glenlea (Table 20). The low MLSS concentration is due to the low organic load going to the system. The general MLSS operating concentration objective is 2500 - 4500 mg/L.

The organic fraction of the MLSS averaged 0.81 except for the grey water case where the mixed liquor consisted of only 63% volatile suspended solids.

7.16 Sludge Volume Index

As shown in Table 20 the SVI for all 3 plants averaged around 120 ml/g. The sludges settled exceedingly well. Some exceptions were noted when sludge bulking conditions prevailed. These, however, never lasted for any significant period of time and did not interfere with the general process performance.

TABLE 21 - SUMMARY OF ENERGY & MIXING PARAMETERS

PARAMETER	UNITS	INSTALLATION		
		GLENLEA	HBM&S	RIVERC.
Total Connected Power	kW	1.74	2.11	6.45
Total Energy Used	kWh/d	25.2	17.3	56.7
	kWh/kg BOD_5 applied	22.9	7.8	0.97 (1.38)
	kWh/kg BOD_5 removed	22.9	7.8	1.02 (1.45)
	kWh/m3 waste flow	5.73	0.414	0.229
Aeration Energy Used	kWh/kg BOD_5 removed	22.8	6.6	0.83 (1.18)
Mixing Energy Input	kW/m3	0.12	0.04	0.06
Air Supplied	m3/kg BOD_5 removed	875	269	61 (91)
	m3/m3 waste flow	219	21.4	13.7
Air Flow Rate	m^3/h.kg MLSS	1.22	0.65	1.42

( ) values calculated on basis of settled BOD_5

7.17 Temperature

The average ML temperatures are shown in Table 20. The low temperature for the Glenlea installation reflects winter conditions. At Glenlea, surface water run-off infiltrated the system. This resulted in sharp ML temperature drops of up to 4°C (10°C - 6°C).

The temperature shocks did not appear to have any detrimental effect on process efficiency.

All installations are enclosed and heated by either heat lamps or thermostatically controlled baseboard heaters.

7.18 Energy and Mixing Parameters

Energy and mixing parameters for the three installations are summarized in Table 21 for comparison. The energy calculations are all based on gross energy, with no allowances for either mechanical or electrical efficiencies.

It is clearly evident that the smaller the system, when based on daily hydraulic load, the greater the energy used per kg BOD_5 removed. The data in Figure 117 show two functions. One for the gross process energy used having deleted the energy requirements for aerobic digestion, equation (38):

$$Ep = 66.6\ Q^{-0.70} \qquad (38)$$

$$r = 0.999$$

$$n = 3$$

where: Ep = Gross process energy used (kWh/kg BOD_{5r})

The second function shows the energy required for aeration only.

$$Ea = 69.1\ Q^{-0.75} \qquad (39)$$

$$r = 0.999$$

$$n = 3$$

where: Ea = Gross aeration energy used (kWh/kg BOD_{5r})

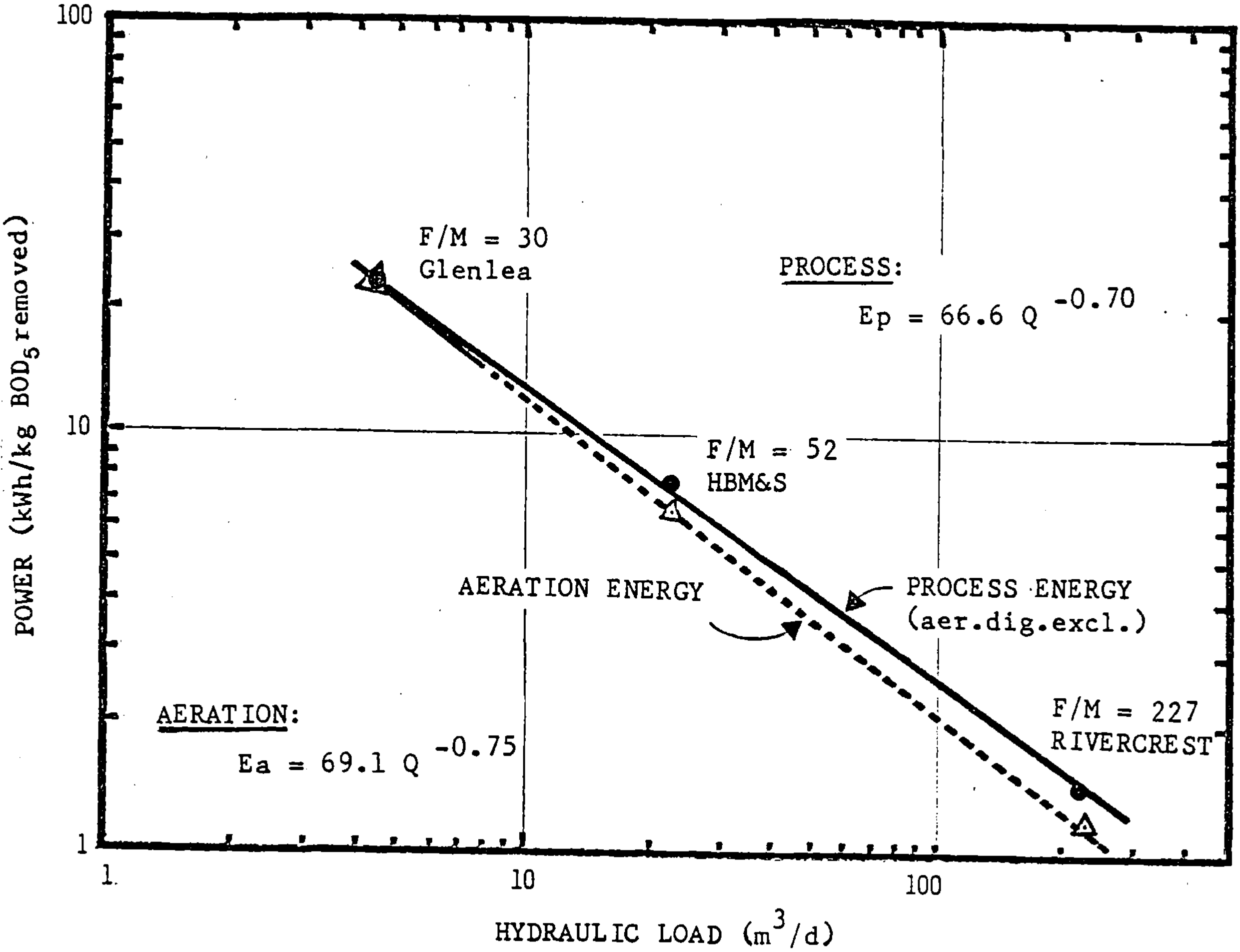

FIGURE 117 ENERGY REQUIREMENTS AS A FUNCTION OF HYDRAULIC LOAD

Equations (38) and (39) permit calculation of the total gross energy requirements per kg BOD_5 removed per day and gross energy requirements for aeration only on a kWh per kg BOD_5 removed per day basis.

It is interesting to see that the data from 3 completely different plants, though batch systems, treating wastes with completely different characteristics could be described by a simple function. The fit of the equations is excellent.

The mixing energy input to keep the solids in suspension varied from 0.04 to 0.12 kW/m^3. A better parameter, m^3 air per hour per kg MLSS, gives mixing parameter values of 0.65 for HBM&S, 1.22 for Glenlea and 1.42 for Rivercrest.

The process cycles for the three plants are summarized in Table 22. While the settling times are approximately equal at 50 minutes, aeration times vary from 91 to 1032 minutes. The data have shown that an aeration time of only 91 minutes is insufficient to convert all of the soluble substrate to biomass. Additional aeration time can be secured by decreasing the draw time. As noted, aeration commenced at the initiation of the fill cycle.

8 BATCH REACTOR PROCESS APPLICATIONS

Applications of batch reactor technology would appear to be unlimited. Situations where highly variable and periodic organic and/or hydraulic loads are encountered are prime candidates for application. This does not only apply to small communities, resorts, schools, institutions and camps but should be of specific interest to those industries which generate biodegradable wastes. Easy construction, start-up and simplicity in operation offers batch reactor technology as an ideal solution to seasonal operations. The canning and fruit and vegetable industries are two industrial examples, resorts which operate on a seasonal basis are further examples for batch reactor application. Construction camps fall into the same category.

Low capital cost, simple materials of construction and ease of operation make the batch reactor approach an attractive proposition for developing nations (18).

TABLE 22 - SUMMARY OF PROCESS CYCLES

PROCESS	UNITS	INSTALLATION		
		GLENLEA	HBM&S	RIVERC.
FILL	min.	1032*	202*	91*
REACT	min.			
SETTLE	min.	50	50	45
DRAW	min.	22	36	80
CYCLE TIME	min.	1104	288	216
CYCLES/DAY		1.3	5	6.7

* Aeration during fill cycle

The number of batch reactor applications is increasing steadily. In the USA installations range from 1 900 m^3/d to 19 000 m^3/d in size (19,20). Batch reactors in conjunction with conventional physical-chemical processes have also been used in an industrial application where a zero discharge requirement had to be met. Effluent reuse and recycle was practiced (21).

In Australia, numerous applications of batch reactor technology for municipal waste treatment have been found to be cost-effective solutions. Investigations by Goronszy (22) have demonstrated that when operating the batch reactor system with a continuous influent during all phases of the operational cycle, effluent quality is not seriously affected.

9 BATCH REACTOR PROCESS DESIGN

For the design of batch reactor systems the following information must be available:

1. waste characteristics (incl. pH, N, P, C);
2. flow and its variability;
3. temperature;
4. effluent targets;
5. available sludge management options.

The information required for successful design must also include information on the variability of the waste parameters.

It is stressed that there is no cook-book design approach which will result in sucessful process operation. Process designs, while deceptively simple, are site specific, hence require that the information be generated for the process design engineer.

However, for very small systems (< 10 m^3/d) treating domestic waste, a certain degree of compromise between design data generation and application of general design criteria based on experience represents a realistic design approach. Invariably, this will result in oversizing the system. However, because of the simplicity of construction and system operation, batch reactor systems are forgiving, in that the respective capital and O&M costs do not increase substantially.

9.1 Design Data Generation

The batch reactor cycle consists of 4 steps.

1. fill;
2. aerate;
3. settle;
4. decant.

Each of these steps require a certain amount of time.

9.1.1 Filling step

The filling of the batch reactor may occur in a number of ways. It may be continuous, hence the reaction vessel liquid volume increases with time. It may be cyclic, if a lift-station is required or if equalization and storage appears to be desirable. (This is most frequently applied in process retrofit situations). As well, storage capacity must be available for the duration of the settling and decant steps.

During the fill step the reactor contents are aerated. The duration of the fill cycle is site specific.

9.1.2 Aeration step

Generally, the aeration step and the filling step are combined. The time required for soluble substrate conversion must be determined from batch reactor bench scale experiments. This is a prerequisite for industrial batch reactor process design. If neglected or ignored, process failure will result.

An estimate of the aeration time required may be made as follows:

$$\text{EFFLUENT BOD}_5\,\text{sol.} = \frac{\text{BOD}_5}{(k_m t + 1)} \tag{3}$$

where:

k_m = substrate conversion rate constant, 1/h
t = aeration time, h
BOD_{5i} = unfiltered influent BOD_5, mg/L.

rearranging terms yields equation (44) in terms of aeration time required.

$$t = \frac{\dfrac{BOD_5}{\text{EFFLUENT } BOD_5\,sol} - 1}{k_{mT}} \tag{40}$$

The rate constant, k_m and must be determined for each waste. If the rate constant for domestic sewage at 20 °C, k_m = 15/h, then depending on the soluble effluent BOD_5 desired and the prevailing influent total BOD_5, a good approximation of aeration time requirements at 20 °C can be made. Equation (4), correcting the rate constant for different liquid temperatures, can be incorporated into equation (40).

$$k_{mT} = (15)(\theta)^{(T - 20)} \tag{4}$$

$\theta = 1.072$ for domestic waste

$$t = \frac{\dfrac{BOD_5}{\text{EFFLUENT } BOD_5\,sol} - 1}{15\,(1.072)^{T - 20}} \tag{41}$$

The results of this process assessment confirm this design approach.

A second consideration concerns the air supply to the reactor. The air serves two function, satisfaction of the oxygen demand by the microorganisms and mixing to ensure that the MLSS remain in suspension. The air requirement can be calulated based on oxygen uptake rates by the microorganisms for cell synthesis and maintenance. For large systems the aeration equipment requirements would follow conventional aeration system design methodology. However, for the case of small systems such as considered here, using the rules of thumb of (16):

$F/M > 0.3$	30 - 55 $m^3/kg\ BOD_5$ removed
$F/M < 0.3$	75 - 115 $m^3/kg\ BOD_5$ removed

are useful and have been demonstrated in this process assessment study to apply. As indicated, the air supply is dependent on the organic loading of the process. Allowances for nitrification air requirements are reflected in these values. If a conventional design approach is used, and air requirements are calculated in detail, then the allowance of 4.6 mgO_2 per mg NH_4-N oxidized must be included.

Air supply requirements can also be judged by the air flow rate per liquid flow rate. For diffused air systems the rule of thumb value of 15 m^3 air per unit time per m^3 liquid per unit time is applicable (17).

The aeration energy requirements can be estimated for ($Q = 4.4 - 227\ m^3/d$) by:

$$Ea = 69.1\ Q^{-0.75} \qquad (39)$$

where:

Ea = aeration energy required in kWh/kg BOD_5 removed.

The overall process energy requirements are estimated by:

$$Ep = 66.6\ Q^{-0.70} \qquad (38)$$

where:

Ep = process energy required in kWh/kg BOD_5 removed.

No allowances for mechanical or electricl energy losses are included in either of these functions.

The minimum MLSS target concentration for the reactor should be 2500 mg/L.

The rule of thumb design criteria for mixing energy requirements (17):

0.4 - 0.5 kWh/m^3 for Extended Aeration
and 0.15 - 0.25 kWh/m^3 for Conventional Activated Sludge systems

were found to apply. Cochrane and Jones (23) stated minimum power requirements for mixing to be 0.026 kW/m^3. In all three installations reported on here, this minimum was exceeded (i.e.$>$ 0.026 kW/m^3).

9.1.3 Settling step

Once, the air supply has been turned off, the settling step is initiated. Unless the reactor is baffled, it will take some time for the energy in the system to be dissipated through the friction loss by the eddies in the system. Large systems will have large eddies which take longer to die out. Small systems have small eddies with high rotational velocity, but will become more quickly extinct because of the increased friction losses by the eddies.

The inference of this comment is that settling is affected by turbulence even in batch systems where close to ideal settling conditions will prevail.

The same settling time in a larger system as in a smaller system will not produce the same effluent suspended solids quality. SBR process experience has shown that a 60 minute detention time should be used for the settling step.

9.1.4 Draw step

The time required for this step should be relatively short and as such is a function of the available pumping capacity and the effluent piping. Because the effluent is going to be discharged over a shorter period of time than the flow which came into the plant the effluent piping diameter should be greater than the influent piping diameter if gravity discharge is used.

The liquid velocity of the discharge should not exceed a rise velocity of 1.33 m/h for conventional activated sludge and 0.66 m/h for extended aeration systems (16). This is an overflow rate and can be used to calculate discharge pump sizes. The rise velocity is also equal to a surface hydraulic loading rate of either 1.33 $m^3/m^2 \cdot h$ or 0.67 $m^3/m^2 \cdot h$, depending on the organic loading of the process. Exceeding this rate will cause settled sludge particles to be resuspended and carried out in the effluent.

It is evident then, that the process cycle length determining steps are governed by substrate conversion and sedimentation/effluent discharge.

Varying cycle step length permits manipulation of effluent quality. It would appear that as a rule of thumb, minimum cycle step times should be 180 minutes aeration, 60 minutes settling, 30 minutes draw.

9.2 Scale-Up and Scale-Down

In continuous process design, allowances to account for differences in scale must always be made. The hydrodynamic state of small systems, especially bench scale, is impossible to reproduce at large scale. Hence, a variety of scale-up methodologies and protocols have been used with varying degrees of success (24).

No such problem is encountered with batch systems. The reactions occuring at small scale will also occur at large scale. The converse is also true. Batch reactor process problems in the field can easily be duplicated in the laboratory, solved and the solution translated back to the field.

10 PROCESS COST ESTIMATION

It is virtually impossible to quote accurate costs for Batch Aeration plants because each installation is site specific and must be evaluated on its own. However, based on past experience some general statements concerning costs can be made. They must be used as very general indicators only. For the moment it would appear that there is no maximum limiting size for the application of Batch Aeration systems. It is expected though, that process control complexity will increase with size. Micro-processors would find excellent application here. As installation size increases (eg. > 500 m^3/d) a cost-benefit analysis becomes increasingly important.

Costs for Batch Aeration Systems can be roughly estimated for sizes to 500 m^3/d by using the following:

1.	Air blower		$\$60/l \cdot s$
2.	Process control panel		$\$3500$
3.	Concrete (in place)		$\$500 - \$800/m^3$ (site specific)
4.	Fiberglass tank up to 25 m^3 size		$\$450/m^3$
5.	Raw sewage pumps		$\$500 - \$5000$
6.	Effluent discharge pumps		$\$500 - \$5000$
7.	Aeration equipment (up to 500 m^3/d)		$\$1000 - \$10000$
8.	Building enclosure		$\$550/m^2$
9.	Installation time	. 25 m^3/d	3 - 4 weeks
		. 500 m^3/d	16 - 32 weeks

It is highly recommended that in order to save on delivery time, cost and time required for replacement of process hardware, as much of the process hardware as possible should be obtained from local 'off-the-shelf' stock. This is especially applicable for small installations in remote locations where transporation costs will significantly affect total project costs (e.g. air freight only to certain Northern Canadian areas).

Estimated installed costs are:

5 m^3/d	\$9000 - \$11000/m^3
5 - 15 m^3/d	\$4500/m^3 decreasing to
up to 500 m^3/d	\$ 550/m^3

An estimate of total cost breakdown between materials and labor is 40% and 60%, respectively.

CONCLUSIONS

Based on the results of the assessment of 3 different sizes of batch reactors, treating 3 different types of wastewater of domestic origin, the following conclusions are drawn:

1. Using batch reactor technology under conditions of widely varying organic and hydraulic load can produce effluents which have a quality equal to and better than conventional suspended growth systems.

2. Process effluent quality is not affected by widely varying hydraulic and organic loads to the system.

3. An effluent BOD_5 of 5 mg/L and SS of 3 mg/L can be achieved on a consistent basis. Higher values reflect process operation under non-optimum conditions which can be modified by adjusting the proportions between cycle increments.

4. Nitrification and denitrification occur simultaneously.

5. Under uncontrolled conditions nitrification was as high as 96%, yielding low effluent NH_4-N concentrations of 2 mg/L. Denitrification was at least 50%.

6. A well settling sludge with an average SVI of 120 for the 3 plants studied was produced.

7. Process effluent quality was not adversely affected with respect to effluent BOD_5 and SS quality when operating at 10 °C liquid temperatures and incremental influent temperature shocks of 4°C lower (over 24h).

8. The critical phases of the process cycle, under the conditions studied are : aeration and decantation.

9. The operator skill level to run batch reactors need not be advanced since the process is easily controlled by preset timing cycles.

10. Major maintenance requirements for Batch Aeration plants observed for this study include:
    - Regular sludge wasting.
    - Regular effluent pump clogging preventative maintenance.
    - Regular observation of low liquid level control rod for debris fouling.

    All of the above must be carried out according to the operations manual provided with each installation.

11. Operator attention is less than that required for other plants producing an effluent of comparable quality.

12. The batch reactor process offers an opportunity for exercising control over effluent quality which cannot be achieved in conventional systems.

13. The retrofitting of poorly operating plants to function in the batch reactor mode is an inexpensive, effective and proven alternative for upgrading existing plants.

14. Not unlike other small biological treatment installations the complete process must be protected from inclement weather. During cold weather periods the enclosed structures must be heated. An ambient temperature of 10 C is adequate.

15. A site specific sludge management strategy must be developed for each location. Sludge wastage after aerobic digestion for sludge stabilization is required and may be as infrequent as once per year. Sludge wasting frequency is a function of overall process design.

16. Utilization of stabilized sludge on land as a soil amendment is a preferred solution. Disposal to the local refuse dump is another popular solution.

17. For the cases analyzed in this study, the data analyses support the contention that grab samples from equalized sewage are perfectly acceptable for presenting a picture of process loading conditions. This is not unexpected. Considerable effort and financial resources can be saved by taking grab samples rather than flow proportionate samples under similar study conditions.

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APPENDIX A

Typical Operations and Maintenance Instructions for a Batch Treatment Installation.

OPERATING INSTRUCTIONS
FOR
RIVERCREST SEWAGE
TREATMENT PLANT
R. M. OF WEST ST. PAUL

OPERATING INSTRUCTIONS
FOR
RIVERCREST BATCH AERATION
SEWAGE TREATMENT

PROCESS DESCRIPTION

The sewage treatment plant at Rivercrest consists of an aerobic biological process known as Batch Aeration. This process is a modification of the conventional extended aeration process. The sewage is treated in this plant by introducing air via a positive displacement blower to the sewage entering the aeration basin called a reactor. Mixing air with sewage promotes the growth of bacteria already present in the sewage. Food is required for bacterial growth.

Food is provided by the "pollution" in the incoming sewage. The aeration period in the reactor allows the "food" or "pollution" to decrease to a concentration where it is suitable for discharge.

A schematic of the Rivercrest Batch Process is shown below as Figure 1.

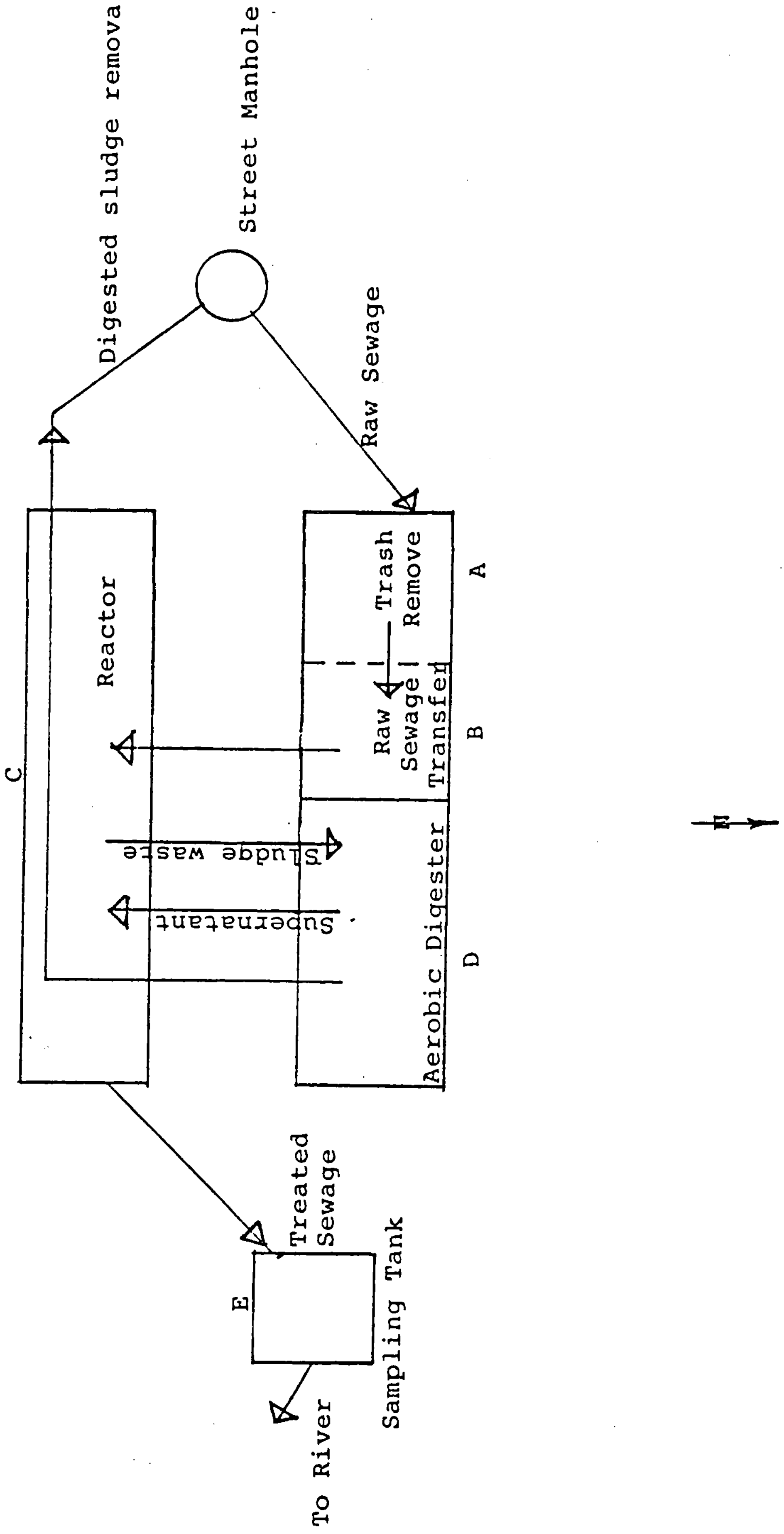

FIGURE 1:

Rivercrest Batch Process Schematic.

A. TRASH REMOVAL

TANK A REPRESENTS THE FACILITY FOR REMOVING TRASH IN THE RAW SEWAGE. IT IS INTENDED TO REMOVE THE LARGER MATERIALS THAT COULD PLUG PUMPING EQUIPMENT IN THE REST OF THE PROCESS. THIS IS ACCOMPLISHED BY A COMBINATION OF SEPARATED WOOD PLANKS AND ALUMINUM MESH SCREEN. THE TRASH CHAMBER IS ABOUT 3500 GALLONS TOTAL VOLUME.

MAINTENANCE

WEEKLY

- LIFT INSPECTION HATCH AND VISUALLY CHECK FOR SOLIDS BUILDUP.

  BUILDUP WILL BE NOTED BY INCREASING LIQUID LEVEL IN THE TANK.

  REMOVE CONTENTS OF CHAMBER WITH VACUUM SEWAGE REMOVAL TRUCK WHEN LEVEL INCREASED TO WIRE MESH SCREEN LEVEL.

B. RAW SEWAGE TRANSFER

TANK B APPROXIMATELY 3500 GALLONS REPRESENTS THE TRANSFER TANK THAT PUMPS RAW SEWAGE TO THE AERATION BASIN. TWO SUBMERSIBLE BARNES PUMPS ARE USED. THE PUMPS ARE INSTALLED WITH FLEXIBLE DISCHARGE HOSE AND LIFTING CHAINS. ALTHOUGH THESE PUMPS ARE DESIGNED TO PASS 2" Ø

B. RAW SEWAGE TRANSFER - CONTINUED:

SOLIDS THEY ARE SUSCEPTIBLE TO PLUGGING WITH FIBROUS MATERIAL THAT MAY PASS THE TRASH TANK.

THESE PUMPS ARE ACTIVATED BY A FLOATING "PIL" SWITCH AND WILL MAINTAIN AN APPROXIMATE 2 FOOT DEPTH IN THE TANK IN NORMAL OPERATION. THE EXTRA CAPACITY IN THE TRASH AND TRANSFER TANK (APPROXIMATELY 7000 GALLONS) IS USED TO STORE INCOMING SEWAGE WHILE THE REACTOR IS SETTLING AND PUMPING (APPROXIMATELY 2½ HOURS).

MAINTENANCE:

DAILY

- LIFT INSPECTION HATCH AND VISUALLY NOTE THAT DISCHARGE HOSES ARE FLAT WHEN NOT PUMPING.
- A ROUND HOSE WHEN THE PUMP IS INOPERATIVE INDICATES A PLUGGED PUMP - REMOVE AND CLEAN.

MONTHLY:

- LIFT SUBMERSIBLE PUMPS TO CHECK AND CLEAN ANY DEBRIS BUILDUP.
- NOTE PROPER PLACEMENT OF PIL SWITCH IN TANK WITH "THIS SIDE UP ONLY".

C. REACTOR

THE REACTOR CONSISTS OF A 16000 GALLON CONCRETE TANK 10 FEET DEEP WITH A 9 FOOT OPERATING DEPTH. THIS IS THE FORMER SOUTH SEPTIC TANK. THIS IS WHERE THE ACTUAL SEWAGE TREATMENT TAKES PLACE. RAW SEWAGE ENTERS THE

C. REACTOR - CONTINUED:

REACTOR FROM THE TWO SUBMERSIBLE PUMPS IN TANK B. THE SEWAGE IS AERATED WITH A BLOWER LOCATED IN THE EQUIPMENT ROOM. THE REACTOR OPERATES BETWEEN PRESET HIGH AND LOW LEVEL PROBES. A THIRD (MIDDLE) PROBE IS AGROUND PROBE. LOW LEVEL IS A DISTANCE APPROXIMATELY 5 FEET DOWN FROM THE TOP OF THE TANK.

WHILE THE TANK IS FILLING, AIR FROM THE BLOWER IS CON STANTLY BEING MIXED WITH SEWAGE IN THE REACTOR. THIS MIXING OF AIR AND SEWAGE IS CALLED THE <u>ACTIVE PROCESS PERIOD</u>.

WHEN THE REACTOR FILLS WITH INCOMING SEWAGE TO THE HIGH LEVEL PROBE THE FOLLOWING HAPPENS:

- THE 2 SUBMERSIBLE RAW PUMPS ARE DEACTIVATED.
- AN <u>ADDITIONAL AERATION PERIOD</u> BEGINS. THE ADDITIONAL AERATION PERIOD ENSURES THAT THE LAST SEWAGE FLOWS ARE GIVEN SUFFICIENT AIR FOR COMPLETE TREATMENT. THE RIVERCREST ADDITIONAL AERATION PERIOD IS ADJUSTED FOR 15 MINUTES. THIS HAS BEEN SELECTED BY EVALUATING THE FLOW RATE (EST. 50,000 GALLONS PER DAY).

C. REACTOR - CONTINUED:

AFTER THE ADDITIONAL AERATION IS COMPLETE (15 MINUTES) THE SETTLING PERIOD BEGINS. THE SETTLING PERIOD IS PRESET TO 45 MINUTES. AT THIS TIME ALL AUTO PUMPS AND COMPRESSORS ARE SHUT OFF. THIS ALLOWS THE SOLIDS (MIXED LIQUOR) IN THE REACTOR TO SETTLE LEAVING CLEAR TREATED SEWAGE ON TOP. THE SETTLED SOLIDS SHOULD OCCUPY ABOUT 1/3 OF THE BOTTOM VOLUME OF THE REACTOR.

AFTER SETTLING THE TREATED EFFLUENT DISCHARGE PERIOD BEGINS. THE INTAKES OF 2 - 1/3 HP CENTRIFUGAL PUMPS LOCATED IN THE EQUIPMENT ROOM ARE APPROXIMATELY 5 FEET DOWN FROM THE TOP OF THE TANK AND DRAW THE CLEAR TREATED EFFLUENT FOR DISCHARGE TO THE RIVER.RUN TIME IS 1 H. 20 MIN.

MAINTENANCE

DAILY

- CHECK THE EQUIPMENT (PUMPS AND COMPRESSOR) TO ENSURE THAT MALFUNCTION HAS NOT OCCURRED. THE EFFLUENT PUMPS MAY EVENTUALLY PLUG WITH HAIR AND GREASE.

- WASH DOWN THE 3 LIQUID LEVEL PROBES.

MONTHLY

- CHECK EFFLUENT PUMP FOR DEBRIS BUILDUP AND CLEAN.

WEEKLY

- CHECK BELT TENSION, CHECK OIL LEVEL AND GREASE FITTING ON THE COMPRESSOR AS PER MANUFACTURERS' RECOMMENDATIONS.

C. REACTOR - CONTINUED:

WEEKLY - PERFORM JAR TEST

JAR TEST

- OBTAIN A 1000 ML PLASTIC GRADUATED CYLINDER OR WIDE MOUTH CLEAR GLASS JAR.
- FILL THE JAR WITH MIXED LIQUOR FROM THE REACTOR WHILE IT IS OPERATING.

  ESTIMATE THE % THAT THE LEVEL IS DOWN FROM THE HIGH LEVEL PROBE. ADD THIS AMOUNT OF TAP WATER TO THE MIXED LIQUOR TO <u>SIMULATE</u> A FULL TANK.
- LET THE JAR STAND UNDISTURBED FOR ½ HOUR.
- OBSERVE THE LEVEL TO WHICH THE SOLIDS SETTLE IN THE JAR.

(1) IF THE SOLIDS OCCUPY LESS THAN 40% OF THE BOTTOM VOLUME, THE JAR OPERATION IS NORMAL.

(2) IF THE SOLIDS DO NOT SETTLE AS ABOVE, OBSERVE THE CONDITION OF THE SOLIDS. THE SOLIDS SHOULD BE DARK BROWN AND SETTLE IN A COMPACTED STATE.

(3) IF THE SOLIDS COLOUR IS ACCEPTABLE BUT THE SOLIDS APPEAR FLUFFY AND DO NOT SETTLE, A CONDITION KNOWN AS FILAMENTOUS GROWTH MAY HAVE OCCURRED. THIS IS A COMMON ALTHOUGH TROUBLESOME FEATURE OF THE ACTIVATED SLUDGE PROCESS.

THIS CAN BE CORRECTED BY ADDING APPROXIMATELY 5 GALLONS OF A 10% CHLORINE SOLUTION TO THE REACTOR.

C. REACTOR - CONTINUED:

ALLOW THE REACTOR TO OPERATE NORMALLY AFTER CHLORINATION AND DAILY REPEAT THE JAR TEST.

IF THE CONDITION HAS NOT CORRECTED ITSELF, REPEAT THE CHLORINE DOSAGE AND OBSERVE. THE FILAMENTOUS PROBLEM SHOULD CORRECT ITSELF IN ABOUT 2 OR 3 TRIES.

(4) IF THE SOLIDS ARE "GRAINY" AND WELL COMPACTED (I.E. SHARP LIQUID-SOLIDS INTERFACE IN THE JAR) BUT OCCUPY MORE THAN 40% OF THE JAR IT IS NECESSARY TO PUMP ADDITIONAL MIXED LIQUOR OUT OF THE REACTOR TO THE DIGESTER.

D. SLUDGE DIGESTER

SLUDGE WASTING IS A CRITICAL OPERATING PARAMETER FOR THE RIVERCREST PLANT. THIS SYSTEM IS HIGHLY LOADED AND WILL PRODUCE CORRESPONDING SLUDGE VOLUMES. IT WILL BE NECESSARY TO WASTE AT LEAST 2000 GALLONS OF MIXED LIQUOR TO THE AEROBIC SLUDGE DIGESTER EACH WEEK. THIS WILL PREVENT THE SOLIDS FROM INCREASING TO A LEVEL WHERE THEY WOULD BE TAKEN IN THE EFFLUENT PUMPS.

WEEKLY SLUDGE WASTE PROCEDURE MANUAL PROCESS - NOT AUTO

(1) TURN OFF AIR TO THE DIGESTER TANK.

(2) ALLOW CONTENTS TO SETTLE AT LEAST 1 - 2 HOURS.

(3) PUMP OUT THE SUPERNATANT TO THE REACTOR USING THE SUPERNATANT PUMP IN THE EQUIPMENT ROOM.

THE DIGESTER LEVEL SHOULD BE DOWN APPROXIMATELY 3 FEET FROM THE TOP OF THE DIVIDING WALL.

(4) TURN OFF THE SUPERNATANT PUMP.

D. SLUDGE DIGESTER - CONTINUED:

(5) TURN ON THE SLUDGE WASTE PUMP SWITCH.

(6) PUMP DOWN APPROXIMATELY 1½ FEET LEVEL IN THE REACTOR TO THE DIGESTER.

(7) STOP SLUDGE WASTE PUMP.

(8) TURN AIR ON TO DIGESTER

IMPORTANT

ADJUST AIR SO THAT A GENTLE ROLL IS NOTED IN THE DIGESTER (VALVE APPROXIMATELY 1/4 OPEN). TOO MUCH AIR TO THE DIGESTER WILL NOT ALLOW ENOUGH AIR TO THE REACTOR.

NOTE THAT THE SLUDGE IN THE DIGESTER WILL EVENTUALLY BEGIN TO BUILDUP. A JAR TEST SIMILAR TO THAT DESCRIBED ABOVE WILL INDICATE INERT SLUDGE BUILDUP.

THIS SLUDGE IS TO BE REMOVED FROM THE SYSTEM WITH THE LARGE CENTRIFUGAL PUMP IN THE EQUIPMENT ROOM OR COMMERCIAL HAULING IF DESIRED. SLUDGE IS TO BE PUMPED UP TO THE STREET INTO A SUITABLE CONTAINER.

ENSURE THAT THE SLUDGE DIGESTER IS WELL AGITATED BEFORE PUMPING TO MINIMIZE PLUGGING. CHECK THE PRIMING PORT EACH TIME THE PUMP IS TO BE USED.

BI-MONTHLY

- RECOMMENDED INTERVAL FOR DIGESTED SLUDGE REMOVAL.
- ESTIMATE 2000 - 3000 GALLONS.

FOAMING

SOME FOAMING CAN BE EXPECTED DURING NORMAL OPERATION OF THE REACTOR AND THE DIGESTER. A NORMAL DARK COLOURED FOAM LAYER WILL NOT EXCEED 2 OR 3 INCHES ABOVE THE LIQUID LEVEL. CHEMICALS ARE AVAILABLE FOR UNUSUAL FOAMING CONDITIONS.

E. SAMPLING TANK

THE SAMPLING TANK CONSISTS OF THE ORIGINAL CHLORINE CONTACT CHAMBER. THE TREATED EFFLUENT FLOWS THROUGH THIS TANK EN ROUTE TO THE RIVER. A SAMPLE TAKEN FROM THIS POINT WILL BE REPRESENTATIVE OF THE LAST DISCHARGE CYCLE. THE EFFLUENT SHOULD ALWAYS APPEAR TO BE CLEAR AND ODOURLESS.

A TURBID EFFLUENT WILL RESULT IF:

(1) THE SEWAGE PLANT HAS BEEN BY-PASSED OR BY EMERGENCY OVERFLOW.

(2) THE SLUDGE BLANKET HAS NOT BEEN MAINTAINED BELOW 40% - SEE SLUDGE WASTE PROCEDURE.

(3) THE COMPRESSOR IS NOT FUNCTIONING NORMALLY/AERATORS ARE PLUGGED.

(4) CHLORINATION OF A FILAMENTOUS GROWTH WILL ALWAYS RESULT IN TURBID EFFLUENT FOR A FEW DAYS. THIS WILL CLEAR UP AS A NEW AEROBIC POPULATION GETS ESTABLISHED.

NOTE:

IT IS RECOMMENDED THAT THE SAMPLING TANK BE CLEANED OUT AFTER EMERGENCY OVERFLOW CONDITIONS.

THE FLUSHING ACTION IS NOT SUFFICIENT TO REMOVE HEAVIER PARTICLES THAT MAY BE TRAPPED DURING BY-PASS CONDITIONS.

MAINTENANCE SCHEDULE SUMMARY

A. DAILY

1) VISUALLY INSPECT RAW SEWAGE SUBMERSIBLE PUMP FOR PLUGGING.
2) INSPECT ALL PUMPS AND COMPRESSOR FOR NORMAL OPERATION.
3) WASH DOWN THE 3 LIQUID LEVEL PROBES.

B. WEEKLY

1) TRASH TANK VISUAL INSPECTION.
2) CHECK AND SERVICE COMPRESSOR. CHECK OIL/GREASE NIPPLE.
3) JAR TEST ON REACTOR MIXED LIQUOR.
4) WASTE 2000 GALLONS REACTOR MIXED LIQUOR.

C. MONTHLY

1) LIFT ALL SUBMERSIBLE PUMPS AND INSPECT/CLEAN.
2) CHECK PIL SWITCH FLOAT PLACEMENT.
3) CHECK CENTRIFUGAL PUMPS FOR HAIR AND GREASF BUILDUP.

D. OTHER

1) WASTE DIGESTED SLUDGE EVERY 2 MONTHS.
2) CLEAN OUT TRASH CHAMBER AT LEAST EVERY 6 MONTHS.
3) CLEAN OUT SAMPLE TANK AFTER EMERGENCY OVERFLOW OR BY-PASS CONDITION.

APPENDIX B

RAW DATA SUMMARIES

- Glenlea
- Hudon Bay Mining & Smelting
- Rivercrest

TABLE B1 SUMMARY DATA FOR GLENLEA

	INFLUENT								EFFLUENT								
DATE	pH Infl.	TEMP degr.C	BOD 5 mg/l	ALK mg/L	SS mg/L	TKN mg/L	NH3-N mg/L	TP mg/L	pH Effl.	DO mg/L	BOD 5 mg/L	ALK mg/L	SS mg/L	TKN mg/L	NH3-N mg/L	NO3-N mg/L	TP mg/L
Jan.3	7.9		136	216	115	46	36	20	6.3	6	4	18	2	5	1	43	12
Jan.4	7.8	8	205	223	111	20	8	6	6.8	5	5	66	6	13	9	30	6
Jan.5	8.1	9	250	276	146	83	50	9	6.5		6	84	1	7	2	20	5
Jan.6	7.3	9	285	295	181	82	30	17	6.6	6	3	57	2	6	2	26	3
Jan.7	7.7	8	183	333	121	73	44	13	6	6.8	3	46	4	5	2	32	4
Jan.10	7.9	8	227	306	130	78	41	7	7.5	tr	6	254	10	36	40	2	11
Jan.11	7.7	8	246	278	174	76	48	11	6.8	4	7	112	14	18	2	16	6
Jan.12	8	8	226	278	172	71	45	11	7	7.5	3	115	1	4	2	17	4
Jan.13	8.1	10	204	291	143	75	51	18	7	7.2	4	79	4	8	1	25	4
Jan.14	7.7	9	229	109	153	40	7		6.8	3.5	7	7	6	2	2		
Jan.17	8.1	8	302	304	161	97	58	10	6.9	6	3	84	1	8	1	21	3
Jan.18	8	8	322	331	212	88	58	3	6.6	4.7	4	95	4	15	4	31	9
Jan.19	8.1	8	195	412	118	102	71	8	6.8	8	10	60	15	10	5	17	3
Jan.20	7.9	8.5	243	331	144	84	67	9	6.8	3.6	7	84	2	7	3	24	3
Jan.21	8	9	161	357	103	137	54	12	6.5	6.2	5	57	6	14	5	33	5
Jan.24	7.9	5	376	398	372	114	72	21	6.8	4	6	104	5	15	2	20	6
Jan.25	7.8	4	595	273	490	57	52	17	6.6	4	7	101	1	15	2	20	7
Jan.26	7.3	5	373	300	340	63	53	10	6.3	7	5	73	11	19	1	31	5
Jan.27	7.8	7	331	346	288	77	65	12	6.3		4	75	9	12	2	29	5
Jan.28	8.2	8	223	394	106	112	83	10	6.4		3	66	3	11	1	35	1
Jan.31																	
Feb.01			361	310	200	69	57	10			23	59	30	18	4	41	6
Feb.02	6.3		800	600	316	143	100	37	6.7		7	54	5	15	8	41	9
Feb.03		6	578	349	680	98	69	18	6.3		4	25	2	32	2	49	5
Feb.04	7.2	7	264	401	331	105	80	13	6.5		3	27	6	28	2	41	3
Feb.07	8	7	239	591	98	237	34	13	5.7	6	3	20	6	12	3	48	4
Feb.08	7.1	8	423	310	252	67	53	13	6.2	4.9	7	32	8	17	3	44	4
Feb.09	7.2	8	216	295	117	71	45	6	6.3	7.6	3	34	2	18	1	41	3
Feb.10	7	10	341	394	143	124	66	15	6.3	8.2	5	39	9	13	1	40	4
Feb.11	7.3	8.5	241	320	207	84	56	9									
Feb.14	7.2	10	342	320	313	120	68	14	6	2.3	3	25	10	9	7	37	3
Feb.15	8.2	10	548	255	140	43	42	7	6.4	2.3	7	29	5	12	3	36	4
Feb.16		8.5	453	222	137	42	40	6		2	20	79	2	19	4	24	4
Feb.17	7.8	9	277	357	166	104	70	12	6.6	4.7	3	44	7	18	1	31	4
Feb.18	6.9	8	331	311	154	74	76	11	6.5	3.7	4	38	4	24	2	34	5
Feb.21	7.7	8	295	343	163	91	70	9	6.4	4	3	46	7	8	1	39	6
Feb.22	7.2		337	310	109	80	73	7	7	2.2	4	69	5	21	6	28	5
Feb.23	8.2	9		447	173	118	97	12									
Feb.24			406	376	195	87	65	13			6	67	7	11	6	32	7
Feb.25	8	7	184	303	178	65	53	6	6.4	4	4	35	10	7	1	39	7
Feb.28	8.4	12	256	408	120	86	79	9	6.2	5	6	17	1	12	1	43	6
Mar.01	7.6	9	252	269	86	50		8	6	6.3	6	21	8	18	1	41	6
Mar.02			161	296	112	57	46	7			7	17	8	20	2	40	6
Mar.03	7.1	9.5	201	232	116	43	33	7	6.1	4.3							
Mar.04	7.6	9.5	275	319	136	79	61	10	6.3	7.5	4	29	6	17	4	40	3
Mar.07	6.9	5	65	106	48	25	24	3	6.8	11.6	4	39	4	10	2	13	3
Mar.08	7.3	7.5	58	190	108	33	33	5	7.1	11.4	7	64	6	10	1	16	4
Mar.09	7.3	8	228	237	113	42	34	8	6.9	7.8	4	82	7	11	1	18	5
Mar.10	7.5	8.5	248	222	106	33	29	7	7.1	10	4	72	5	14	1	21	4
Mar.11	7.7	9.5	142	231	107	40	35	9	7.1	7.7	4	80	5	7	1	22	5
Mar.14		9.5	222	313	97	72	51	10	7	3	3	78	2	20	3	25	6
Mar.15	8	9	294	371	153	79	68	11	6.7	6.2	3	62	5	9	1	28	6
Mar.16	7.6	10	320	332	155	70	55	10	6.9	5.7	2	58	4	6	1	30	3
Mar.17	8.4	9.5	328	433	118		66	8	6.7	5	4	62	4	14	6	31	6
Mar.18			246	437	115	100	82	10	6.9	6.5	3	111	1	13	1	32	7
Mar.21	8.1	9	178	274	173	137	59	13	6.8	4.1	5	54	8	19	1	40	7
Mar.22			167	354	138	74	70	11			8	47	10	23	2	34	6
Mar.23	7.4		320	243	161	60	47	13	6.5	4.2	4	49	7	20	1	34	8
Mar.24	7.4	9.5	130	247	133	45	39	10									
Mar.25	7.9	9	111	276	139	54	53	10	6.5	7.2	7	35	6	15	2	37	8
Mar.28	8.1	8	235	387	374	149	77	13	6.4	7	3	23	8	15	2	43	6
Mar.29	7.3	10	328	231	164	63	46	10	6.7	6.5	8	34	7	17	1	25	5
Mar.31	7	7	66	190	85	28	24	5	6.6	6	3	49	1	12	1	22	3

TABLE B2 SUMMARY DATA FOR GLENLEA - MIXED LIQUOR

DATE	No.	FLOW	pH	DO	TEMP	MIXED LIQUOR MLSS	VSS	MLVSS	SETSOL	ML WAS	SVI
		m3/d	ML	mg/L	deg.C	mg/L	perc.	mg/L	mL	m3/d	mL/g
Jan.3	1		6.3	7.2	11	3504	84.93	2976	315		90
Jan.4	2	3.97				4724	82.98	3920			
Jan.5	3	4.81	7		11	3280	87.2	2860	310		93
Jan.6	4	4.49	6.9	8.5	9	3856	82.05	3164	415		108
Jan.7	5	4.70	5.8	8.2	11	4356	81.82	3564	480		110
Jan.10	8	5.45	6.8	6.2	11	3572	83.65	2988	390		109
Jan.11	9	5.22	7.2	8.8	10	5300	86.57	4588	370		70
Jan.12	10	4.59	7	9.5	10	4412	85.68	3780	400		91
Jan.13	11	5.22	6.9	8.6	10	4632			480		104
Jan.14	12	5.65	6.9	11	10	4648	82.96	3856	400		86
Jan.17	15	5.22	6.8	9.5	9	4136	82.01	3392	390		94
Jan.18	16	5.45	7	9.7	9	4786	83.38	3992	420		88
Jan.19	17	5.13	7.2	9.5	9	3676	82.15	3020	400		109
Jan.20	18	4.81	6.9	9.1	10	4280	82.24	3520	500		117
Jan.21	19	5.22	6.5	7.2	10	5092	83.5	4252	490		96
Jan.24	22	4.38	6.8	6	10	4436	82.69	3668	510		115
Jan.25	23	3.73	6.8	10	9	4500	82.58	3716	530		118
Jan.26	24	7.63	6.4	9.5	9	5256	80.59	4236	510		97
Jan.27	25	2.09									
Jan.28	26	4.81	6.6		10	4476	81.41	3644	530		118
Jan.31	29	8.78								3.13	
Feb.01	30					3084	83.14	2564			
Feb.02	31	5.90	6.6		8	2768	87.57	2424	340		123
Feb.03	32	4.81	6.4		7	2908	88.72	2580	340		117
Feb.04	33	5.22	6.7		9	3444	87.8	3024	380		110
Feb.07	36	2.72	6.2	7.5	8.5	3624	81.46	2952	360		99
Feb.08	37	6.17	6.7	9.3	10	3576	82.09	2952	350		97
Feb.09	38	5.22	6.9	9.5	10	4872	82.59	4024	380		78
Feb.10	39	1.14	6.7	9.3	10	3724	81.63	3040	400		107
Feb.11	40	5.22	6.6	9.5	10	3756	82.22	3088	375		100
Feb.14	43	3.56	6.1	5.6	11	3940	81.93	3228	400		102
Feb.15	44	1.68	6.7	8.1	11.5	4556	82	3736	430		94
Feb.16	45	4.09		8.2	11	4088	82.09	3356	470		115
Feb.17	46	1.82	6.7	9.4	11		82.62		450		
Feb.18	47	1.25	6.7	9.6	10	3932	81.38	3200	420		107
Feb.21	50	3.22	6.5	8.1	11	4624	81.06	3748	520		112
Feb.22	51	3.77	7.1	8	10	4516	82.02	3704	490		109
Feb.23	52	3.47	7.1	10	11	4320	81.94	3540	550		127
Feb.24	53					4788	81.12	3884			
Feb.25	54	3.56	6.4	2.7	10	4944	81.63	4036	580	2.50	117
Feb.28	57	5.68	6.5	6.8	10	3292	82.62	2720	400		122
Mar.01	58	3.18	6.4	8	10	3232	82.05	2652	400		124
Mar.02	59	3.86			12	3516	82.03	2884			
Mar.03	60	0.95	6.2	8	11	3428	80.86	2772	450		131
Mar.04	61	2.41	6.5	7	11	3672	83.88	3080	580		158
Mar.07	64	15.89	6.6	11.8	6	2616	81.65	2136	400	2.50	153
Mar.08	65	6.17	7.2	12.3	6.5	2576	81.05	2104	400		154
Mar.09	66	4.49	6.9	10	6	3016	81.56	2460	430		143
Mar.10	67	2.93	7.2	11.2	8	4500	83.64	3764	420		93
Mar.11	68	5.13	7.2	10	9	3140	80.64	2532	470		150
Mar.14	71	4.90	6.8	7.5	7.5	3304	81.00	2674	480		145
Mar.15	72	3.77	6.7	9.2	10	3408	80.63	2748	500		147
Mar.16	73	2.41	6.9	6.7	10	3528	80.27	2832	480		136
Mar.17	74	3.04	7	8.5	10	3480	80.23	2792	500		144
Mar.18	75	2.41	6.9	9.5	10	3556	81.55	2900	550		155
Mar.21	78	7.63	6.8	10	9	4352	80.42	3500	550		126
Mar.22	79	2.95				4544	79.05	3592	650		143
Mar.23	80	1.68	6.3	6.2	10	4092	80.16	3280	600	1.73	147
Mar.24	81	1.82	6.5		11	2832	79.74	2264	400		141
Mar.25	82	2.20	6.5	9.2	10	3072	80.21	2464	410		133
Mar.28	85	6.70	6.3	9.1	10	3324	81.35	2704	440		132
Mar.29	86	6.17	6.6	6.6	10	3540	80.11	2836	440		124
Mar.31	88	8.40	6.9	9	10	3572	81.19	2900	460		134

TABLE B3 SUMMARY OF DATA FOR HUDSON BAY MINING & SMELTING

	BOD_5		ALK.		SS		TKN		NH_4-N		TP	NO3-N		MLSS	VSS	SETTL
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	OUT	-	-	SOL
Jun. 2	107	6	141	75	110	6	21	5	15	3	2	0.1	6	5430	60.50	250
10	95	3	152	89	60	8	20	5	13	2	2	0.1	5	4750	61.63	300
24	46	4	137	112	226	10	17	5	9	2	4	-	2	2790	62.33	350
30	38	2	120	87	44	2	15	8	8	2	3	0.2	3	2500	62.40	300
July 4	30	7	110	89	36	4	11	5	6	3	1	0.1	2	1792	62.50	310
21	64	3	118	79	39	1	14	6	8	2	2	0.2	4	2064	60.66	280
Aug. 4	54	3	134	77	59	1	19	6	10	1	2	-	6	2004	64.47	-
5	54	4	134	79	109	2	18	5	10	1	3	0.2	5	2320	62.24	-
18	35	4	98	77	44	7	12	4	6	1	1	0.2	3	524	64.12	100
Oct. 3	41	1	109	79	82	1	13	8	5	2	1	0.1	5	2472	70.06	310
25	87	2	105	73	323	8	24	6	7	2	5	-	5	2808	69.23	290

All values except % VSS and Settl. Sol. in mg/L

Settl. Sol. in ml/L

TABLE B4 SUMMARY OF DATA FOR RIVERCREST

	BOD$_5$		ALK.		SS		TKN		NH_4-N		TP		NO_3-N	MLSS	VSS	SETTL.
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	OUT	-		SOL
Oct. 3	154	25	559	532	150	38	59	34	35	28	10	11	1	1220	88.52	-
5	117	13	559	559	113	14	69	39	36	32	9	7	1	1448	81.22	100
10	147	11	543	555	116	20	54	44	35	34	9	7	1	2056	81.91	120
12	176	12	520	541	163	10	48	42	32	32	7	6	1	-	-	-
13	188	14	518	562	86	4	46	46	30	37	7	6	1	2752	79.36	160
17	242	5	566	544	609	14	60	39	34	35	10	8	1	2892	76.76	190
20	241	10	568	485	283	1	60	30	37	26	8	7	2	-	-	-
24	310	11	536	354	468	9	62	11	36	4	9	7	2	3640	76.70	290
27	211	6	570	384	113	17	58	7	36	1	7	7	4	3332	77.43	280
31	115	7	522	388	157	9	51	4	25	1	7	6	3	3312	77.29	260
Nov. 5	356	5	522	350	604	26	71	13	47	1	9	5	21	2700	77.48	290
8	283	7	566	362	199	27	71	9	41	1	9	5	18	2808	79.91	300
13	225	24	572	370	208	66	60	13	39	3	8	7	14	3784	78.86	500
22	282	20	528	394	145	4	77	8	38	1	10	5	8	3944	81.74	800
30	261	30	546	396	374	19	94	8	51	2	13	6	4	2564	82.84	350
Dec. 14	325	37	566	498	203	34	54	34	33	26	10	4	1	3504	84.02	400
21	336	12	511	471	479	19	58	27	33	22	9	1	5	3700	82.59	410
28	273	7	550	337	252	11	65	14	39	1	9	3	24	3672	84.10	450

All values except % VSS and Settl. Sol. in mg/L

Settl. Sol. in ml/L

APPENDIX C

Equipment Installed at Glenlea, HBM&S and Rivercrest Plants

TABLE C1 EQUIPMENT COMPARISON

TYPE	GLENLEA	HBM&S	RIVERCREST
PUMPS			
Raw	Pneumatic air lift	1 x 1/2 hp centrifugal	2 x 1/2 hp submersible
Effluent	1 x 1/3 hp centrifugal	1 x 1/2 hp centrifugal	2 x 1/2 hp centrifugal
Sludge-waste	-	1 x 1/2 hp submersible	1 x 1/2 hp submersible
Sludge Supernatant decant.	-	-	1 x 1/2 hp centrifugal
BLOWERS	1 x 1 1/2 hp pos. displace	1 x 1 1/2 hp pos. displace	1 x 6.5 hp pos. displace
HEAT	1 to 3 x 250 W heat bulbs	1 x 10 kW w/thermo.	(Control room) 1 x 1.5 kW 1 x 5 kW (aeration access) - Thermostat controlled

NOTES:

All pumps Monarch or Barnes locally available.
Compressor - all Roots.
Heaters - chromalox set to operate at 10 °C.

APPENDIX D

- Statistical Significance Evaluation of Mixed Liquor and Effluent pH - Glenlea
- Nitrogen Balance - Glenlea
- Nitrogen Balance - Rivercrest

STATISTICAL SIGNIFICANCE EVALUATION OF MIXED LIQUOR AND EFFLUENT pH - GLENLEA

pH

Parameter	Mixed Liquor	Effluent
x	6.71	6.60
σ	0.31	0.33
n	55	54

$$\Delta \bar{x} = 6.71 - 6.60 = 0.11$$

Standard error of the mean = $S.E._m = \frac{\sigma}{\sqrt{n}}$ (D1)

$$S.E._{m1} = 0.0418 \qquad S.E._{m2} = 0.0449$$

Standard error of the difference between the two means:

$$\begin{aligned} S.E._{diff.} &= \sqrt{(S.E._{m1})^2 + (S.E._{m2})^2} \\ &= \sqrt{(0.0418)^2 + (0.0449)^2} \\ &= 0.06 \end{aligned} \qquad (D2)$$

At the 95% certainty level:

$$\begin{aligned} &= \Delta\bar{x} - (2 \times S.E.diff.) \\ &= 0.11 - (2 \times 0.06) \\ &= -0.01 \end{aligned}$$

This means that the difference between the mixed liquor pH and the effluent pH is completely removed by chance alone. The apparent difference in pH is therefore NOT statistically significant.

NITROGEN BALANCE - GLENLEA

TKN influent = 79 mg/L

Organic-N = 24 mg/L

NH_4-N = 55 mg/L

The nitrogen requirement for cell synthesis can be calculated from knowing that approximately 12% of cell consists of nitrogen (15). The new biomass production rate is taken from Figure 19 to average 570 g/d.

Therefore mass of N required for cell synthesis = 570 g/d x 0.12

= 68 g/d

The daily N concentration reduction is calculated as:

$$\frac{68 \text{ g/d}}{4.4 \text{ m}^3\text{/d}} = 16 \text{ g/m}^3$$

From this, the organic Nitrogen effluent concentration should be:

24 mg/L - 16 mg/L = 8 mg/L

Checking with Figure 45, the mean Organic nitrogen concentration was indeed 8 mg/L. From these observations and calculations it can be estimated that the amount of NO_3-N denitrified per litre is 22 mg/L.

To summarize:

$$TN_{in} = TN_{out} + TN_{cells} + TN_{denit.}$$

$$TN_{out} = \text{Organic N} + NH_4\text{-N} + NO_3\text{-N}$$

$$= 8 \text{ mg/L} + 2 \text{ mg/L} + 31 \text{ mg/L}$$

$$TN_{cells} = 16 \text{ mg/L}$$

Therefore TN denitrified = $TN_{in} - TN_{out} - TN_{cells}$

= (79) - (8 + 2 + 31) - (16)

= 22 mg/L

For clarity, this information is best shown as follows:

	IN	CELLS	OUT	DENITRIFIED
TKN	79			
Org-N	24	16	8	
NH_4-N	55		2	
NO_3-N			31	22
TN =	79 =	16 +	41 +	22

This means that the total amount of nitrification was 53 mg/L and 22 mg/L lost due to denitrification. (i.e. 96% nitrification and 42% denitrification)

The stoichiometric relationships for alkalinity removed per unit ammonia oxidized and alkalinity produced per unit of nitrate reduced can be used to give an estimate of the amount of nitrate lost due to denitrification. On a mass balance basis this had been calculated to be 22 mg/L. On a stoichiometric basis this is calculated as follows:

$$\frac{\text{mg alkalinity removed}}{\text{mg } NH_4\text{-N oxidized}} = 7.14 \qquad \text{(D3)}$$

$$\frac{\text{mg alkalinity produced}}{\text{mg } NO_3\text{-N reduced}} = 3.6 \qquad \text{(D4)}$$

and

$$\Delta\text{alk.} = (\text{alk. in}) - (\text{alk. out}) + (\text{alk. produced}) \qquad \text{(D5)}$$

where:

Δalk. = net change in alkalinity
alk_{in} = influent alkalinity
alk_{out} = effluent alkalinity
alk_{prod} = alkalinity generated due to denitrification

Substituting equations (27) and (29) into (28) and simplifying:

$$NO_3\text{-}N_{reduced} = \frac{7.14\,(NH_4\text{-}N_i - NH_4\text{-}N_e) - (\text{alk.}_{in} - \text{alk.}_{out})}{3.6} \qquad \text{(D6)}$$

where:

$NH_4\text{-}N_i$ = influent ammonia conc. mg/L
$NH_4\text{-}N_e$ = effluent ammonia conc. mg/L

Substitution of observed values into equation (D6) where:

$NH_4\text{-}N_i$ = 55 mg/L (Figure 27)
$NH_4\text{-}N_e$ = 2 mg/L (Figure 28)
alk_{in} = 314 mg/L (Figure 26)
alk_{out} = 56 mg/L (Figure 29)

$$NO_3 - N_{reduced} = \frac{7.14(55 - 2) - (314 - 56)}{3.6}$$

$$= 33 \text{ mg/L}$$

Thus, on a stoichiometric basis, 33 mg/L of NO_3-N was lost due to denitrification. Considering the many assumptions made in both the mass balance calculation and knowing that the stoichiometric ratios of equations (D3) and (D4) have been observed by others to be lower (11), the calculated reduction in nitrate concentration of 22 mg/L, when compared to 33 mg/L is in remarkable agreement.

NITROGEN BALANCE - RIVERCREST

Judging from the data, a high degree of nitrification and denitrification must have occured. For example, the nitrification rate was calculated to be 44 g NH_4-N removed/kg MLVSS/day. It should be remembered though, that the sewage is a settled sewage. A significant portion of the influent SS have been removed and nitrogen associated with SS has been removed accordingly.

A nitrogen balance can be established as follows:

TKN influent = 62 mg/L
Organic N = 37 mg/L
NH_4-N = 26 mg/L

The nitrogen requirement for cell synthesis can be calculated by assigning 12% of the cell weight to nitrogen and using the biomass production rate of 4580 g/d (Figure 97).

Therefore, mass N required for cell synthesis = 4580 g/d x 0.12
= 550 g/d

The daily N concentration reduction is therefore calculated as

$$\frac{550 \text{ g/d}}{227 \text{ m}^3\text{/d}} = 2.5 \text{ g/m}^3 \qquad \text{(use 3 mg/L)}$$

A mass balance would be as follows:

$$TN_{in} = TN_{out} + TN_{cells} + TN_{denitrified}$$
$$TN_{out} = \text{Organic N} + NH_4\text{-N} + NO_3\text{-N}$$
$$= 8 + 10 + 3$$
$$= 21 \text{ mg/L}$$

$$TN_{cells} = 3 \text{ mg/L}$$

Therefore TN denitrified = TNin - TNout - TNcells
= (62) - (21) - (3)
= 38 mg/L

For clarity, this information is best shown as follows:

	IN		CELLS		OUT		DENITRIFIED
TKN =	62						
Org N =	37		3		8		
NH_4-N =	26				10		
NO_3-N =					3		39
TN =	63	=	3	+	21	+	39

This would indicate that the total amount of nitrification was 42 mg/L and 39 mg/L was lost due to denitrification.

Nitrification efficiency was:

$$((37) - (3 + 8) + (26 - 10)) / \ 63 = 42/63 = 67\%$$

Denitrification efficiency was:

$$(42 - 3)/42 = 93\%$$

The amount of oxidized nitrogen (NO_3-N) lost due to denitrification can also be estimated from stoichiometric considerations. Using equation (D6):

$$NO_3\text{- N reduced} = \frac{7.14\ (\ NH_4\text{- N}_i - NH_4\text{- N}_e\ ) - (\ \text{alk.}_{in} - \text{alk.}_e\ )}{3.6} \qquad (D6)$$

where:

NH_4-N_i = 26 mg/L + (37 - 11) = 52 mg/L
NH_4-N_e = 10 mg/L
alk.in = 545 mg/L
alk.e = 400 mg/L

$$NO_3\text{- N reduced} = \frac{7.14\ (\ 52 - 10\ ) - (\ 545 - 400\ )}{3.6}$$

$$= 43 \text{ mg/L}$$

Thus, on a stoichiometric basis, 43 mg/L of NO_3-N was lost due to denitrification. This checks with the value of 39 mg NO_3-N/L from mass balance considerations..

Using the values for alkalinity lost (6.5) and generated (3.0), due to N oxidation and reduction, as found in the literature (11) gives the same NO_3-N concentration of 43 mg/L.