MODELING AND MICROBIOLOGY OF A NEW ZEALAND DAIRY INDUSTRY ACTIVATED SLUDGE TREATMENT PLANT

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ABSTRACT

An extended aeration activated sludge plant treating dairy factory wastewater was studied. The effectiveness of organic and nutrient removal was investigated in conjunction with the causes of existing foaming and bulking problems.

Excellent removal efficiencies of 99.7% BOD5, 98.8 % COD, and 96.9% TKN were achieved thoughout the period studied. The removal of total phosphorus however, was only 33.8% and this may become an issue that requires attention in the future.

The dominant filamentous organisms in the sludge were identified as *Type 0914*, *Type 0092*, *Nocardia pinensis*, *Nocardia amarae*-like organisms, and *Nostocoida limicola III*.

It was determined that these organisms were the major cause of the bulking and foaming conditions at the Waste Treatment Plant, although the use of surfactants in the factories and nitrogen and iron deficiencies were probably also contributing.

All of the dominant filaments identified have been previously found to exist in large numbers in low food to organism ratio/high sludge age conditions. It was therefore recommended that the sludge age be reduced and the F/M ratio increased by increasing the amount of sludge wasted from the treatment plant.

Existing kinetic coefficients were used, together with the Activated Sludge SIMulation programme utilising Activated sludge Model No.1, to successfully model

the existing system. This model can now be used by treatment plant employees (with some training required) to predict the results of alterations to plant operation and/or configuration.

ACKNOWLEDGMENTS

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Thanks also to Rao Bhamidimarri of Massey University for his technical expertise; and to New Zealand Dairy Research Institute, especially Mike Donkin, for substantial assistance with the modeling process.

Last but not least I would like to thank Bernard, my husband, for his support, encouragement and patience.

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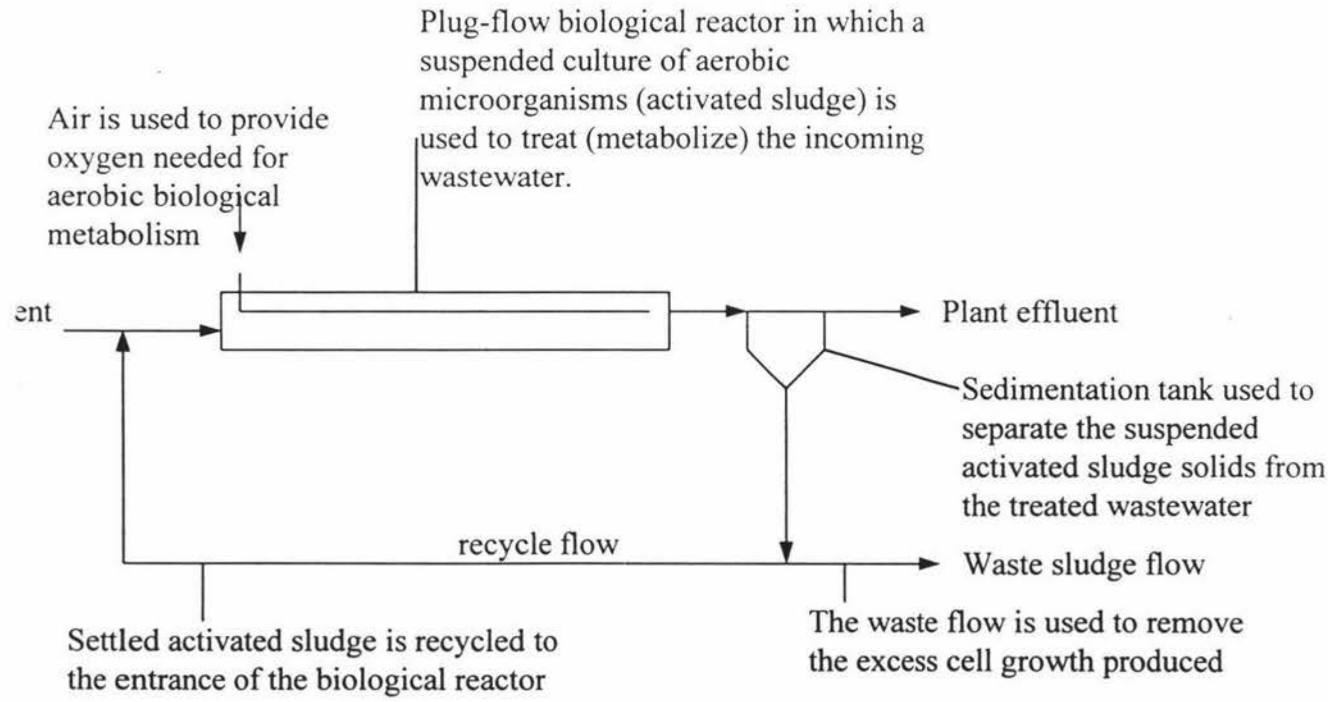
INTRODUCTION

In the New Zealand dairy industry the wastewater treatment emphasis has been towards land irrigation and biological treatment of factory discharges. Biological treatment, and in particular Activated Sludge systems, have been used extensively worldwide to treat wastewaters from manufacturing dairy factories. In a conventional Activated Sludge system (Figure 1), wastewater is fed into an aerated basin, followed by a clarifier in which the biomass settles out, and from which a clear effluent is discharged. Some of the settled biomass is recycled to the aeration basins to maintain the population of microorganisms.

Figure 1.

Conventional Activated sludge system



The Activated Sludge process is widely known to reduce the concentration of dissolved, particulate, and colloidal organic pollutants in wastewater. The process uses the metabolic rates of microorganisms to produce an acceptable effluent quality by removing substances that have an oxygen demand. The basic design parameters are fairly well known and adequate conservative designs based on empirical data have evolved over the years. Poor operation, however, poses continuing problems for many plants.

Wastewaters generated by the processing of wholemilk vary according to the products being manufactured, but are generally characterized by high organic matter, high nutrients and varying pH. These wastewaters require substantial treatment in order not to have adverse effects on the environment. Discharge standards often require removal efficiencies of more than 95% of BOD and 90% of COD. Discharges are also often regulated by the BOD of the wastewater, as opposed to the COD (an analysis time of 5 days compared to two hours). The COD parameter is the most appropriate parameter to use to control the Waste Treatment Plant provided that a reproducable relationship can be determined between BOD and COD.

Anchor Products - Waitoa Site.

This site is located adjacent to the Waitoa River, in the Waikato region of New Zealand. The Waitoa River is currently used as the main source of potable water, and receives clean and treated water discharges from the site.

Biological Treatment Plant Description

The biological treatment plant at Anchor Products Waitoa has had a chequered history of bad performance and odour problems. The treatment plant under the current layout is now performing satisfactorily and is meeting the site's Resource Consent. There have been concerns however, about several issues, including the concentration of phosphorus being discharged to the river, the amount of foam on the surface of both ponds, and the lack of solids settling in the sludge volume index test. The Anchor Products Waitoa site has been earmarked for further expansion, and hence the treatment plant must be optimised to its full potential.

The plant to be studied in this report treats dairy factory wastewater from four factories on site. These factories manufacture the following dairy products:

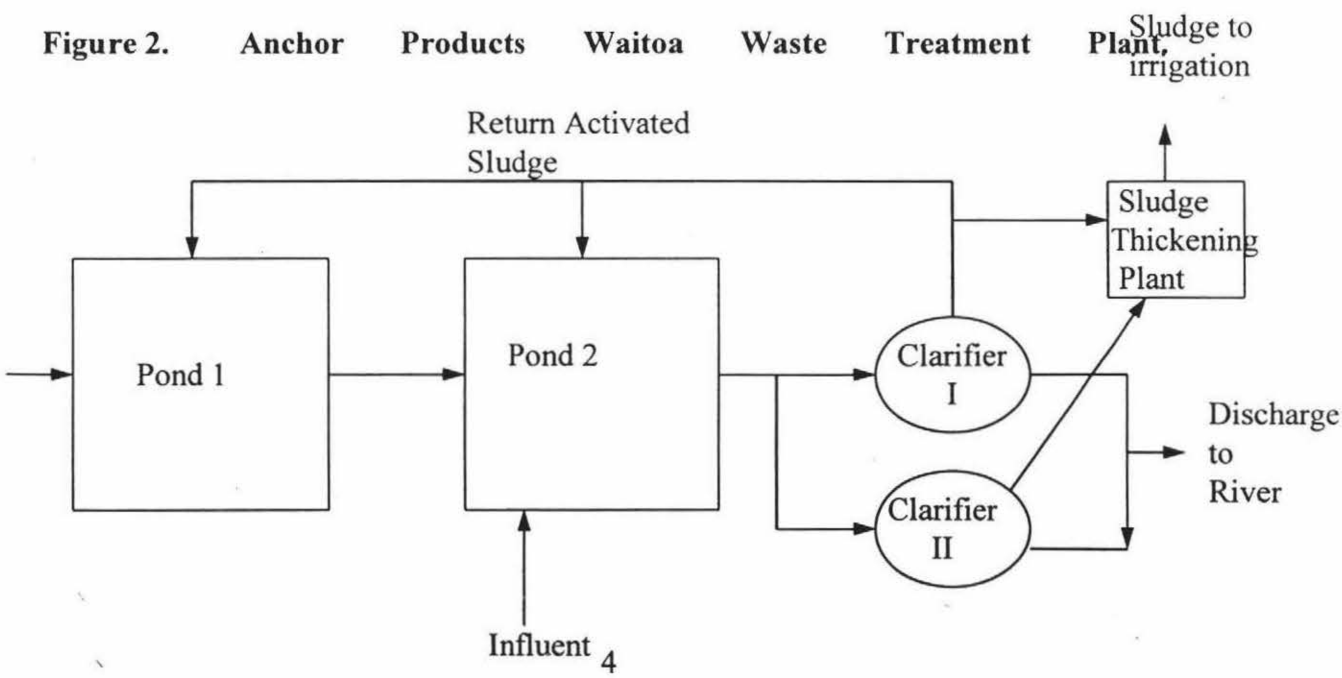
1. Milk powder (up to three million litres of raw milk per day)
2. Cheese (up to 1.5 million litres of raw milk per day)
3. Nutritional Products, including baby foods (up to 0.5 million litres of raw milk per day)
4. Powder Development Center producing experimental products and specialist products only requiring small runs (cheese powders, goats' milk powder) - up to 0.2 million litres of raw milk per day.

A demineralization plant processes some of the whey from the cheese factory using ion exchange and electrodialysis processes, for use in the Nutritional Products factory. This process discharges high loadings to the waste treatment plant. The initial rinses from each plant that contain strong milk wastes and no chemicals, are fed to pigs and are not treated at the treatment plant. Extra whey is fed to cows or irrigated onto pasture.

The sewage from site is reticulated separately and treated with a small package treatment plant, hence the larger plant contains only waste dairy produce, water and cleaning chemicals.

Due to the nature of the product mix and the fact that whey demineralization is carried out on site, the wastewater handling systems for the site are of a significant size (Figure 2). Two aerated lagoons with a total aeration volume of 44,000 cubic meters are operated in series, using up to 1,100 kW of aeration, controlled by Zullig dissolved oxygen probes from a PLC. From the second pond, wastewater passes through two clarifiers operated in parallel. Effluent from the clarifiers passes through a sandfilter and is then discharged into the Waitoa River. Separated sludge is either returned to the pond system, or is thickened and irrigated onto maize or pasture. The influent and return Activated Sludge can be directed either to pond one or to pond two, however, both the influent and the return sludge will normally discharge into pond 1.

Figure 2. Anchor Products Waitoa Waste Treatment Plant.



A large proportion of Activated Sludge process problems involve poor solids' separation in the clarifier, which can be attributed to the development of a sludge with poor settling characteristics. Settling characteristics are in turn determined by the conditions provided for the microorganisms in the aeration basin. Bulking is one of the most common and widespread sludge separation problems. It is characterized by a high sludge volume index (>150 ml/g). The sludge settles slowly and thickens poorly, but produces a clear supernatant (good clarification). Effluent quality typically is high unless the sludge blanket begins to escape over the weirs. Bulking is associated with the excessive growth of filamentous microorganisms of which there have been more than 20 different types found in Activated Sludge. The particular set of conditions leading to the excessive growth of one type of filamentous microorganism may be completely different from those favoring another type. Another, less common, form of bulking sludge is caused by bound water, in which the bacterial cells composing the floc swell through the addition of water to the extent that their density is reduced and they will not settle.

Once the cause of the settling problems is determined, steps can be taken to change the conditions in the treatment plant that encourage the particular organisms or behavior, and minimise the effect on the plant.

Foam on the Waste Treatment Plant surface is also an issue and may in fact result from the same cause as the filamentous bulking. There are a number of reasons to reduce the amount of foam on the aeration basins:

1. Aesthetics.

2. May overflow onto walkways etc. and become a health and safety hazard.

3. Makes cleaning and maintainance of the plant more difficult.

4. Foam may carry a high percentage of the plants solids, that aren't being included in sludge calculations.

5. Foam may be responsible for a reduction of oxygen transfer at the surface of mechanically aerated aeration basins.

6. Foam may putrefy in warmer climates.

7. Aerosols of foam producing organisms may be potential health hazards (some organisms in foam are opportunistic pathogens).

The emphasis of this work was to investigate an existing Activated Sludge plant treating dairy factory wastewater and determine its effectiveness in several areas including carbon, nitrogen and phosphorus removal, secondary clarification, filamentous bulking, scum/foam reduction, BOD:COD ratios. The system was then modeled with ASIM (Activated Sludge SIMulation programme) in order to provide a predictive environment for future operation. The ASIM programme allows for the simulation of a variety of different biological wastewater treatment systems: Activated Sludge systems with up to six different (aerobic, anoxic, anaerobic) reactors in series, including return Activated Sludge and an internal recycle, batch reactors, thermostat reactors etc. The software allows for the introduction of process control strategies (simple proportional controllers) and dynamic simulation (variable loading, temperature, aeration, sludge removal etc.). The biokinetic model may be freely defined, stored and edited enabling the use of a site specific model.

LITERATURE REVIEW

Dairy Processing Industry Wastewaters

Dairy industry wastes are generally dilutions of milk or milk products, together with detergents, sanitisers, lubricants, chemicals from boiler and water treatment, washings from transport tankers and domestic wastes (Marshall and Harper, 1984). The dairy industry generates strong wastewaters characterized by high BOD and COD concentrations reflecting their organic matter, and these predominantly soluble carbohydrate type wastewaters (except for some lubricants, cleaners and sanitisers) have historically been regarded as difficult to treat by activated sludge processes (Goronszy, 1990). A simple ratio for industrial wastewater treatability is the ratio of COD to BOD. Below a ratio of 2.5, the wastewater is readily degradable in an activated sludge process. A ratio above 2.5 indicates that there are molecules that are refractory to biodegradation, therefore a longer residence time will be required (Capps et al., 1995).

A variety of treatment methods for dairy factory wastewater have been used by the dairy industry throughout the world, and these methods have been summarized by Barnett et al. 1994. These methods include membrane systems, the reuse of condensate and cleaning solutions, pretreatment, land treatment, biological treatment and tertiary treatment. In the past the extended aeration activated sludge form of biological treatment has been used in the New Zealand dairy industry. Donkin (1996) is currently investigating the use of sequencing batch reactor technology to reduce the tendency of these systems towards filamentous bulking, and inadequate nitrogen and phosphorus removal.

The principal organic constituents in milk are fat, lactose and protein. The lactose in milk wastes easily converts to lactic acid under oxygen limited conditions. The soluble BOD fraction of dairy wastes is generally more than 80%. One percent of milk in a wastewater produces about 12 mg/l of phosphorus and about 55 mg/l of nitrogen. (Goronszy, 1990). Whey and associated wastes are known for their resistance to biodegradation and treatment, however when consisting of only a minute fraction of the total plant effluent, it has proved to be quite biodegradable with almost the same characteristics as the general discharge (Orhon et al., 1993).
While the total contribution of cleaning agents to the total organic load is quite small, they can have a significant effect on a biological system. Quaternary ammonium cationic surfactants are widely used in milk processing facilities as antiseptics and germicides, as well as for their detergent action. Alkyl ethoxylates, a class of nonionic synthetic surfactants, are used widely in industrial cleaning operations. Long acclimatization periods are required for their breakdown, and breakdown products from the ethoxy chains can support the growth of Nocardia. Alkyl phenol hydrophobes with either linear or branched alkyl groups can markedly retard biodegradation. Highly branched hydrophobes increase biodegradation resistance. (Goronszy, 1990).

Activated Sludge Modeling

The two major units involved in the activated sludge process are a biological reactor where pollutants are degraded by bacteria, and a clarifier, to thicken the biomass for recycling to the aeration basin and to clarify the effluent.

Earlier modeling of the activated sludge processes began in the 1940s when Monod (1949) proposed the empirical biological reaction equation for the microbial mass growth. Many rate equations have been published since and Orhon and Soybay (1989) presented a summary of these models. Most of the mathematical models for activated sludge processes consider two major variables, the limiting substrate and the microbial mass.

Biscogni and Lawrence (1971) developed a relationship between biological solids retention time and the settling characteristic of non filamentous activated sludge. This includes the issues of non filamentous bulking, deflocculation, and dispersed growth or the presence of pin point floc. They discovered that for minimum solids to be lost to effluent the sludge age value should be between 4 and 9 days and predict that extended aeration units operating at 6-30 days sludge age will experience pin-point floc, deflocculated particles and SVI about 100. At longer values of sludge age, settling and bioflocculation is accompanied by an accumulation of polysaccharide material.

Busby and Andrews (1975) modeled the activated sludge process by including more than one complete-mix reactor, the contribution of the biomass to the effluent BOD concentration, the performance of the clarifier, time varying inputs, and the Monod expression instead of first order kinetics with respect to substrate concentration.

Manickam and Gaudy (1979) modeled the effect of recycle sludge concentration on the ability of the system to accommodate shock loadings. They determined that shock loadings (qualitative and quantitative) will have less effect on the effluent BOD if the recycle solids concentration is increased.

Therien and Perdrieux (1981) characterized the carbon stream by utilising SOC (soluble organic carbon) and SSOC (suspended solid organic carbon) instead of the more conventional BOD, COD, and MLVSS. They discovered that SOC and SSOC described the dynamic behavior of activated sludge adequately.

Clifft and Andrews (1981) modeled the dynamics of oxygen utilization in the activated sludge process. They separated the removal of particulate and soluble substrates and incorporated the concept of substrate storage by the floc to create a model that predicted lag and dampening in oxygen utilization.

Benefield and Molz (1983) developed a model describing substrate removal, oxygen utilisation, and biomass production. This work showed that floc behavior is an important parameter to consider as well as microbial growth and storage. This model was then extended (Benefield and Molz, 1984), a mathematical model that describes organics removal, oxygen utilisation, ammonia-nitrogen removal, ortho-phosphate removal, and biomass production. It successfully described the competition between autotrophic nitrifying bacteria and heterotrophic bacteria for oxygen and ammonia-nitrogen in activated sludge processes.

The IAWPRC Task Group published a general model for single sludge systems, described in an abbreviated paper (Henze et al. 1987). This task force was set up to review all existing models and to publish the simplest one to describe the realistic performance of carbon oxidation, nitrification and denitrification in single sludge systems.

Andrews (1991) provided a complete overview of historic and modern model development of aerobic biological treatment processes. The model proposed by the IAWPRC task group was described.

The ASIM programme (Activated Sludge simulation programme) allows for the simulation of a variety of different biological wastewater treatment systems: activated sludge systems with up to 6 different (aerobic, anoxic, anaerobic) reactors in series, including return activated sludge and an internal recycle; batch reactors, thermostat reactors etc. The software allows for the introduction of process control strategies (simple proportional controllers) and dynamic simulation (variable loading, temperature, aeration's, sludge removal etc.). Examples of the applications of ASIM are documented in the publication by Gujer and Henze, 1991.

ASIM was used in conjunction with Activated sludge Model No. 1 to effectively model a New Zealand Dairy processing site extended aeration activated sludge plant (Donkin and Kerridge, 1997). The results from that study form the basis of the modeling reported in this thesis.

The IAWQ Task Group's Activated Sludge Model No.2 (ASM2) was introduced by Gujer et al. 1995. This improved on the Activated Sludge Model No. 1 (ASM1) by including a term for phosphorus accumulating organisms in the biological phosphorus removal processes. Application of the model with and without biological phosphorus removal at thirteen full-scale wastewater treatment plants highlighted the ability of the model to predict accurately nitrogen removal (Daigger and Nolasco, 1995). Results suggest that more work is required for the effects of bioreactor configuration and oxygen transfer system as well as the dynamic aspects of biological phosphorus removal. Henze *et al.* (1995) described the characterization of biomass and wastewater for use in the Activated Sludge Model No.2 and emphasized the need to include phosphate accumulating organisms and storage compounds in the biomass characterization.

Reichert *et al.* (1995) described the use of AQUASIM to estimate the parameters for activated sludge models. The flexibility of the program to assess parameters and combine several experiments with universal or experiment-specific parameters was demonstrated.

The growth of floc forming and filamentous bacteria within activated sludge floc particles was simulated under diffusion limited conditions (Takacs and Fleit, 1995). This model successfully predicted the onset of bulking conditions while other models that neglected diffusion limitations did not. Food to microorganism ratio bulking and scumming in activated sludge plants with anoxic or anaerobic selectors was simulated using a model incorporating surfactant and hydrophobic substrate concentrations (Kappeler and Brodmann, 1995). The model predicted proliferation of low F/M filaments during incomplete nitrification and that episodes with extended sludge blankets in the secondary clarifiers negatively influence completely aerobic systems but positively influence systems with predenitrification zones.

Donkin et al. described a non-linear least squares fit of data from a laboratory scale activated sludge plant treating dairy factory wastewater. The coefficients obtained were yield coefficients of b=0.074 (s.e.=0.013) per day, and Y_h=0.45 (s.e.=0.05) mgVSS/mgCOD. The coefficients μ_{max} and K_s were unable to be obtained due to errors in the effluent COD concentrations. Leonard (1995) has also determined kinetics for a similar synthetic dairy factory wastewater and obtained a Y_H of 0.68 mgCOD/mgCOD, μ_{max} of 1.15 per day, and K_s of 17g/m3. Orhon *et al.* 1993 measured the kinetic coefficients of an integrated dairy factory wastewater, and collected other studies of dairy factory waste kinetic coefficients. The results are shown in Table 1.

Table 1. Studies of Dairy Factory Waste Kinetic Coefficients

Source	μ (day-1)	K_s (mg/l)	b (d-1)	Y_H (mgVSS/mgCOD)	Comments
Whey-washwater mixture	3.1	100	0.22	0.44	Orhon et al., 1993
General discharge	3.3	74	0.32	0.41	Orhon et al.1993
Whey-process milk	3.74	257	0.19	0.538	Mayer et al. 1983
Dairy waste	0.6-2	5-33		0.48--0.68	Leonard, 1993,1996
Process milk	-	100	0.045	0.48	Archievala, 1981
Synthetic Milk	-	-	0.14	0.483	Hung, 1984

Clarifier Modeling

Activated sludge clarifiers serve several functions including clarification, solids thickening and solids storage. Clarification is especially important because effluent quality is related directly to the separation of the biological solids from the effluent stream.

A common approach is to relate the settling properties to the sludge volume index (SVI) and suspended solids concentration (Wahlberg and Keinarth, 1988; Takacs *et al.*, 1991). Much research on the hydraulics of clarifiers has been conducted in both the field and laboratory by Price and Clements (1982), Ostendorf (1986), McCorquodale *et al.* (1988), Godo and McCorquodale (1991), Bretscher *et al.* (1992) and Ji *et al.* (1996). Two dimensional numerical modeling of the flow pattern and sedimentation in clarifiers has made it possible to predict the effluent concentration of suspended solids as well as the return sludge concentration from a wide range of hydraulic conditions (Iman et al., 1983; Abdel-Gawad and McCorquodale, 1984; Celik et al., 1985; Devantier and Larock, 1986; Devantier and Larock, 1987; McCorquodale et al., 1991a; Zhou and McCorquodale, 1992a; Zhou and McCorquodale, 1992b; Ji *et al.*, 1996).

Activated Sludge Process Optimization

Influent

Because wastewaters of all types are encountered in the plant's influent, in most cases it is necessary to characterise them by their impact on the plant processes. Typically pH, BOD, COD, TSS, and VSS are measured to assess influent strength. Phosphorus, nitrogen, and alkalinity may also be measured to ensure that nutrients are present in the proper amounts. Other substances such as iron (necessary in trace amounts as a nutrient) or toxic organic materials are often overlooked until a problem is apparent (Task Force on activated sludge, 1987). While milk wastes consist of multi-component substrates a major fraction of the soluble component in the wastes can be removed by enzymatic transfer mechanisms and converted to intracellular bio-storage compounds. Typical soluble substrate removal by enzymatic mechanisms is shown in Figures 3 and 4 (Goronszy, 1990)

Figure 3.

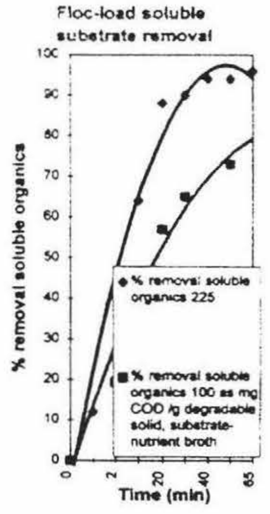
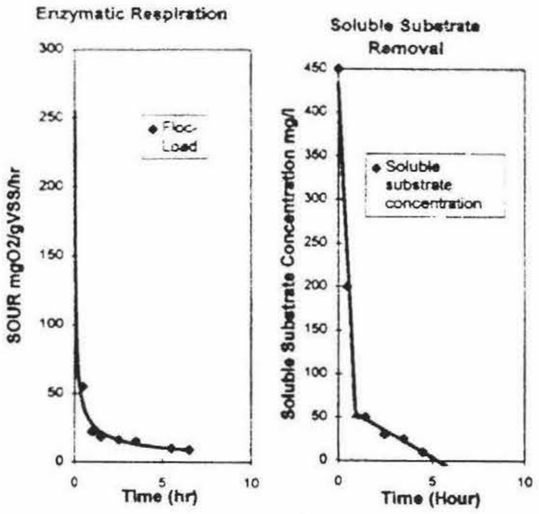


Figure 4.



Floc-loading has been shown to be effective to describe the prevention of filamentous sludge bulking for nutrient-balanced, readily degradable, carbohydrate-type wastewater under conditions simulating a compartmentalized fed-batch reactor (Goronszy, 1990).

Food to microorganism ratio is a key variable for process control. Low food to microorganism ratios (BOD < 0.2) indicate a system in which the microorganisms are food limited and therefore exist in an endogenous respiration state. Cells that die and deteriorate provide food for the remaining microorganisms. At high food to microorganism ratios (BOD > 0.5), the microorganisms are undergoing rapid growth and reproduction because of the abundance of food. Rapidly growing and reproducing bacteria do not flocculate or settle rapidly. Typically a maximum F/M ratio of 0.18 to 0.25 should apply for industrial wastewaters, however the design should provide for between 0.15 and 0.5 day-1. Refinery plants often maintain F/M (COD) ratios below 0.2 to control minimum sludge age and to provide reserve biological oxidation capacity for sudden increases in load, such as from spills (Capps et al., 1995).

Aeration basin

Dissolved Oxygen

The dissolved oxygen concentration in the aeration tank must be sufficient to sustain at ALL times the desirable microorganisms in the aeration tank, clarifier, and return activated sludge lines back to the aeration tank. When oxygen is limited, the growth of filamentous microorganisms may predominate and the settlabilty and quality of the activated sludge may be poor. On the other hand, over-aeration can create excess turbulence and may result in the breakup of the biological floc and waste energy (poor settling and/or high effluent solids). The dissolved oxygen levels should normally be maintained at about 1.5 to 4 mg/l in the aeration tank for adequate microorganism activity (Task Force on activated sludge, 1987).

Good sampling procedures for mixed liquor suspended solids concentrations are essential. Mixed liquor samples must be taken using consistent technique, grab samples at consistent times and locations (Task Force on Activated Sludge, 1987).

Nutrient requirements

With nitrogen limiting conditions, the amount of cellular material synthesised per unit of organic matter removed increases due to the accumulation of polysaccharide, restricts the rate of BOD removal, and stimulates filamentous growth that can lead to poor floc formation and bulking problems. Nitrogen is available to the biomass as ammonium (NH_4^+) and nitrate (NO_3^-). Ammonia is preferred as the organic removal rate is substantially higher than with nitrate (nitrate needs to be reduced to ammonia first). When organic nitrogen is present in the wastewater as protein or amino acid, it must first be biologically hydrolysed to release ammonium (Eckenfelder and Grau, 1992).

In order for the biomass to assimilate phosphorus it must be in the form of soluble orthophosphate (PO_4). Complex and inorganically bound phosphorus must first be bio-hydrolysed to orthophosphate to be available to the biomass.

The ratio of BOD_5 to nitrogen, phosphorus and iron changes with sludge age. Higher sludge ages produce less sludge and result in lower nitrogen and phosphorus requirements. Nitrogen and phosphorus must be available in the BOD:N:P ratio of 100:(3-5):1 for complete BOD removal. Where the COD test is used, the ratio of COD concentration to nitrogen concentration (with nitrogen added as ammonium ion) of 25/1 to 20/1 is needed to ensure that carbon is the nutrient that limits the growth rate (Gaudy and Gaudy, 1984). TKN should be used as the measure of nitrogen. If nitrification is occurring ammonia residuals will be low which could lead to large increases in nitrogen feed rates for purposes other than as a nutrient.

Goronszy (1990) showed the importance of nitrogen availability for the maintenance of balanced biological growth. He demonstrated that an effluent ammonia nitrogen concentration of around two mg/l was enough to prevent sludge bulking at the studied facility. Eckenfelder (1989) stated that all the minor elements essential for organic matter metabolism are usually present in sufficient quantities in carrier waters, except process water generated from deionised water where iron and other nutrients may be deficient. Trace elements are required in the following quantities: Mn $10x10^{-5}$, Cu $14.6x10^{-5}$, Zn $16x10^{-5}$, Mo $43x10^{-5}$, Se $14x10^{-10}$, Mg $30x10^{-4}$, Co $13x10^{-5}$, Ca $62x10^{-4}$, Na $5x10^{-5}$, K $45x10^{-4}$, Fe $12x10^{-3}$, CO_3 $27x10^{-4}$.

The operation of activated sludge facilities treating dairy wastes under high organic loads (in excess of 2,000 mg/l BOD) has been reported to affect the ability of the biomass to use amino acids as a nitrogen source, which can impact on process performance through sludge bulking.

If nutrients are not available then they must be added. Commonly used forms of nitrogen include urea and anhydrous ammonia. Phosphoric acid and trisodium phosphate are often used as a source of phosphorus. Ferric chloride is used to add iron. Another option is a liquid fertilizer that contains both nitrogen and phosphorus. One way to determine if sufficient nutrients have been added is to measure the residuals in the aeration basin effluent (ortho-P (PO^{4-}), ammonia and nitrate) (Marshall, 1992, Task Force on Activated sludge, 1987).

Protozoa

Normally encountered indicator microorganisms in activated sludge samples are of the phyla: Protozoa (protozoans); Rotaforia (rotifers); and Nematoda (roundworms). Wanner (1994) reviewed population dynamics in activated sludge and its role in the treatment process and treatment efficiency. The relationship between Protozoa and effluent quality was investigated, and ciliates found to be good indicators of effluent quality when the BOD_5 concentration was between 4 and 18 mg/l. The presence of *Actineta tuberosa*, *Euplotes* sp., and *Zoothamniun* sp. were found to be an indicator of high effluent quality, while presence of the most common species such as *Uronema nigricans*, *Vorticella microstoma*, and *Opercularia coarctata*, were found to be an indicator of worse effluent quality (Salvado et al., 1995). The microorganisms that appear most frequently and the activity of these microorganisms enables the operator to decipher occurrences in the process. These microorganisms and their relative numbers are shown in Figure 5 (APHA 1992, Task Force 1987).

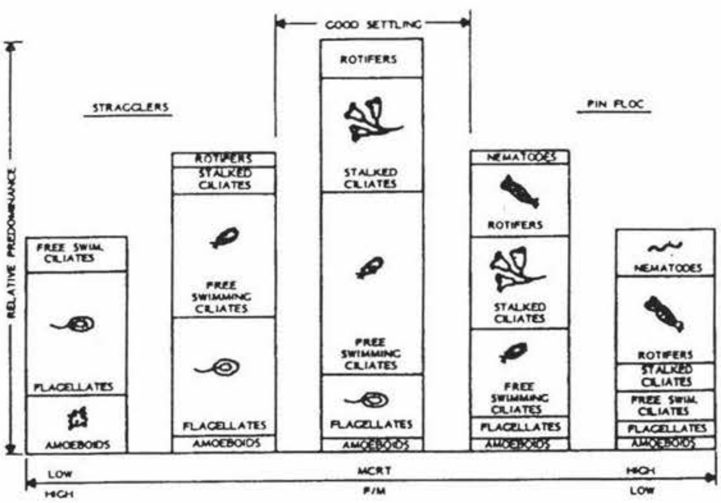


Figure 5. Relative Predominance of Microorganisms versus F/M and MCRT.

The most commonly observed protozoans are Sarcodina (amoeboid forms); Mastigophora (flagellates); and ciliata (free swimming ciliates and stalked ciliates). Amoeboids predominate during plant start-up or when the plant is recovering from an upset. Flagellates predominate in light or dispersed mixed liquors at high food to microorganism ratios (low sludge ages). Because they are excellent swimmers they compete readily, and have more of an opportunity to develop and multiply within the short lifespan of the process. During this low sludge age condition effluent quality is usually poor due to the loss of dispersed, nonflocculant (straggler) sludge particles. Free swimming and crawling ciliates predominate as their bacterial food increases (food to microorganism ratio decreases). Stalked ciliates predominate when there is an abundance of bacteria (large flocs). When these microorganisms dominate (normal sludge age), effluent and sludge quality are usually best. As the food supply decreases (old sludge) rotifers and worms, higher forms of life, normally compete and predominate. In most cases this indicates worsening effluent quality and overoxidised sludge (pin floc). However some plants (extended aeration activated sludge plants) are designed to operate under these conditions and it may be common to see rotifers and worms predominate and still have excellent effluent quality (Task Force on Activated Sludge, 1987). If the protozoa appear normal and active, but the effluent is cloudy, the activated sludge floc may be dispersed as a result of excessive turbulence (overaeration) (Task Force on Activated Sludge, 1987).

Reactor Configuration

An approach for developing industrial wastewater treatment plant design specifications was presented by Capps *et al.* 1995. The method takes into consideration variations in the wastewater and targets for the design. A step feed was trialed during high flow conditions. In a four reactor system, influent feed into reactors 1 (60%) and 2 (40%) was compared with influent feed into reactors 2 (50%) and 3 (50%) and the normal situation of 100% into reactor 1. Return activated sludge was set at 44% of the inflow rate. The two step feed operations reduced the effluent suspended solids, hence improving the systems performance. The lowest effluent suspended solids were achieved by the second scenario. This was due to reactor one holding a greater mass of solids than for under normal conditions, and hence keeping solids from flushing out of the system during peak flows. This scenario however will also reduce the contact period for wastewater treatment, increasing the BOD/COD in the discharge. Optimal control of the system would be achieved by adjusting the return activated sludge flow rate and the step feed system during high flow events to minimize the combination of the suspended solids and the soluble substrate concentration in the effluent (Ji et al).

Recycled flow streams within wastewater treatment plants are another factor affecting performance. Sludge treatment processes particularly can contribute significantly to operational problems. Centrate, filtrates, thickener overflows, and heat treatment decants, which are usually recycles to the head of the plant, are normally high in BOD and TSS. This can be up to 10-15% of the loadings. Some guidelines to reduce the effects of recycled flows include:

add recycle flows continuously to minimise shock loads.

Improve efficiency of sludge handling processes.

Avoid pumping excess water to sludge handling processes

Aerate or pretreat recycled flows to reduce oxygen demands.

Keep an accurate accounting of recycle loads on the activated sludge process.

(Task Force on Activated Sludge, 1987).).

Mixed liquor suspended solids represents all the solids in the aeration basin, whereas mixed liquor volatile suspended solids represents the combustible solids, and hence better represents the living organisms in suspension. MLVSS is typically 70-80% of MLSS (Capps et al., 1995).

Secondary Clarifier

Conventional clarifiers are large round tanks with a circular overflow weir at the top and a conical. rake swept section at the bottom for collecting solids. A conservative design loading rate is 6,000 $l/d/m^2$. however operation at 8,150 to 32,600 $gal/d/m^2$ is typical for waste treatment. The design depth depends on achieving a hydraulic retention time of two to 4 hours. Clarifier depth is typically 1.2 to 2.4 m (Capps et al., 1995)

There are four reasons why an activated sludge clarifier will not process a low effluent suspended solids (10 mg/l): denitrification, thickening overloads, flocculation problems, and hydraulic problems (Wahlberg, 1996).

A distinction may be made between flocculation and hydraulic problems by using dispersed suspended solids (DSS) and flocculation suspended solids (FSS) tests and comparing the results. Where floc breakup is occurring then the addition of a flocculation zone to the clarifier should be considered. Short circuiting can often be alleviated with baffling or improved solids blanket management (Wahlberg, 1996).

Hydraulics

There are many hydraulic characteristics of clarifiers including turbulent dispersion and mixing, bottom density current, buoyant density current, short circuiting, recirculation, entrainment, and density waterfalls in the inlet mixing zone (Zhou and McCorquodale, 1992a).

The flow pattern and suspended solids transport in a secondary clarifier is not only vertically distributed like a settling column but it also varies in the horizontal dimension (Ji *et al.*, 1996). Clarifier hydraulics play an important role in the activated sludge process. The density currents that usually exist in a clarifier as a result of solids laden water falling through relatively solids free water are difficult to avoid. When this density current strikes the clarifier's end wall, it is deflected to the effluent weirs, often carrying solids into the effluent. This effect can be minimised with baffles placed either near the center of the tank to dissipate the currents momentum or placed on the end wall to deflect the rebounding current away from the effluent weirs. Some research has shown that higher mixed liquor suspended solids concentrations entering secondary clarifiers negatively affect the tank's hydraulics by exaggerating unwanted density currents (Wahlberg, 1996). Wahlberg (1996) also found that baffles placed in a secondary clarifier reduced the effluent suspended solids to consistently 40-50% lower than before.

Deeper secondary clarifiers (18-20 feet) have been known to produce effluents lower in suspended solids than do shallower clarifiers (9 to 14 ft). This is due to the storage capacity available (needed due to the variation in flow and solids settling characteristics typical of most activated sludge facilities) (Wahlberg, 1996). Taebi-Harandy and Schroeder (1995) evaluated the performance of secondary clarifiers with respect to structural features, inlet configuration, weir location, intermediate baffle existence, and sludge draw-off location. Moursi et al. (1995) examined the effect of density currents in circular clarifiers and determined that fluctuations in the influent temperature can cause moving hydraulic jumps within the clarifier that could lead to a deterioration in clarifier performance.

One of the most common design or construction deficiencies that contributes to poor performance is the placement and leveling of the effluent weirs. A slight difference in the weir levels can result in a large volume flow over the low side. Solids washout often occurs (Task Force on Activated Sludge, 1987).

Denitrification

For denitrification to take place the mixed liquor temperature must be high and/or the sludge age long (food to microorganism ratio is low). Denitrification occurs in the settled sludge under anaerobic conditions (less than 0.5 mg/l dissolved oxygen) and in the presence of nitrates (more than 5 mg/l usually) and residual BOD_5 (more than 10 mg/l usually). Where possible alleviate the above causes and/or increase the sludge collection speed, reduce the number of clarifiers on line, or chlorinate. Another way to avoid denitrification is to limit the amount of nitrogen going into the plant. Plants that do not have to nitrify can operate at a sludge age low enough to prevent nitrification from occurring. If this action does not reduce the nitrate concentration to the secondary clarifier, then the anoxic zone needs enlarging. Plants that only nitrify cannot reduce the amount of nitrate going to the secondary clarifier without a major process modification. Rapid solids removal at these plants (prevents solids blankets from forming) helps to prevent problems with floating solids (Siegrist et al., 1995; Task Force on Activated Sludge, 1987; Wahlberg, 1996).

Thickening Overloads

Higher mixed liquor suspended solids concentrations also result in lower mixed liquor settling velocities. Wahlberg (1996) therefore suggests operating at lower mixed liquor suspended solids concentrations. A solids balance (state point analysis) is useful for making process control decisions, troubleshooting secondary clarifier performance, and optimizing the activated sludge process. This should avoid thickening overloads, where the storage capacity of the clarifier is smaller than the amount of solids in the blanket (Wahlberg, 1996).

Solids washout can occur where good settling is observed in the Sludge Volume Index test, however billowing homogeneous sludge is rising near the weirs in the clarifier (even though the sludge blanket is otherwise in the lower half of the clarifier). Probable causes of washout include:

1. equipment malfunction (return activated sludge pumps, flow meter and lines, sludge collection equipment baffles and skirts, weir levels);

2. hydraulic overload (even flow distribution, compare calculated surface overflow rate with the design rate);

3. solids overload (if the return activated sludge rate is increased and the blanket rises and stays high, the solids loading rate is outside 7.08 and 9.28 $kg/m^2.h$ - peak flow and 6.1 $kg/m^2.h$ for average flow, reduce the mixed liquor suspended solids concentrations, use a temporary settling aid, build additional clarifiers);

4. temperature currents (in large deep clarifiers and colder climates, if deeper temperatures are consistently cooler by 2^oC or more), (Task Force on Activated sludge, 1987).

Conversion from plug flow to step feed to contact stabilisation etc. can cause a redistribution of biomass from the clarifers to the aeration tanks. This type of process change can be very effective for dealing with excessive blanket depths in the clarifiers. The effect of this solids transfer is relatively short lived, but it can provide a breather while the long term benefits of the mode change take effect. A mode change towards contact stabilisation provides a short term mechanism for avoiding solids carryover resulting from excessive sludge blankets. This gives a sludge blanket that is dense and deep, however effluent quality may degrade somewhat. Other control procedures such as the simultaneous increase in the waste rate to resolve the problem of excessive solids concentrations in the clarifiers must be taken to provide long term correction. A rapid move towards contact stabilisation at the onset of the high flow conditions can transfer most of the solids out of the clarifier at the peak flow and help to avoid excessive solids loss. Unless a permanent change in mode is required because of an anticipated long-term increase in the plant flows, the process should be returned back to the initial mode when the peak hydraulic episode is over (Task Force on Activated Sludge, 1987).

The effects of configuration on aeration time can be significant. In general the doubling of the aeration time is said to allow the same quantity of bacteria to metabolise twice as much food (Task Force on Activated Sludge, 1987).

The rake arm of a circular collection mechanism can affect performance. If the speed is too high, insufficient sludge may remain in the tank to form a desirable sludge blanket. This can lead to a turbid effluent, and can create gradients and cause a loss of solids due to turbulence. If the rake arm speed is too slow (or turned off) sludge can accumulate and be washed into the effluent or remain in the clarifier too long under a low dissolved oxygen environment (damaging microorganisms and causing rising sludge) (Task Force on activated sludge, 1987).

Flocculation Problems

These include bulking sludge, clumping/rising sludge, cloudy secondary effluent, ashing, pinpoint floc, and straggler floc. Some remedies include changes in aeration, balancing influent and return activated sludge flows, adjusting waste activated sludge rates, chemical settling aids, supplemental nutrients, chlorination, controlling recycle flows. It can take two or three sludge ages before a positive change is apparent. (Task Force on Activated sludge, 1987).

Pin floc is generally related to a sludge that settles rapidly but lacks good flocculating characteristics hence small dense, pinpoint floc particles are observed suspended in the clarifier. This is caused by either an F/M near or in the extended aeration range (0.05-0.2), or by excessive turbulence (Task Force on Activated Sludge, 1987).

The appearance of small ash-like particles floating on the surface of the clarifier is commonly referred to as ashing. The ash may be particles of dead cells, as well as normal sludge particles and grease. Some probable causes of ashing are:

denitrification is beginning or occurring in the clarifier

the F/M is extremely low (<0.05)

the mixed liquor has an unusually high grease content

The floating solids from the sludge volume index test can be used to troubleshoot this problem. (Task Force on Activated Sludge, 1987).

Filamentous Bulking

The presence of a cloudy effluent above a poorly settling sludge indicates dispersed growth and either improper organic loading, overaeration, or toxins; however a clear supernatant above a poorly settling sludge is caused by the presence of filamentous microorganisms. (Task Force on Activated sludge, 1987).

The causes of sludge-bulking that are most commonly cited in literature are related to 1. Plant operation, 2. Treatment plant design limitations, and 3. Physical and chemical characteristics of the wastewater. If bulking is caused by filamentous microorganisms, the types of microorganisms should be identified so that a proper solution can be undertaken (Seviour et al., 1994; Jenkins et al., 1993; Strom and Jenkins, 1984). Operating causes of nonfilamentous bulking include widely varying organic loading, low food to microorganism ratio, insufficient soluble BOD_5 gradient, nutrient deficiency, low dissolved oxygen in the aeration tank, overaeration, or the presence of toxins (Marshall, 1992).

Low food to microorganism ratios, particularly in completely mixed systems, may encourage the growth of certain types of filamentous organisms. High food to microorganism ratio may result in the presence of a small dispersed floc, remedied by increasing the waste activated sludge.

The traditional sludge age is often used to control food to microorganism ratios. This calculation is susceptible to random noise and thus can indicate solids aging more than a day in one day. Also, an increase in BOD loading does not result in any change in traditional sludge age with time, although in a real system the average sludge age initially decreases because of an increased amount of new sludge being produced. Another parameter (dynamic sludge age) calculates the true average sludge age, without the problems of the traditional sludge age (Vaccari *et al.*, 1988).

Wastewater characteristics that can affect sludge bulking include fluctuations in flow and strength, pH, temperature, staleness, nutrient content, and the nature of the waste components. Filamentous organisms, unlike the floc forming ones, adapt easily to various culture conditions, and once dominant, it is hard for the process to recover (Nam et al., 1996).

The absence of certain components, or the nature of certain components especially those found in industrial wastewaters can lead to the development of a bulked activated sludge system. Floc forming microorganisms are vulnerable to high BOD_5, acidic wastes, depletion of nutrients etc. and cannot adapt well to sudden changes in culture conditions. Strom and Jenkins (1984) presented the results of a study creating a relationship between types of filaments and the control methods used. The growth requirements of 68 strains of filamentous bacteria were investigated by Kampfer *et al.* 1995. Most of the filamentous organisms required at least 20 mg/l of Ca, 0.1 mg/l Mg, 1.0 mg/l NH4-N, and 2.5 mg/l P. The authors suggested the presence of a specific filamentous organism in a bulking sludge could be associated with the nutrient balance of the system. Nutrient deficiencies have been discussed elsewhere in this chapter.

Yamamoto-Ikemoto et al. (1994) shown that removal of nitrate from the influent increased the concentration of filamentous Type 021N along with the concentration of sulfate reducers. The authors suggested sulfate reducing conditions enhanced filamentous bulking due to Type 021N.

Wide fluctuations in pH are also known to be detrimental in plants of conventional design. A pH of less than 6.5 in the aeration tank many inhibit floc forming bacteria. The pH in the mixed liquor can be raised by adding sodium bicarbonate, caustic soda, or lime. The pH should not rise to above pH9 (Marshall, 1992, Task Force on Activated sludge, 1987).

Design limitations include air supply capacity, clarifier design, return activated sludge pumping capacity limitations, short circuiting, or poor mixing. If the problem is due to limited dissolved oxygen, it can usually be confirmed by operating the aeration equipment at full capacity. Under these conditions, the aeration equipment should have adequate capacity to maintain at least two mg/l of dissolved oxygen in the aeration tank under normal loading conditions. To avoid plant overloading, recycle loads (filtrate from sludge dewatering) should not be returned to the plant flow during times of peak hydraulic and organic loading. Bulking is often a problem in center feed circular clarifiers where sludge is removed from the tank directly under the point where the mixed liquor enters the tank. Examination of the sludge blanket may show that a large part of the sludge is retained in the tank for many hours rather than the desired 30 minutes. If this is the case then the design of the tank is at fault and changes must be made in the sludge withdrawal equipment.

In an emergency situation or while investigating the problem, chlorine and hydrogen peroxide may be used to provide temporary help. Chlorination is effective in controlling some bulking caused by filamentous growths, however, it is ineffective when bulking is due to light floc containing bound water (nutrient deficiency) (Jenkins et al., 1989). Because filamentous microorganisms extend beyond the floc boundary into the bulk liquid and because they have a high surface area:volume ratio, they will be exposed to a toxicant to a greater degree than the floc-former bacteria. Toxicants usually result in a turbid effluent due to the death of nitrifying organisms (and floc breakup can occur if the dose is too high). Chlorine is usually used because of the low cost and availability at many plants. Hydrogen peroxide is used where chlorination is not usually practiced.

Chlorination of return activated sludge in the range of 2-3 mg/l of Cl_2 per 1000 mg/l of MLVSS is suggested, with dosages of 8 to 10 mg/l per 1000 mg/l in severe cases. The correct dose can be determined empirically or by using assay techniques - assessing the physiological (dehydrogenase) activity of filamentous organisms in activated sludge, or tetrazoleum reduction (Koopman et al., 1984). Frequency of toxicant exposure is important. The filamentous microorganisms must be exposed to the toxicant at a frequency greater than their growth rate, greater than three times per day (Task Force on Wastewater Biology, 1990). The dosing point must be in an area of high turbulence to ensure thorough mixing Target values of SVI should be established at which the plant can be operated satisfactorily without sludge settling problems. Daily SVI values should be plotted and doses adjusted accordingly. Cells of organisms will deform and gaps appear in the sheaths until only open and empty sheaths remain. Intracellular sulfur granules disappear also. Overdoses result in the complete disappearance of filaments and the presence of small, broken-up flocs and fine particles. Other signs are the complete loss of protozoa and rotifers (if these are present and active then there is no overdose).

Although most conventional activated sludge plants will dose chlorine into the return activated sludge, this does not work for plants with hydraulic retention times greater than 8 hours where the ratio of return activated sludge to total basin volume is much lower. It is better to dose directly into the mixed liquor at a point distanced from the influent in these cases.

Phosphorus removal can be reduced at $8gCl_2/1000gMLSS.d$ and prolonged Cl_2 doses but recovers rapidly (within 5 days) when chlorination is stopped. Poor anaerobic zone phosphorus release has been observed (Jenkins et al., 1993). Lakay et al.

reported no change in nitrification-denitrification but biological phosphorus removal initially decreased from 20 mgP/l to 14mgP/l, recovering during chlorination to 19 mgP/l. This was when dosing 8 $mgCl_2/gMLSS.d$ in a laboratory-scale biological nutrient removal system. Higher levels of chlorine may have to be investigated, especially when nitrite is present ($HOCl + NO_2^- \rightarrow NO_3^- + H + Cl$). This reaction is rapid and consumes 5.1 mg Cl_2/mg NO_2-N. NH_2Cl is formed when ammonia is present. This is not as potent a toxicant as HOCl but remains for a longer period (Jenkins et al. 1984). If the ratio of Cl_2 to ammonia nitrogen at the chlorine dose point is such that the breakpoint reaction will occur ($Cl_2:NH_3$-N ratio of 10:1), chlorine will oxidize ammonia nitrogen to nitrogen gas, thereby preventing the attack of filaments. This can be overcome by increasing the dose. Lakay et al. demonstrated the reduction of *Type 0092*, *Microthrix parvicella* and *Type 0914* in a biological nutrient removal system. *Type 0914* was the most and *M. Parvicella* the least susceptible to chlorination. There is always an increase in effluent soluble COD but not soluble BOD during chlorination. Nitrification, denitrification and phosphorus removal may not be affected.

Hydrogen peroxide attacks the sheath, destroying the filamentous form, the filaments break up, become shorted and cells show signs of lysis. Hydrogen peroxide also produces oxygen that is available to supplement dissolved oxygen ($2H_2O_2 \rightarrow 2H_2O + O_2$). It is not known whether treatment should be continuous or in periodic slugs and little guidance on doses is available. Hydrogen peroxide has a deflocculating action, increasing the concentrations of suspended solids in the final effluent (Shao and Jenkins, 1989).

The dosage of hydrogen peroxide and treatment time depend on the extent of the filamentous development. Effective doses may be somewhat higher than required for chlorine. The time required to reduce the SVI to 50% of the initial value is a function of the dose e.g. 0.34 kg H_2O_2/kg MLSS.d results in a 50% reduction in less than one day; 0.1 kg H_2O_2/kg MLSS.d results in a 50% reduction in 8 days. The minimum effective dose is approximately 0.1 kgH_2O_2/kg MLSS.d.

Aerobic (high food to microorganism ratio and dissolved oxygen 2-5 mg/l, sludge age less than 5 days), anoxic (dissolved oxygen's 0-0.5 mg/l, recycled nitrate-N, high sludge age), and anaerobic (inconsistent results unless selector is achieving enhanced phosphorus removal) selectors have been shown to aid filamentous bacteria reduction (Bradley and Kharkar, 1996).

Synthetic organic polymers or inorganic flocculating agents e.g. ferric chloride or alum can overcome filament interference with floc aggregation and formation. These agents do not affect the activity of the filamentous microorganisms but allow the formation of large floc that will settle in the secondary clarifier. Usually cationic, high molecular weight polymers are used, either alone or in conjunction with anionic polymers. This is short term control only (Task force on wastewater biology, 1990). In general the use of polymers for bulking control is expensive compared to return activated sludge chlorinating and filaments are not destroyed in the process (Pitman, 1984).

Chemical coagulation processes using metallic coagulants ($Ca^{\cdot}$, $Fe^{\cdot}$, or Al salts) smooth the surface of the bulking sludge floc without changing the floc density (destabilize the filaments and protuberances) (Chao and Keinath, 1979; Adamse, 1968). The best is commercial ferrous sulphate (Albertson, 1991; Echeveria et al., 1993), and the polymers Zetag 63 and Ferric Chloride also produce goods results.

The application point should be after the aeration tanks but prior to the second clarifier, or to the clarifier center well, to allow for floc formation. Disappointing results may be observed when conditioners are added in solid form (Logue et al., 1983).

When lime is added to wastewater, the calcium precipitates as a dense crystalline solid with a low and negatively charged surface area. Organic matter is removed by colloidal destabilization and precipitation, also by chemical reactors e.g. precipitation of phosphates, heavy metals and magnesium in addition to microorganism removal. Lime performs better than alum in removing phosphate and magnesium, but has the disadvantage of high pH in the treated water (more than 48 hours is needed to reduce the pH from 11 to 8. Precipitation with lime (calcium hydroxide) caused a significant reduction in the sludge volume index obtained in municipal wastewater. It almost completely repressed *Type 021N* within 10 days by adding 11 g/m3 to the influent. The phosphorus concentration in the sludge also increased (Chambers and Tomlinson, 1982). Pebble quicklime, CaO is used in larger facilities (WEF, 1992).

Ferrous sulphate encourages the growth of psychrotropes and yeasts, removes a portion of the lactose, interferes in the binding of the surface active whey protein B-lactoglobulin with the biomass and is a possible biomass flocculation aid, but not for zoogloea species (Environmental Protection Agency, 1971). The best to use is commercial ferrous sulphate. A ferrous salt may lead to excess phosphorus removal due to ferric phosphate formation. This could unbalance the nutrient requirements in the mixed liquor (Albertson, 1991). The addition of ferrous sulfate (10-14 mg as Fe/L) to the influent of an activated sludge plant treating canning wastes reduced the SVI and caused the disappearance of *Type 021N* (Jenkins et al., 1993). *Type 0041* was repressed within a few days by the addition of 26 g/m3 ferrous sulphate creating a coagulant effect and a high sludge phosphorus content. Other filamentous organisms affected by ferrous salts include: types 1701, 0961, 1863, and *Sphaerotilus natans*. No reaction was observed for *Microthrix parvicella, H. Hydrossis, Nocardia* and *Type 0092* (Chambers and Tomlinson, 1982).

Supplementing secondary treatment with folic acid has been reported to overcome sludge bulking, foaming, nitrification problems, and overloading problems. Folic acid creates shifts in the microorganism populations (flagellates are replaced with ciliates), increases the oxygen uptake rates (savings in aeration), reduces polymer use and avoids plant expansions. The effluent quality is improved and the sludge density is increased. The saving includes reduced aeration costs and reduced sludge wasting costs. DOSFOLAT is a commercial product of complex tetrahydropholic acid and encourages a stable reactor performance, increased biomass production. Sludge bulking is controlled (Eruglu, et al., 1992).

Dominant filamentous bacteria in a laboratory scale activated sludge plant treating dairy factory wastewater were identified as *Type 0411, 021N* and *Sphaerotilus Natans.* These could not be linked to any specific reactor or substrate conditions. (Donkin et al. 1995). Miller (1995) described a treatment plant in New York with dominant *filament Type 1851* with smaller amounts of *Type 0041*, *Type 0675*, and *Microthrix parvicella*. This was caused by low organic load into the aeration tank. Chlorination had been utilized with some success for many years however there were concerns especially plant stability, cost and health and safety. The two other options considered were increased solids removal from the system, and a selector. It was found that the use of an aerobic selector on an intermittent basis, was successful within one to three weeks. The selector was sized at 7000 gals for a 0.14-mgd treatment plant.

Foam

The presence of some foam on 10 to 25% of the aeration tanks surface is normal for the activated sludge process.

Three general types of problem foam are often seen: a stiff white foam; brown foams (a greasy dark tan foam, and a thick scummy dark brown foam); and a very dark or black foam (Task Force on Activated sludge, 1987).

Stiff white billowing foam, indicating a young sludge (low sludge age) is found either in a new plant or an overloaded plant. The foam may consist of detergents or proteins that cannot be converted to food by the bacteria that grow in the mixed liquor at a high food to microorganism ratio. Probable causes include: no return activated sludge; low mixed liquor suspended solids (plant start-up, excessive wasting, or high organic load); toxic or inhibiting materials, abnormal pH, insufficient dissolved oxygen, nutrient deficiencies or temperature changes.

Under conditions of nutrient limitation, wastewater cultures can create an excessive amount of extracellular, polymer-like material with surfactant-like properties (facilities with chemical phosphorus removal and retrofitted post-nitrogen removal systems may have these problems). The foam produced by this condition is thick and viscous (not soft and billowy as for limited process conditions) (Bradley and Kharkar, 1996; Task Force on Activated sludge, 1987). Marshall (1992) investigated a food processing plant with severe foaming problems (*Thiothrix Type II*, *Nocardia* and *Thiothrix Type* I and excess polysaccharide in the foam). The cause was associated with nutrient deficiency.

Excessive brown foams are associated with plants operating at low loading ranges. A food processing facility was investigated. This plant was cycling between settling problems (*Type 0041* or *Type 1701*, *H hydrossis*, *zoogloea* fingers and *S. Natans*). Large organic fluctuations were causing the cycling between low food to microorganism ratio filaments and high food to microorganism ratio filaments/zoogloea fingers. The solution here was greater communication with the processing plant to enable shock loadings to be dealt with in the treatment plant (Marshall ,1992). Plants operating in nitrifying mode will normally have low to moderate amounts of rich chocolate brown foam.

Plants with filamentous Nocardia like organisms *(N. amarae, N. Asteroides, N. Pinensis,* or *Rhodococcus* sp.) will have a strong greasy, stable, viscous dark tan foam that will carry over onto the clarifier surface. It may be associated with an odour. *N. Amarae*, the most frequently found organism in foaming activated sludge, is most likely not actually a member of the genus *Nocardia*; rather seems more appropriately placed in the genus *Gordonia* (Jenkins and Peirano. 1996).

A non-actinomycete Microthrix parvicella has also been associated with filamentous foam. Other organisms can be associated with synergistic foaming and bulking and include *Nostocoida limicola* and *Type 0041*. These bacteria have hydrophobic cell walls that enable the attachment of microorganisms to air bubbles, causing them to rise to the surface. They also produce and store surface active materials (reducing the surface tension in the mixed liquor), degrade many complex hydrocarbons (including oil and grease) which would otherwise float on the aeration tanks surface, have a slow growth rate (enables microorganism wash-out at low sludge ages), slower substrate uptake rate than floc formers at high food to microorganism ratios and faster uptake rates at low food to microorganism ratios (low food to microorganism ratios are therefore favourable to filaments).

Filament populations have been shown to increase over a sludge age of 1.5 to 15 days, declining to nondetectable levels at sludge ages of 1.5 to 2.2 days. More highly concentrated filaments (higher mixed liquor suspended solids) have a greater tendency to foam, because the aeration rate per unit volume is higher, facilitating the transfer of filaments to the water surface. A minimum concentration of filaments has been shown to be required for foam production. Mixed liquor suspended solids should however never be reduced to the extent that noncompliance becomes a risk.

The aeration rate also affects filamentous foam by the stripping of cells from the mixed liquor to the water surface, and directly influences the foam height. Nocardia growth rates are directly proportional to temperature, however research has also shown that foaming occurs most frequently during seasonal changes. Research indicates that a pH of 6.5 is optimum for Nocardia-like foam growth (nitrifying activated sludge operates at relatively low pH levels due to the consumption of alkalinity during nitrification).

Surfactants have the ability to lower the surface tension and thereby stabilize the liquid film surface between air bubbles, resulting in increased retention and accumulation of foam in the aeration basin. While the hydrophilic group in a surfactant is more or less readily soluble in water, the hydrophobic group is repelled by water giving a tendency for that portion of the molecule to leave the aqueous phase. This leads to a higher concentration at the surfaces than in the main body of the solution with a net resulting greater tendency towards bubble and foam formation. Blowing air through the solution results in foam formation that lowers the surfactant concentration in the main body of water through foam fractionation. Microbial solids may, through surface adsorption, cause a strong attraction of either the hydrophobic or the hydrophilic group. Common hydrophilic groups include sulfonate, sulfate, carboxylate, quaternary ammonium, polyoxyethylene, sucrose, and polypeptide. Surfactants can be adsorbed on the biomass as feed, and then subsequently degraded, so that concentrations in the liquid phase and on the sludge are kept below toxic thresholds.

Increased branching of the modular structure causes an increase in resistance to biodegradation with most resistance occurring when quaternary branching occurs at all chain ends in the molecule. While structures with quaternary carbon atoms are more difficult to degrade, the presence of quaternary carbon does not interfere provided there is also present a sufficient length of open end chain. (Goronszy, 1990). Bacteriotoxicity also tends to increase with increased hydrophobe chain length. The chemical nature of the hydrophilic group is only of minor importance in affecting biodegradability. Biodegradation of surfactants require bacteria that are capable of synthesizing enzymes that are structurally matched to that chemical. In the absence of such enzymes, degradation may proceed after a time lag if the appropriate enzymes can be synthesized by some of the species present. Alkaphenol ethoxylates (a class of surfactant) are degraded slowly during the activated sludge process.

Resistance to biodegradation of a detergent component in a wastewater in a facility is evidenced by foaming persistence in both the reactor basins and in the effluent collection/pump wells (Goronszy, 1990). Partial degradation of a surfactant can produce byproducts that still maintain surface activity with an ability to stabilize a *Nocardia sp.* or any other type of foam.

Knight et al. (1995a) evaluated the microbial community during a start up period of a full scale nutrient removal activated sludge plant. The filamentous organisms Microthrix parvicella and Eikelboom Types 0092 were found in the foam. *Nocardia amarae* was identified as the microorganism associated with foaming in two activated sludge plants (Chua and Le, 1994). The authors suggested fatty acids in the wastewater may contribute to the growth of foaming organisms.

Surface activity has been shown to contribute to the growth of floating scum through the surface fractionation of filamentous microorganisms of the long strand type such as *Nostocoida limicola.* Examination of the surface scum has shown it to consist of a viscous mass of minute bubbles containing *Nostocoida limicola* (external to the bubbles) and *Nocardia* sp. (within the internal bubble structure). Studies on pure cleaning agents mixed with biomass has shown that the use of a foam suppressant is impractical and has little effect on the stability of the foam scum, while the addition of a chlorine solution (40mg/l) showed immediate decolorisation contraction of the foam. (Goronszy, 1990).

If a stable foam has already formed then chlorination of the return activated sludge or mixed liquor suspended solids will have limited success due to the microorganisms already above the water surface. Direct foam chlorination is more effective in this situation. Periodic chlorination of return activated sludge or mixed liquor suspended solids can still be useful as a preventative measure (1-10 kg chlorine/day for each 1000 kg solids total). Chlorine can be directly applied to the foam using a foam trap in the effluent channel or aeration tank, and spraying a highly concentrated chlorine spray directly to the foam. Selective foam wasting has been used successfully, utilising foam pits or sumps (although there have been difficulties selecting a foam pump). Ozone addition of 2-6 mg/l to the aeration basin was used to control *Nocardia* foaming (Goi *et al.*, 1994). This treatment effectively stopped foam formation, did not negatively affect effluent quality, accelerated nitrification, and also improved sludge settleability.

Biological treatment systems that operate at relatively high sludge ages are most susceptible to foaming. Plug flow systems are less susceptible than continuous systems (high food to microorganism ratio at head end of process), sludge reaeration systems are more susceptible (concentrated mixed liquor suspended solids being aerated), step feed configurations produce high mixed liquor suspended solids and low food to microorganism ratios over a significant tank volume.

Scum containing filaments should be wasted from the system rather than be returned to the aeration tanks. Submerged aeration tank outlets or effluent baffles may prevent a significant portion of Nocardia-like filaments being wasted. This also traps the floating substrate required by the microorganisms.

Thick scummy dark brown foam indicates an old sludge and can result in additional problems in the clarifier by building up behind the influent baffles and creating a scum disposal problem. Probable causes include: low food to microorganism ratio possible due to nitrification; insufficient sludge wasting (Task Force on Activated sludge, 1987; Bradley and Kharkar, 1996).

The presence of a very dark or black foam indicates that there is insufficient aeration or dyes and inks are present (Task Force on Activated sludge, 1987).

Recycles from solids handling systems can cause excessive loading at biological nutrient removal plants and foaming caused by a carryover of polymer (and also affects solids settleability). Excessive recycling of fines can also produce a 'volcanic' or 'pumice-like' foam.

Floating sludges caused by denitrification in settling tanks are also technically foam (looks like floating sludge and can be dispersed with a water spray). This can be reduced by reducing the solids and oxygenating the influent.

Floating scum is an agglomeration of flotable materials e.g. fats, oils, and grease brought to the surface by air flotation.

Nutrient Removal

Nitrogen is a relatively inert element and does not combine easily with other elements. The important reactions by which nitrogen is transformed for use by living organisms are microbially regulated.

Ammonia Assimilation - All life forms require nitrogen for the synthesis of new cells. Most bacteria, especially those responsible for the aerobic decomposition of organic matter, prefer ammonia as their source of nitrogen.

$$NH_3 + \text{bacteria} \Rightarrow \text{protein}$$

Aerobic biological treatment processes typically require that two to 5 kg of ammonia nitrogen be available for every 100kg of BOD in the byproduct.

Nitrate Assimilation - green plants and algae prefer nitrate as a source of nitrogen:

$$NO_3^- + CO_2 + \text{green plants} \Rightarrow \text{protein}$$

Ammonification - occurs when organic nitrogen breaks down to release ammonia.

$$\text{Organic N} + \text{bacteria} \Rightarrow \text{NH3}$$

This is the reaction that is responsible for the release of ammonia when waste activated sludge is digested or when dead plant or animal matter decays.

Nitrogen Fixation - Several species of bacteria, fungi, and blue-green algae are involved in the process of nitrogen fixation. These organisms convert organic nitrogen into ammonia , which is used by higher plants to manufacture complex nitrogen-containing compounds.

$$N_2 + \text{microorganisms} \Rightarrow NH_3$$

Two common genera of soil bacteria, the anaerobic Clostridium and the aerobic Azotobacter, produce nitrites and nitrates from free nitrogen. Nitrogen fixation to produce either ammonia or nitrates is an energy consuming reaction, depending on organic matter or on sunlight for its energy source.

Nitrification - The soil bacteria that are responsible for the process of nitrification are fairly common. Nitrification is a two step process. Some bacteria convert ammonia to nitrites:

$$2NH_4+ + 3O_2 + \text{bacteria} \quad \Rightarrow \quad 2NO_2^- + 4H^+ + 2H_2O$$

Nitrobacter species convert nitrites to nitrates:

$$2NO_2^- + O_2 \quad \Rightarrow \quad 2NO_3^-$$

Nitrates are the form in which green plants then use the production of amino acids. The nitrification reactions generally do not proceed in the presence of high concentrations of organic matter.

Denitrification - Many bacteria can convert nitrogen-containing compounds into atmospheric nitrogen, a process known as denitrification.

$$NO_3^- + \text{organic energy source} \quad \Rightarrow \quad N_2$$

These bacteria obtain energy by breaking down not only the nitrogen compounds urea and uric acid that are excreted by living animals, but also the carbon compounds produced by decaying organic matter.

The basic feature that makes it possible to nitrify is the maintenance of a high MCRT (or low F/M) of sufficient duration to allow the more slowly growing nitrifiers to develop. The actual MCRT or F/M type that this is possible is temperature dependent. It lies in the 6-10 day range during the summer when the wastewater temperature is in the 20°C range, but may climb into the 12-20 day range as the temperature drops. When the wastewater temperature drops below 10°C it may not be possible to develop a nitrifying culture if it has been lost, however it can generally be maintained once it is developed. (Task Force on Activated Sludge, 1987). Capps et al. state that a minimum sludge age of 40 days is recommended for effective COD and ammonia nitrogen treatment for industrial wastewater.

The dissolved oxygen in nitrifying systems must be maintained at a higher concentration than in carbonaceous activated sludge systems. A dissolved oxygen above 4.0 mg/l should ensure that no inhibition is occurring. The nitrification process consumes alkalinity and may depress the mixed liquor pH to a level where inhibition of the nitrification occurs. If this begins to take place, it must be corrected by the application of a caustic chemical; such as sodium hydroxide or lime (Task Force on Activated Sludge, 1987).

A single stage nitrification system is phased out by using the following steps:

Increase the wasting rate to bring the MCRT below the minimum level needed to support nitrification.

Reduce the dissolved oxygen concentration to 0.5 to 1.0 mg/l to inhibit the nitrifiers. The nitrifiers can be more quickly eliminated by chlorinating the return activated sludge during this period (2-3 kg Cl_2/1000kg MLSS/day). During the transition period from nitrification to carbonaceous oxidation, an effluent that does not meet permit standards may be produced (Task Force on Activated Sludge, 1987).

In order to nitrify the following are required in the treatment plant (Schultz et al., 1996):

1. Adequate detention time to remove BOD and allow the nitrifying bacteria to convert ammonia to nitrate.
2. Sludge age of at least 15 days at 10°C.

3. Alkalinity to keep process above pH of 7.2.

4. 2kg of oxygen per lb of nitrified TKN and 0.5kg of oxygen per 0.45 kg BOD removed.

Phosphorus can be bound into the activated sludge mainly by three mechanisms (Jardin and Popel, 1996):

1. Physiological phosphorus (phosphorus for metabolism and growth as nucleic acids, phospholipids, and nucleotides).

2. Additional phosphorus can be stored as poly-P, $Me_{n+2}P_nO_{3n-1}$ (n = chain length of poly-P, Me represents a metal cation). Usually Mg^{2+} and K^{+} are associated with poly-P synthesis.

3. Physiochemical fixation of phosphate mainly by precipitation or adsorption can occur.

During sludge treatment, these P-fractions will be released to a different extent and at different rates. The amount oxygen of possible feedback will normally be determined by the rate and extent of poly-P hydrolysis. A substantial P-feedback can be expected with gravity thickeners, which are usually operated at a sludge retention time of more than 0.5 days.

Magnesium and potassium uptake usually accompany poly-P formation, however there is no correlation with phosphorus and calcium, iron or aluminum. A precipitate of magnesium in the form of $MgNH_4PO_4 \bullet 6H_2O$ (struvite) seems the most likely reaction to occur. Another important relationship was found between the phosphorus content and the amount of non volatile solids of the waste activated sludge. When operating a biological nutrient removal plant this can mean an additional dry solids production of 3g TS/g phosphorus stored as poly-P, corresponding to an increase of solids productivity of approximately 4% based on total solids production. In cases of high P-concentrations in sludge water, precipitation of phosphate in the centrate or filtrate of the dewatering facility can be necessary. In principal, all common chemicals for phosphate precipitation could be used, but in view of the relatively high ammonium concentrations and the high alkalinity of the process water, precipitation with calcium can require large amounts of lime. Using iron, the reduction of Fe^{3+} to Fe^{2+} has to be considered (Jardin and Popel, 1996).

Optimisation of return activated sludge

The return activated sludge from the clarifier is a key control parameter of the activated sludge process, and the rate of sludge return affects the solids balance between the clarifier and the aeration basin. In general low return activated sludge is beneficial to the thickening function of the clarifier but not favorable to its clarifier function. When return activated sludge is increased, the clarification function of the clarifier is improved while the thickening function may be deteriorating. The system performance reaches an optimum at a return activated sludge of 40% to 60% (Ji et al., 1996; Task Force on Activated Sludge, 1987). Return activated sludge rates should not be reduced to the level where thick sludge may block the sludge withdrawal pipes. It is critical for the operators at each plant to monitor and understand the interrelationship between the return activated sludge and mixed liquor suspended solids, and sludge blanket expansion (Task Force on Activated Sludge, 1987).

Operators have historically used several procedures to determine return sludge flow. Most of these procedures rely on determining the fixed flow rate, % of plant flow, clarifier sludge flow demand, or the fixed sludge volume index and mixed liquor suspended solids level.

The return of sludge at a constant rate is simple, requiring less operator time, however means that the F/M and MRCT constantly changes, and that the sludge blanket may approach the clarifier surface during high flows promoting solids loss. If flow is paced at a percentage of influent flow the mixed liquor suspended solids, F/M, sludge blanket and MCRT are more constant, however this system is complex, requiring more operator attention (Task Force on Activated Sludge, 1987).

The return activated sludge can also be calculated using the direct sludge blanket control method where an optimum sludge blanket level is maintained in the clarifiers, this is low enough to permit efficient settling and high enough to store a sufficient quantity of return activated sludge and provide a properly thickened concentration. Generally a sludge blanket level of between 0.3 and 0.9 m in the clarifiers is appropriate. The blanket should never be allowed to rise above 25% of the nominal side water depth of the tank unless dictated by other control parameters. Deep circular clarifiers, however, may be able to handle relatively deep blankets and produce improved performance under these circumstances (rarely successful due to diurnal flow fluctuations and sludge quality). Generally any changes made should be small (no greater than 10% per day). Usually if the sludge blanket is rising then the return activated sludge should be increased and vice versa, however, an increase in the return rate with bulking sludge may cause the blanket to rise. Increased return rates will also often increase the flow into the clarifier causing more turbulence. (Task Force on Activated Sludge, 1987).

The settleablilty test can be used to estimate the desirable sludge return rate. This is less accurate than other methods and will not be described here. (Task Force on Activated Sludge, 1987).

A mass balance can be used to calculate the return activated sludge rate, however, it assumes that the sludge blanket level in the clarifier is constant. This is based in the knowledge that the solids entering the clarifier must equal the solids leaving. ((Task Force on Activated Sludge, 1987).

Boe (1994) suggested that a sludge quality-based method is used to calculate return sludge flows. This is described in the methods section of this thesis. A sludge quality chart is shown to demonstrate typical ranges for return sludge control. Analyzing return activated sludge flow trends should lead to a stable operating period where sludge quality parameters are steady and a high quality effluent is produced. Slight changes in return activated sludge concentrations are not significant as long as concentrations generally remain between the SSC30 and SSC60 values.

Another return activated sludge flow determination method utilises the sludge quality to optimize the detention time in the clarifier. The time is selected based on the mixed liquor settleability curve of settled sludge concentration vs. time. The curves for rapid and normal settling sludges level off after some time, showing that little additional concentration occurs with time. Thus an optimum settling time can be determined just before the leveling off period. For a slow settling sludge the optimum settling time occurs at the inflection point, after which the effluent quality may deteriorate. Short detention times are chosen for rapidly settling sludges (15-30 minutes), moderated detention times for normal sludges (40- 60 minutes), and long detention times for slow settling sludges (100-140 minutes) (Task Force on Activated Sludge, 1987).

In general the return activated sludge flow has been reduced too low if the return activated sludge concentration remains constant while the clarifier sludge or wastewater flow changes dramatically (excessive sludge has reached maximum compaction in the clarifier). The return activated sludge flow has also been reduced too low if the aeration tank concentration lowers substantially after the clarifier sludge flow has been reduced (with constant wastewater flow and sludge wasting) (Task Force on Activated Sludge, 1987).

When DSS and FSS tests are used to troubleshoot poor secondary clarifier performance (high suspended solids), three samples are taken: DSS, FSS, and effluent suspended solids). Four situations can be identified in this way:

1. High DSS, low FSS - either the mixed liquor does not have enough time for flocculation after it leaves the aeration basin, or a conveyance structure (pump, freefall, or pipework) is causing the floc breakup prior to the secondary clarifier. The DSS can be repeated at upstream locations to identify where breakup is occurring.

2. High DSS, high FSS - The high DSS suggests a flocculation problem, but the high FSS concentration suggests the problem cannot be solved with a flocculation step. These results point to a biological problem in the aeration basin or the existence of a dispersant or toxicant in the plant influent.

3. Low DSS, high FSS - This is rare, indicating the samples for the two tests were collected at different locations or times or both and the tests should be reconducted.

4. Low DSS, Low FSS - an indication that well-flocculated solids already exist, and there is a hydraulic problem in the clarifier. Operators should test the hydraulic characteristics of the clarifier, using the Crosby (1980) dye tests, to identify where the short circuiting is occurring.

Waste activated sludge optimisation

The wasting of sludge affects the process more than any other process control adjustment. The waste activated sludge removed from the process affects the effluent quality, the growth rate of the microorganisms, oxygen consumption, mixed liquor settleability, nutrient qualities needed, the occurrence of foaming/frothing, and the possibility of nitrifying. Waste activated sludge maintains a balance between the microorganisms and the F/M ratio. The objective of sludge wasting is to remove just that amount of microorganisms to maintain a constant F/M and MCRT.

The four most common methods used to determine the amount of sludge to waste are: constant MCRT, constant F/M, constant Mixed liquor suspended solids, and sludge quality. If the operator consistently controls the system by the same method under normal conditions the process should approximate the same condition as if it were consistently controlled by another method. In general it will take a period equivalent to two to three MCRTs for the process to fully respond to even minor changes in mixed liquor suspended solids, F/M and MCRT (Task Force on Activated Sludge, 1987). Whatever method utilised, the wasting rate should only be changed by 10% in one day, and 20% or less in one week (Task Force on Activated Sludge, 1987).

A precise solids inventory allows for accurate operational calculations such as food to microorganism ratio and sludge age. The solids held in the clarifier can be significant and should be included in the daily inventory. Sometimes it is necessary to account for the solids in return activated sludge channels. (Task Force on Activated Sludge, 1987).

Sludge wasting based on maintaining a normal settling sludge usually requires that sludge wasting be increased when:

Mixed liquor settles too rapidly in the settleometer and SSC60 rises significantly above 20.

Ash or clumps start rising to the clarifier surface

A dark scummy brown foam appears on the aeration basin surface

A sludge blanket, composed of good quality normally settling sludge, rises too closely to the clarifier surface.

Sludge wasting should be decreased, if and when:

Mixed liquor settles too slowly in the settleometer and the SSC60 values fall to 10 or less (this will normally be accompanied by a rising clarifier sludge blanket).

Large billows of white foam start forming on the aeration tank surface (Task Force, 1987)

MATERIALS AND METHODS

Activated Sludge Plant

The activated sludge plant investigated was located at the Anchor Products manufacturing site at Waitoa, Waikato, New Zealand (Figure 2). Two aerated lagoons with a total aeration volume of approximately 46,500 cubic meters are operated in series, using up to 1,100 kW of aeration (controlled by Zullig dissolved oxygen probes from a PLC).

From the second pond (25,750 m^3), wastewater passes through two circular secondary clarifiers operated in parallel. Clarifier one removes sludge from beneath a rotating bridge using 6 vertical tubes and hydraulic pressure. Clarifier two's rotating bridge directs sludge into the center of the vessel, where it is pumped from the clarifier.

Separated sludge is either returned to the pond system, or thickened in an Ekotuotanto designed Gravity Belt thickener and irrigated onto maize or pasture paddocks as a fertiliser. Both the influent and the return sludge can be directed either into pond one or into pond 2, however, both will normally discharge into pond one. The average Return activated sludge flow was 9491m^3/d over the period studied.

Effluent from the clarifiers passes through one of two AquaABF sandfilters and is then discharged into the Waitoa River.

Data was collected from the operation of the Waste Treatment Plant over the period September to December 1996, although some historical data was also used.

The quantities and organic characteristics of the Waste Treatment Plant influent and effluent streams based on the monitoring data for the 1995-97 seasons are summarised below (Tables 2 and 3).

Table 2. Composition of Influent from the Anchor Products Waitoa Site

Parameter	Volume (m3/d)	COD (mg/l)	BOD5 (mg/l)	pH	TKN (mg/l)	Nitrate (mg/l)	TP (mg/l)	Phosphate (mg/l)	TS (mg/l)
Average	7760	2340	1665		60	14	125	112	363
Maximum	9200	3600	2340	11.8	81	25	152	138	443

Table 3. Composition of wastewater discharged to Waitoa River

Parameter	Volume (m3/d)	COD (mg/l)	BOD5 (mg/l)	pH	TKN (mg/l)	Nitrate (mg/l)	TP (mg/l)	Phosphate (mg/l)	TS (mg/l)
Average	6690	34	6.2		2.1	0.31	95	91	326
Maximum	7570	111	39	7.3	5	0.42	106	97	369

Analytical Methods

Soluble analysis was performed by filtering the sample through a Whatman GFC 90mm filter paper before analysis by the appropriate method.

Chemical Oxygen Demand (COD)

The COD of the influent, effluent, ponds mixed liquor and sludge thickening plant filtrate was measured using the Reactor Digestion Method (Jirka and Carter, 1975), a Hach reactor Model 45600 and DR 100 Colorimeter.

Solids Concentration

Suspended solids of the influent, effluent, ponds mixed liquor and the filtrate from the sludge thickening plant were measured using the method described in Standard Methods (APHA, 1992).

Total solids of the waste sludge to and from the thickening plant were measured by heating the sample in a microwave oven on medium power for 4 minutes, and measuring the weight remaining in the crucible.

Biological Oxygen Demand (BOD_5)

The BOD_5 of the influent and the effluent was determined using the method described by Water and Soil Miscellaneous publications, No. 38; Physical and Chemical methods for water quality analysis, NWASCO, 1981.

Nitrate, nitrite, ammonia, total phosphorus, DRP, TKN, total sulphur

Nutrients in the influent and effluent were analysed by R.J. Hill Laboratories using the following methods:

Sample filtration for general testing: sample filtration through 0.45μm membrane filter APHA 3030B.

Ammonium-N. Phenol/hypochlorite colorimetry, Segmented flow analyser. EPA 350.1 (Modified) - detection limit is 0.01 g/m-3.

Total Kjeldahl Nitrogen. Kjeldahl digestion, phenol/hypochlorite colorimetry APHA 4500-Norg - detection limit is 0.1 g/m-3.

Nitrate + nitrite-N: Cadmium reduction column, colorimetry, FIA. Low range method. APHA 4500-NO3 F (Modified for FIA) -detection limit is 0.002 g/m-3

Nitrate-N: Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. Low range method) - detection limit is 0.002 g/m-3.

Nitrite-N: Azo dye colorimetry APHA 4500-NO2 B (Modified for FIA) -detection limit is 0.002 g/m-3.

Dissolved Reactive Phosphorus: Molybdenum blue colorimetry APHA 4500-P - detection limit is 0.004 g/m-3.

Total phosphorus: Persulphate digestion, colorimetry NAWASCO Method 8 - detection limit is 0.004 g/m-3.

Calcium: ICP-OES - detection limit is 0.02g/m-3.

Magnesium: ICP-OES - detection limit is 0.005g/m-3

Sodium: ICP-OES - detection limit is 0.5g/m-3

Potassium: ICP-OES - detection limit is 0.1g/m-3

Total Sulphur: Boiling nitric/perchloric acid digestion. ICP-OES - detection limit is 0.5g/m-3

Nitrates and nitrites in the influent, effluent and ponds mixed liquor were also tested daily using Merckoquant 10 020 nitrate test strips.

pH

pH of the influent, effluent and ponds mixed liquor was measured with a Radiometer Copenhagen PHM 61 laboratory meter and Schotte Gerate N61 pH probe.

Dissolved Oxygen

Dissolved oxygen of the ponds mixed liquor was measured with a YSI model 5739 membrane electrode, and Zullig DO94 dissolved oxygen meter with an iron anode and silver amalgam cathode.

Conductivity

The conductivity of the effluent was measured with a CDM83 meter and CDC 304 probe.

Temperature

The temperature of the ponds mixed liquor was measured with the YSI dissolved oxygen meter.

Volumes/Samples

Influent

The combined wastewater into the treatment plant was sampled using a Polysonics model MST Ultrasonic flowmeter and a twenty four hour flow proportional sampler. A PLC logs the continuous volumes pumped into the treatment plant.

Mixed liquor

The mixed liquor was grab sampled in both ponds.

Effluent

The treated wastewater discharged from the treatment plant was measured with an EMC flowmeter and peristaltic pump sampler. A PLC continuously logs these volumes.

Return activated sludge

A Polysonics UFM 91 flow meter contiguously measures the return activated sludge flow from clarifier 2, however the return activated sludge from clarifier one was not accurately measured.

Waste activated sludge

The volume of sludge into the sludge thickening plant was measured using an ABB Kent Magflowmeter Magmaster 80NP, IP65 flow meter. This was continuously logged onto a PLC. The volume of sludge out of the sludge thickening plant, sent to the silo for wasting was measured using a Kent Magflowmeter Magmaster 80NP, IP65 flowmeter that was also continuously logged onto a PLC. This was double-checked by logging the number of truckloads of sludge to leave the Waste Treatment Plant.

Sludge Age

Sludge age is calculated according to the method described by Vaccari et al. (1988).

Food to microorganism ratio

The food to microorganism ratio is calculated by the following equation:

$$F/M = \frac{\text{Pond influent COD (kg) x 1000}}{\text{average Pond one and two MLSS (mg/l) x total ponds volume}(m^3)}$$

Microbiology

Samples of mixed liquor from the aeration basin were examined microscopically and filamentous bacteria identified by reference to standard texts in conjunction with various staining methods (Jenkins et al., 1993; Seviour et al., 1995).

Other microorganisms were identified using Task Force on Wastewater biology (1990).

Plant Control

Sludge Volume Index

The Sludge volume index was calculated as given in Standard Methods (APHA, 1992). One liter of the mixed liquor was placed in an Imhoff Cone and the sludge volume read after 30 minutes. The SVI was then calculated by using the following equation:

$$SVI = \frac{\text{Settled Sludge volume (mixed liquor, 30 minutes)(ml/l) x 1000(mg/g)}}{\text{Suspended solids (mg/l)}}$$

Stirred sludge volume index/Settled Sludge Volume

The Stirred Sludge volume index was calculated as given in Standard Methods (APHA, 1992).

Aeration Time

Aeration time was calculated by using the following calculation (Task Force, 1987):

$$\text{Aeration time, hr} = \frac{(V)(24\ \text{hr/day})}{Q + R}$$

Where: V = tank volume, m^3

Q = wastewater flow rate, m^3/d

R = return activated sludge flow rate, m^3/d

Determination of nutrient deficiency

Suggested ratios by weight in the influent are (Task force, 1987):

$BOD_5/N = 100/5 = 20$

$BOD_5/P = 100/1 = 100$

$BOD_5/Fe = 100/0.5 = 200$

Determination of potential foaming properties of wastewater. (Goronszy 1990)

1. Conduct shake tests using various concentrations of the major foam producing cleaning agents.

2. Measure foaming persistence by measuring the relative time of foam height collapse using a graduated 1l measuring cylinder filled to the 500 mixed liquor graduation with the liquid in question and two alka Selzer tablets introduced to standardize gasification conditions.

3. Establishment of a foam that persists for 30 seconds after the completion of gasification indicates a potential for problems associated with detergent foaming.

Determining phosphorus release in sludge thickening plant (Jardin and Popel, 1996)

1. Take samples of WAS, filtrate return and Pond two outlet sludge and soluble filtrate.

2. Analyze for TP, PO4, Mg.

Depending on the retention time and temperature, gravity thickening results in a substantial P-release within the sludge layer.

ASIM Simulation Programme

ASIM was written as a teaching program, however it is sufficiently large and powerful enough to be used for practical applications. The original programme was designed to demonstrate to the student the time and space dependent behaviour of biological treatment systems (especially of modern activated sludge systems). Activated sludge systems with up to six different (aerobic, anoxic, anaerobic) reactors in series may be modeled, including return activated sludge and an internal recirculation; batch reactors; chemostat reactors, etc. The software allows for the introduction of process control strategies and dynamic simulation (variable loading, temperature, aeration, sludge removal, etc.).

ASIM has several models that may be chosen, or altered. The model used in this simulation was based on the IAWPRC "Activated Sludge Model No. 1" (Henze et al., 1987). Model No. 1 allows for the dynamic simulation of nitrification/denitrification in a variety of activated sludge flow schemes (Gujer and Henze, 1991). The model is in the form of a matrix notation (Table 4), relating changes of concentrations throughout the system to transport (reactor configuration, mixing, waste activated sludge) and transformation processes (aerobic growth of heterotrophic biomass and lysis of heterotrophic biomass). Model No. 2 adds the process of biological phosphorus removal, and involves a highly complex model. The coefficients for this model are very difficult to determine.

The Activated sludge model No. 1 utilised by Version III of ASIM has been improved from that initially published. Hydrolysis of organic nitrogen is not considered because all particulate organic fractions are assumed to contain a constant fraction of nitrogen. Ammonification is not considered because all soluble organic fractions are assumed to contain a constant fraction of organic nitrogen. A Monod switching function was introduced for ammonium as a nutrient, in order to prevent negative concentrations occurring in the simulation (Gujer, 1995).

The following processes were modeled in this study:

- aerobic growth of heterotrophs
- Anoxic growth of heterotrophs (denitrification)
- Decay and lysis of heterotrophs
- aerobic growth of autotrophs (nitrification)
- Decay and lysis of autotrophs

Table 4. Process kinetics and stoichiometry matrix for the Activated sludge Model No 1. (Henze et al., 1987)

Component → i / j Process ↓	1 $X_{B,H}$	2 X_E	3 $X_{B,A}$	4 X_S	5 X_I	6 X_{ND}	7 S_S	8 S_{NH}	9 S_{ND}	10 S_{NO}	11 S_{ALK}	12 S_I	13 S_O	Process rate, ρ_j $M L^{-3} T^{-1}$
1 Aerobic growth of heterotroph with ammonia-N	1						$-\frac{1}{Y_H}$	$-i_{XB}$			$-i_{XB}/14$		$-\frac{1-Y_H}{Y_H}$	$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{S_O}{K_{O,H}+S_O}\right)X_{B,H}$
2 Anoxic growth of heterotrophs	1						$-\frac{1}{Y_H}$	$-i_{XB}$		$-\frac{1-Y_H}{2.86Y_H}$	$\frac{1-Y_H}{14\times 2.86\times Y_H}$ $-i_{XB}/14$			$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)X_{B,H}\eta_G$
3 Death of heterotrophs	-1	f_E		$1-f_E$		$i_{XB}-f_E i_{XB}$								$b_H X_{B,H}$
4 Hydrolysis of enmeshed COD				-1			1							$K_H\frac{(X_S/X_{B,H})}{K_X+(X_S/X_{B,H})}\left[\left(\frac{S_O}{K_{O,H}+S_O}\right)+\eta_S\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\right]X_{B,H}$
5 Hydrolysis of particulate organic N						-1			1					$\rho_4(X_{ND}/X_S)$
6 Ammonification of soluble organic N								1	-1		1/14			$K_R S_{ND} X_{B,H}$
7 Aerobic growth of autotrophs			1					$-i_{XB}-\frac{1}{Y_A}$		$\frac{1}{Y_A}$	$-i_{XB}/14$ $-1/7Y_A$		$-\frac{4.57-Y_A}{Y_A}$	$\hat{\mu}_A\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{O,A}+S_O}\right)X_{B,A}$
8 Death of autotrophs		f_E	-1	$1-f_E$		$i_{XB}-f_E i_{XE}$								$b_A X_{B,A}$
Observed conversion rates, $M L^{-3} T^{-1}$								$r_i=\sum_j v_{ij}\rho_j$						
	Active heterotrophic biomass—$M(COD)l^{-3}$	Endogenous mass—$M(COD)l^{-3}$	Active autotrophic biomass—$M(COD)l^{-3}$	Enmeshed slowly degradable substrate—$M(COD)l^{-3}$	Unbiodegradable particulate substrate—$M(COD)l^{-3}$	Particulate organic degradable nitrogen—$M(N)l^{-3}$	Readily biodegradable substrate—$M(COD)l^{-3}$	NH_3-NH_4^+ nitrogen—$M(N)l^{-3}$	Soluble organic degradable nitrogen—$M(N)l^{-3}$	$NO_2^-+NO_3^-$ nitrogen—$M(N)l^{-3}$	Alkalinity—molar units	Unbiodegradable soluble substrate—$M(COD)l^{-3}$	Oxygen—negative COD—$M(-COD)l^{-3}$	

Stoichiometric parameters:

Heterotroph yield: Y_H

Autotrophic yield: Y_A

Inert fraction of biomass: f_E

Mass N/mass COD in biomass: i_{XB}

Mass N/mass COD in inerts: i_{XE}

Kinetic parameters:

Heterotrophic growth and decay: $\hat{\mu}_H$, K_S, $K_{O,H}$, K_{NO}, b_H

Correction factor for anoxic heterotrophic growth: η_G

Autotrophic growth and decay: $\hat{\mu}_A$, K_{NH}, $K_{O,A}$, b_A

Hydrolysis: K_H, K_X

Correction factor for anoxic hydrolysis: η_S

Ammonification: K_R

- Aerobic hydrolysis of organic matter
- Anoxic hydrolysis of organic matter

The following five soluble fractions and four particulate fractions were determined:

- S_o $gO_2.m^{-3}$ dissolved oxygen - taken from DO readings in the aeration basins. Assumed to be zero in the influent to the plant.
- S_s $gCOD.m^{-3}$ readily biodegradable substrate - assumed to be the COD soluble less the calculated S_I in the influent. Initial aeration basin conditions were assumed to be equal to the final mean effluent soluble COD for the period studied
- S_{NH} $gN.m^{-3}$ ammoniacal nitrogen - assumed to be TKN. Some TKN data had to be estimated from the equation TKN = 0.03036*COD-24.75, (determined by linear regression of the available data, R^2=0.7). Initial aeration basin conditions are assumed to be equal to the final mean effluent for the period studied.
- S_{NO} $gN.m^{-3}$ nitrate and nitrite - Some data substituted with the mean nitrate+nitrite value. No significant correlation could be obtained with other influent data. Initial conditions assumed to equal the mean final effluent nitrate plus nitrite for the period studied.
- S_I $gCOD.m^{-3}$ inert soluble substrate - related to the soluble fraction of the COD that remains after extended batch aeration. Found to be 1.067% in similar laboratory scale system, therefore assumed to be 1.067% of the influent COD. Initial conditions are assumed to be 1.067 of final mean effluent COD.

- $X_{B,H}$ gCOD.m^{-3} active heterotrophic biomass - assumed to be zero in the influent. Initial conditions assumed to be the initial MLVSS recorded in each basin.
- $X_{B,A}$ gCOD.m^{-3} active autotrophic biomass - assumed to be zero in the influent. Initial conditions assumed to be 2% of the MLSS based on the mean BOD_5:TKN ratio for the influent (Orhon & Artan, 1994, p370)
- X_S gCOD.m^{-3} enmeshed slowly biodegradable substrate - calculated as COD - soluble COD - X_I in the influent. Initial conditions assumed to equal mean Suspended solids in the final effluent over the period studied.
- X_I gCOD.m^{-3} inert particulate substrate - Leonard (1996) states that this is negligible. Assumed to be 1% of COD in influent.

Also utilised where possible were stoichiometric coefficients from the dairy processing industry (Table 5). Where dairy-related information could not be obtained, estimates from the literature relating to general activated sludge modeling were used. The inert fraction of the biomass in the system, f_E, was calculated from the non-volatile proportion (MLVSS). While the volatile proportion (MLVSS) consistently consisted of 80% of MLSS at Anchor Products Waitoa, the recycling of the biomass means that the fraction of inert products actually formed is lower (Henze et al., 1987), and is calculated from the equation:

$$f_E(\text{observed}) = \frac{f_E(\text{model})}{1-Y_H(1-f_E(\text{model}))}$$

Table 5. **Stoicheometric coefficients from the Dairy Processing Industry.**

Parameter	Value	Origin
Heterotrophic yield, Y_H	0.68 gcell COD.gCOD^{-1}	Leonard (1996)
Autotrophic yield, Y_A	0.24 gCell COD.gN^{-1}	Gujer & Henze (1991)
Inert fraction of biomass, f_E	0.08	Calculated from Waitoa sludge

The kinetic parameters used to formulate the process rate equations are shown in Table 6. Correction factors applied to the aerobic equivalents were used to approximate the anoxic heterotrophic growth rate and anoxic hydrolysis rate. The half-saturation constants are used primarily as switching functions for the various process reactions. The impact of temperature changes on the kinetic coefficients is incorporated into the ASIM model, however the default coefficients chosen by the model were utilised due to the absence of reliable information for dairy processing wastewaters.

Daily parameters monitored for the Anchor Products Waitoa Waste Treatment Plant included influent flows, return activated sludge flows, waste sludge volumes, temperatures and influent characteristics over a three month period. These results are summarised in Appendix II. Mean values for all influent parameters were calculated over the study period, and daily variation files were constructed in which daily values, as a ratio of their mean values, were used (Appendix IV). These variation files for each day were then run against the model, with the initial conditions for each run being those simulated from the end of the previous days run.

Table 6. Kinetic Parameters used to Formulate the Process Rate Equations.

Parameter	Value	Origin
Heterotrophic growth and decay		
Max. Specific growth rate, μ_H	3.31 day^{-1}	Mayer et al. (1982)
Decay coefficient, b_H	0.14 day^{-1}	Hung (1984)
Half-saturation constants:		
K_S (carbon source)	17 $gCOD.m^{-3}$	Leonard (1996)
$K_{O.H}$ (dissolved oxygen)	0.2 $gO_2.m^{-3}$	Henze et al. (1987)
K_{NO} (nitrate-N)	0.5 gNO_3-$N.m^{-3}$	Henze et al. (1987)
Autotrophic growth and decay:		
Max. Specific growth rate, μ_A	0.8 day^{-1}	Henze et al. (1987)
Decay coefficient, b_A	0.1 day^{-1}	Orhon & Artan (1994)
Hydrolysis rate, k_H	3.0 $gCOD.day^{-1}$	Henze et al. (1987)
Half-saturation constants:		
K_{NH} (ammonia-N)	1.0 gNH_3-$N.m^{-3}$	Henze et al. (1987)
$K_{O.A}$ (dissolved oxygen, anoxic biomass)	0.4 $gO_2.m^{-3}$	Henze et al. (1987)
K_X (hydrolysis)	0.03 $gCOD.gCOD^{-1}$	Henze et al. (1987)
Correction Factors		
Anoxic heterotrophic growth, $\acute{\eta}_g$	0.58	Orhon et al. (1996)
Anoxic hydrolysis, $\acute{\eta}_b$	0.4	Henze et al. (1987)

A variation file, including daily temperature changes for each day was run against the model. The system conditions were then integrated forward in time over 24 hours, without requiring that a steady state be reached within 24 hours. The model output consisted of four hours final effluent data and aeration basin data. This data was then utilised as the initial conditions for the subsequent day's run. All modeled parameters were then compared with the actual data gathered.

RESULTS AND DISCUSSION

PERFORMANCE OF THE BIOLOGICAL TREATMENT PLANT

Removal efficiencies

The overall performance of the Waste Treatment Plant over the period studied was very good. The removal of carbon compounds in the Waste Treatment Plant was excellent, with a BOD_5 removal of 99.7%. This was more than enough to comply with the current resource consent for discharge to the Waitoa River. As the treatment plant was nitrogen limited (see later this chapter), the nitrogen removal was also very good. This data has been summarised in Table 7.

Table 7. Removal Efficiencies for the Waste Treatment Plant during the period Studied.

	COD	CODs	BOD	SS	Fat	TKN	NO3	NO2	NH4	TP	DRP	S	Iron
ıoval	98.8	98.2	99.7	96.6	58.7	96.9	98.1	95.6	96.6	33.8	29.0	26.7	80.4

BOD:COD ratio in influent

The average COD to BOD ratios in the influent and effluent during the trial period (calculated from data shown in Appendix II) are summarised in Table 8.

Table 8. COD to BOD Ratios

	Average	Minimum	Maximum
Influent	1.5	1.2	2.2
Effluent	0.18	0.05	0.68

While these ratios can be highly variable due to the changing chemical composition of the wastewater over the dairy season, average ratios can still be used to predict the BOD in the effluent discharge (for compliance purposes) and in the influent (for design purposes). Ratios less than 2.5 have been described as readily degradable (Capps et al., 1995), indicating a shorter retention time required for treatment.

Nutrient Studies

Effluent nutrient characteristics

Influent phosphorus concentrations averaged 120 mg/l (600 kg/day) during September 1996 and dissolved reactive phosphorus was elevated in the discharge from the Waste Treatment Plant (Appendix II). The oxygen limiting conditions required to control denitrification to within the treatment plant, rather than in the secondary clarifiers, reduces most luxury biological phosphorus uptake that may otherwise occur. Only 30 percent of the phosphorus (Table 9) is removed as biomass, with minimal luxury uptake of phosphorus occurring, or phosphorus later being lost elsewhere in the treatment plant (Jardin and Popel, 1996).

Table 9. Phosphorus Balance around the Biological Treatment Plant. (Results are from average data listed in Appendix II).

Volume. Sludge removed (m^3/d)	Total phosphorus (g/m^3 sludge)	TP removed with sludge (kg)	TP into Waste Treatment Plant (kg/d)	TP removed (33% removal) (kg/d)
360	765	280	970	320

Analysis of dissolved reactive phosphorus was undertaken at several points around the treatment process. The sample taken just prior to the clarifier inlet was 83.4 mg/l compared to that from the sludge thickening plant supernatant (97.2 mg/l). It was therefore determined that phosphorus was being released in the treatment process between the last aeration basin and the thickened sludge silo. It was estimated that 30 kg of dissolved reactive phosphorus per day was being pumped back into the second aeration basin from the sludge thickening process.

Chemical dosing, or reconfiguring the Waste Treatment Plant specifically for biological phosphorus removal will be required to increase the efficiency of phosphorus removal in this treatment plant (Jardin and Popel, 1996).

Nutrient source studies

Many tonnes of carbon, nitrogen and phosphorus compounds entered the site with milk during the processing. Significant amounts of nitrogen, phosphorus, sodium and sulphur are also used as cleaning chemicals on site. Ammonia is used in the refrigeration machinery that services the plant however normal maintenance procedures prevent a significant loss of ammonia to the wastewater.

Approximately 1.6, 2.2, 24.7, and 41.0 tonnes of nitrogen, phosphorus, sulphur and sodium respectively, and an insignificant amount of carbon was transported to site as bulk cleaning chemicals during the 70 days investigated. Table 10 summarizes a nutrient balance around the site. Raw data is shown in Appendix III.

Table 10. Nutrient Balance Around the Waitoa Production Site

	nitrogen	phosphorus	sulphur	sodium	chlorine
Onto site as bulk chemicals (kg)	1606	2155	24688	40983	169
Into Waste Treatment Plant (kg)	8667	14150	40837	62258	COD 262889 (BOD=131445)
Ratios into WTP	3.3	5.4	15.5	23.7	100
Difference (will include product losses) (kg)	7061	11995	16149	21275	

Treatment Plant Nutrient Requirements

The nutrient composition of the Waste Treatment Plant influent was monitored for fourteen days during September 1996. The influent was analysed for COD, BOD, Suspended solids, Fat, TKN, Nitrate, Nitrite, Ammonia, Total phosphorus, dissolved reactive phosphorus, sulphur and iron. These results were used to calculate the actual nutrient requirements of the treatment plant at that time (shown in Appendix 1). The Waste Treatment Plant was found to be deficient in two nutrients, nitrogen and iron (Eckenfelder and Grau,1992; Gaudy and Gaudy, 1984; Goronszy, 1990).

The weight of chemical required to be added to the influent to prevent nutrient deficiency was then calculated and costed (Appendix I). It was decided that the cost to dose the required chemicals was excessive, and that ways would be sought to decrease phosphorus usage and increase nitrogen usage (in proportion to the carbon discharged) within the production units. The present nutrient deficiencies did not seem to be effecting treatment efficiencies, although the foam on the surface of the ponds was a nuisance for maintenance staff.

Two factories were prepared to change from using triplex (predominantly phosphoric acid) to nitric acid, to improve the cleaning efficiencies. It was calculated that nitrogen loading to the ponds would increase by 530 kg/d, and the phosphorus loading would decrease by 80 kg/d, if this were to occur. The extra nitrogen (500 kg/d) is enough to eliminate the nitrogen deficient conditions (required 150 kg/d), although the removal of 80 kg of phosphorus per day from the discharge will not greatly decrease the phosphorus loading on the river. Iron deficiency may still be an issue and the effect of this will need to be determined when the nitrogen deficient conditions are eliminated.

BULKING AND FOAM FORMATION

Filamentous Bulking Determination

Five types of filamentous bacteria were consistently identified in both Ponds. These bacteria are shown in Table 11 in decreasing order of abundance (Seviour et al, 1994; Jenkins et al. 1993; Strom and Jenkins, 1984). The characteristics and operating parameters for treatment plants where these organisms have been previously found are also included in Table 11 (Seviour et al, 1993)

Low F/M ratios and high sludge ages are common characteristics for all of the filaments identified, and are known to have caused bulking conditions at other waste treatment plants (Marshall, 1992; Nam et al, 1996; Strom and Jenkins, 1984; Kampfer et al, 1995). It was also noted that the Nocardia species were more abundant in the second Pond than the first.

The sludge age during the period studied is calculated in Appendix II and ranges between 30 and 24 days. The F/M ratio is significantly lower in the second pond due to the readily degradable nature of the influent and in fact that there is little change in the soluble COD between Pond one, Pond two and the effluent composite (most if not all of the organic substrate degradation is occurring in Pond 1). It is therefore possible that the filamentous bulking condition may be significantly improved by reducing the solids (increasing the F/M ratio, and decreasing the sludge age), and perhaps by investigating the diversion of some influent into Pond 2.

Table 11. Filamentous Bacteria Dominant in the Waste Treatment Plant.

	Favoured Operation Parameters *	Characteristics
Type 0914	Low F/M. Long sludge ages.	May be gliding motile. Frequently seen in biological phosphorus removal plants. Not often the dominant filament.
Type 0092	Low F/M. Long sludge ages. Slowly degradable or particulate substrates.	Grows poorly on sugars, capable of degrading some proteins. Capable of aerobic and anaerobic metabolism.
N. pinensis	Low F/M. Long sludge ages.	Diverse carbon/nitrogen/sulphur sources.
Nocardia amarae like organisms	Low F/M. Wide range of sludge ages.	Diverse carbon/nitrogen/sulphur sources. Denitrifies to nitrite rather than nitrate. Fast growers. Strict aerobes.
Nostocoida limicola III	Readily degradable soluble substrates. Moderate to high sludge age. Low F/M.	Diverse carbon/nitrogen/sulphur sources. Grows in absence of both O_2 and NO_3^-. Sheathless.

Foam Cause Identification

After reviewing the literature (Task Force on Activated sludge, 1987; Jenkins and Peirano, 1996; Goronszy, 1990; Chua and Le, 1994; Knight et al. 1995a), the possible causes for foam production at this particular plant were narrowed down to:

1. nutrient deficiency (nitrogen and iron see Appendix I).
2. filamentous organisms associated with plants operating at low loading (see Table 11).

surfactants in the influent (many cleaning chemicals are used in large quantities on the factory site).

The causes of foam referenced in the literature search that could be discarded included:

1. young sludge (foam was not white and billowing),
2. insufficient aeration (dissolved oxygen was continuously monitored, and foam was not dark).
3. dyes or inks (none of these were present).

Nutrients in the influent and effluent were measured throughout the trial (Appendix 1). The nutrients of concern were shown to be nitrogen which had a BOD_5:TKN ratio of 27:1 (a BOD_5:TKN ratio of 20:1 - 25/1 is recommended) and iron with a BOD_5:Fe ratio of 880:1 (a BOD_5:Fe ratio of < 200:1 is recommended). Aerobic biological processes require 2-5 mg/l of ammonia for every 100 kg of BOD. At the Waitoa plant the ratio averaged 0.3 mg/l. However, of the filamentous organisms identified, only one (*Type 0041*) is typically found in nutrient deficient plants. *Type 0041* was only seen in small numbers, and not on every occasion. Other typically nutrient deficient filaments (*Type 0675*, *Type 021N*, *Thiothrix I* and *II* and *S. natans*) were not observed (Bradley and Kharkar, 1996; Task Force on Activated sludge, 1987; Marshall, 1992).

It was calculated that 730 kg of urea and 430 kg of ferric chloride should be added per day in order to treat 12750 kg of BOD_5 (Appendix 1), however, at $620/day, this was considered to be uneconomic. At the time that this report was written, the foam was causing nuisance value only, and there were other causes more strongly linked to the filament identified (see below). It was also possible that a change of cleaning chemical in some of the factories would increase the amount of nitrogen discharged to the Waste Treatment Plant, and decrease the amount of phosphorus.

Of the filamentous organisms observed, all have been previously shown by Seviour et al 1993 to be associated with low F:M conditions in the plant. Table 12 summarizes the dominant filaments found in the Waste Treatment Plant and their foaming abilities.

The raw results and calculated F:M ratio and sludge age are shown in Appendix II. The calculated F:M ratios throughout the trial ranged between 0.05 and 0.1, averaging 0.07. The sludge age was shown to be 38 days at the beginning of the trial, decreasing to 27 days at the end of the three months (Appendix II). As discussed in the bulking studies, low F:M conditions did therefore exist in the plant, encouraging the growth of the bulking and foaming organisms dominant in the Waste Treatment Plant (Task Force on Activated sludge, 1987; Bradley and Kharkar, 1996). In order to increase the F/M, sludge wasting needs to be increased.

Table 12 Foaming Associations of the Dominant Filaments

	Favoured Operation Parameters	Foaming Characteristics
Type 0914	Low F/M. Long sludge ages.	Has been reported as the dominant organism in foam. (Task Force on Activated sludge, 1987)
Type 0092	Low F/M. Long sludge ages. Slowly degradable or particulate substrates.	Hydrophobic - produce and stabilize foams. (Chua and Le, 1994)
N. pinensis	Low F/M. Long sludge ages.	Hydrophobic - produce and stabilize foams. (Sevior et al, 1993; Jenkins and Peirano, 1996).
Nocardia amarae like organisms	Low F/M. Wide range of sludge ages.	Hydrophobic - produce and stabilize foams. (Seviour et al, 1993; Jenkins and Peirano, 1996; Goronszy, 1990)
Nostocoida limicola III	Readily degradable soluble substrates. Moderate to high sludge age. Low F/M.	Has been reported as the dominant organism in foam. (Goronszy, 1990)

Ten of the major chemicals and products discharged to the Waste Treatment Plant were investigated for their foaming characteristics using the method of Goronszy (1990).The results are summarised in Table 13.

Table 13. Investigation into Chemical Causes of Foaming

Substance	Formed foam	Stability after 30 secs
Whole milk	240 ml	270 ml
Skim milk	350 ml	190 ml
Cream	20 ml	40 ml
Influent (13/11/96)	40 ml	10 ml
Solgon	150 ml	100 ml
Sterbac	500 ml	210 ml
Microquat B	500 ml	600 ml
Supersan	250 ml	300 ml
First Degree	500 ml	650 ml
Influent 14/11/96	30 ml	30 ml

From these results the cleaning chemicals Microquot B and First degree were shown to form a highly stable foam, and skim milk and Supersan forming a moderately stable foam. From the foaming tests performed on the influent samples, it is not likely that surfactants alone are the dominant cause of the foaming on the surface of the treatment plant. The usage of Microquot B was shown to be relatively minor (0.44 m^3 per year), however the usage of First degree at 70 m^3/year could be a minor factor, increasing the stability of the foam produced by the filamentous bacteria.

Ultimately it was shown that the major cause of the excessive foam production at this Waste Treatment Plant was likely due to foam forming filamentous bacteria, encouraged by the low F/M and high sludge age. Minor additional influences included the use of surfactants on the processing site, and a nitrogen and iron deficiency in the inlet feed.

APPLICATION OF ASIM

The modeling presented in this thesis was completed in close collaboration with the New Zealand Dairy Research Institute, Resource Management section, and is also discussed in a Technical Report by Donkin and Kerridge, 1997.

To verify any complete model for an activated sludge process, the influent, effluent, return and waste flow conditions such as flow rate, chemical oxygen demand COD concentration, and the suspended solids concentration have to be given in respect to time (Appendix II). These actual results must then be compared to the predicted results. Variation files which include the data used for all modeling are shown in Appendix IV.

The model chosen (ASM No.1) was one out of thirteen models available with ASIM (Activated Sludge SIMulation Program) Version 3.0 (Gujer, 1995). It was considered that the major process occurring in Waitoa's waste treatment system was the removal of organic carbon (biomass utilizes organic substrates in order to grow and multiply), with nitrification and denitrification secondary. The following processes therefore were required to be included in any model required to accurately simulate the Waitoa system: growth of biomass; lysis and hydrolysis (loss of biomass) using organic substrates; inert particulate solids in influent; nitrification and denitrification.

COD Removal

The modeled COD of the effluent was compared to the actual COD in the discharge to the river (Figure 6). The actual COD removal rate was 98% compared with an estimated removal efficiency of 99%, showing that the model predicts the final effluent COD concentrations well. This indicates that for this treatment plant, the kinetic and stoicheometric coefficients and equations used in this model adequately predicted organic carbon removal. Included in Waitoa's treatment system is sandfiltration for a portion of the discharge. Much of the final suspended material in the wastewater is removed in this manner, enabling a closer prediction of final effluent characteristics than might otherwise have been the case (ASM No.1 assumes that there is no carry-over of suspended solids from the clarifier i.e perfectly operating). Previous experience indicates that a substantial proportion of the remaining suspended solids in the discharge from the clarifiers are removed in the sandfilters. The only noticeable exception is when significant numbers of single cells are present in the discharge due to a toxic dose in the Waste Treatment Plant. Single cells are not as effectively removed by the sand filters, however no event of this nature occurred during the period investigated.

It was found that the prediction of final effluent COD was fairly insensitive to changes in the kinetics and stoicheometric coefficients due to the extended aeration configuration of the plant (low F:M), which enables maximum COD metabolisation (Donkin and Kerridge, 1997)

The inert fraction of the influent averaged 25mg/l throughout the trial. This indicates a very low proportion of the total influent is non-degradable (1.1 %). The slowly biodegradable substrate concentration in the influent averaged 1090 mg/l (46.6 %). This fraction must first be hydrolyzed in order to become available for degradation and is assumed to be associated with the solids phase of the activated sludge (adsorbed, entrapped) instantaneously. It therefore does not appear as soluble COD. If either nitrate or oxygen is present, this fraction will be converted and used, otherwise (anaerobic conditions) this fraction will accumulate. As the total COD in the discharge is usually proportional to the suspended solids concentration, and not continually increasing, then it is understood that degradation of this fraction is taking place.

The readily degradable fraction of the influent causes a rapid usage of oxygen in a short time frame. The concentration of this fraction averaged 810 mg/l or 34.7 % of the total influent.

ASM model No.1 does not include phosphorus removal as a treatment process but even so has been proven adequate for Waitoa's system. The loss of COD during the small amount of phosphorus removal in this treatment system (33%) does not affect the accuracy of the model as removal is due to that utilized by the sludge cells for cell synthesis and energy transport only. Other initial assumptions which have been proven accurate are:

1. initial aeration basin conditions equal final mean effluent soluble COD
2. inert soluble substrate same as for similar lab scale system therefore lab scale system shown to be an accurate approximation of the full scale system in this area.
3. Inert particulate substrate of this particular wastewater negligible. Average COD to BOD5 ratio of 1.5 indicates a readily degradable influent (less than 2.5 is considered readily degradable).

Nitrogen Removal

The predicted concentrations of nitrogen in the effluent were also compared to the actual concentration of nitrogen in the final discharge to the river (Figure 6). A predicted value of 99% compared with an actual removal rate of 97% indicates that the chosen model was able to predict the final concentration of nitrogen in the effluent within acceptable analytical error limits.

In order for denitrification to be modeled accurately, the kinetics of heterotrophic growth must be corrected for anoxic conditions (organisms have the enzymatic ability to use nitrate as an electron acceptor in the absence of dissolved oxygen). There are hence some issues to overcome when attempting to model denitrification:

1. not all the biomass will adapt itself to anoxic conditions (some microorganisms will be incapable of utilizing nitrate as an electron acceptor).
2. The maximum specific growth rate of heterotrophs may be reduced under anoxic conditions and a correction factor is required.

Usually the nitrogen fractions in influent do not need to be characterized in as much detail as the organic fractions because most of the nitrogen is present as ammonia, which has no coupling to the organic compounds (Henze et al., 1995). In Anchor's influent however, a significant proportion of the nitrogen is present as nitrate (Appendix II). Fixed nitrogen fractions for the various COD components were used with the assumption that all particulate and soluble organic fractions contain a constant fraction of organic nitrogen.

While the Waitoa plant was originally designed with the prime intention of removing carbon from the wastewater, it is also currently achieving high levels of nitrogen removal, mostly due to denitrification (the aeration basins are operated at a dissolved oxygen range of 0.7-1.5 mg/l encouraging simultaneous nitrification/denitrification).

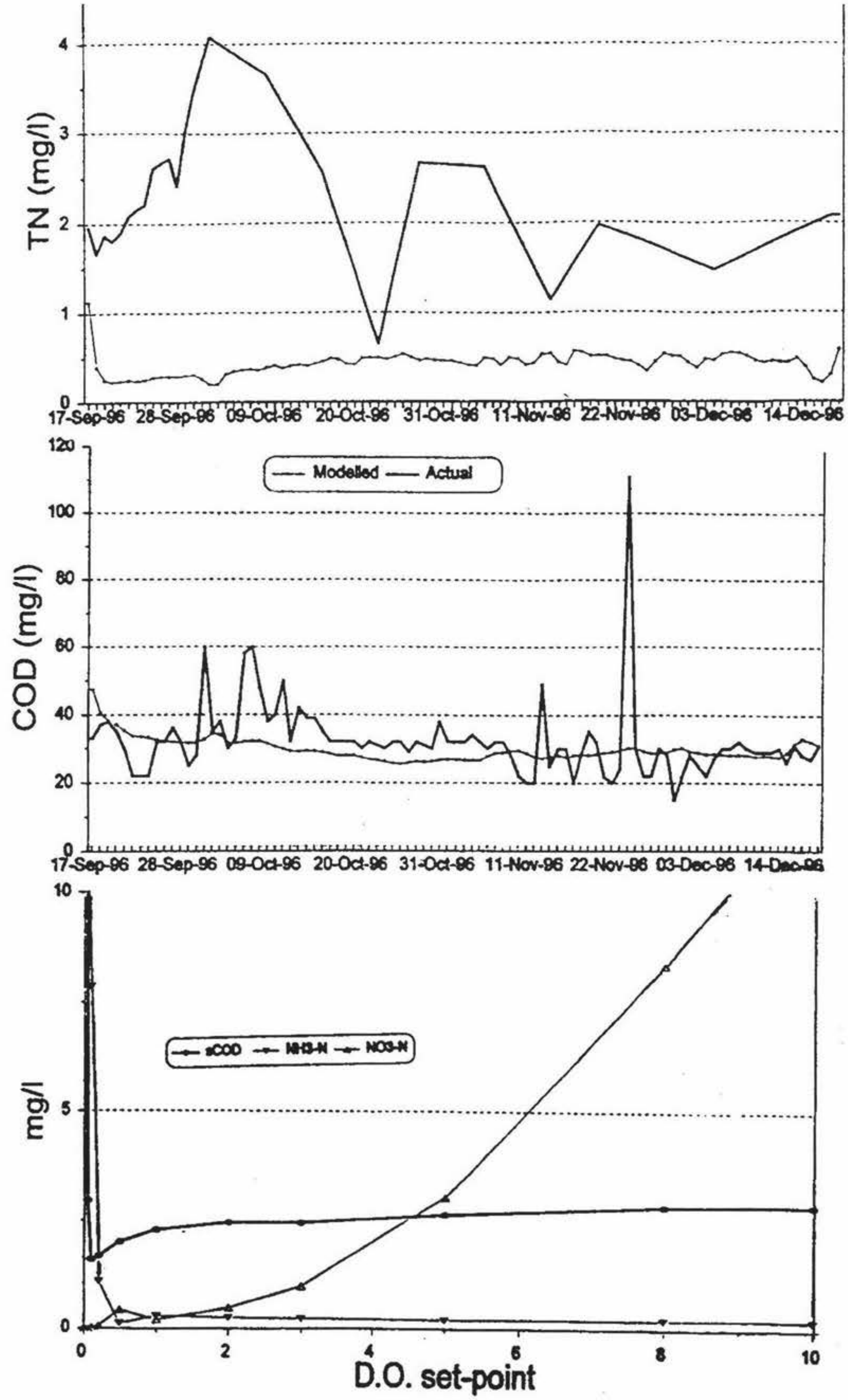
Solids Removal

Unfortunately a combination of suspended solids and total solid's analysis was used at the Waste Treatment Plant, and the return activated sludge volume from one of the clarifiers was also not accurately measured and had to be estimated. This meant that it was difficult to compare the suspended solids in the ponds mixed liquor, return activated sludge and discharge to the total solids measured in the waste sludge. Consequently the correlation between the predicted solids and the actual solids throughout the system was not as good as was expected.

Dissolved Oxygen

The model was also used to estimate the effect of varying the dissolved oxygen set points in the aeration basins (Figure 6). This indicated an optimum aeration set point range of 0.5 to 1.5 mg/l dissolved oxygen. At levels above 2.0 mg/l the nitrate levels were predicted to increase, while at levels below 0.5 mg/l the soluble COD and ammonia concentrations were predicted to increase dramatically due to incomplete oxidation occurring. These trends are substantiated by previous operator experience at the Waitoa Waste Treatment Plant and plant already operates within this dissolved oxygen range.

Figure 6. COD, nitrogen and Dissolved Oxygen Modeling (Donkin and Kerridge, 1997)



CONCLUSIONS

Filamentous bulking in the sludge was determined to be due predominantly to low F/M, high sludge age filamentous bacteria. It is expected that a reduction in these organisms could be achieved by increasing the F/M, and reducing the sludge age i.e. by increasing the waste sludge removal from the system.

The dominant bulking organisms in the Waste Treatment Plant were also shown to have been associated with foam, or known foam formers. It is therefore expected that the foam will also reduce with the reduction in sludge age. Two additional conditions that may be enhancing the foam production and stability include a nitrogen and iron deficiency in the influent, and the use of surfactants for cleaning on the processing site. Several other methods of foam control are known, including the spraying of the foam with chlorine (Jenkins et al, 1989; Koopman et al, 1984; Task Force on Activated sludge, 1987). The reduction in foam could be enhanced by foam chlorination, a foam wasting program, correction of the nitrogen and iron deficiency, and an investigation into the usage of the detergent First Degree.

Nitrogen deficient conditions in the Waste Treatment Plant could be improved if not eliminated by altering the cleaning regime in some of the factories to include nitric acid instead of triplex. Iron deficiency may still effect the bulking and foaming conditions in the plant. Replacing triplex with nitric acid would not eliminate the high total phosphorus discharges into the Waitoa River from the Waste Treatment Plant, although these would be reduced by a small amount.

The concentration of phosphorus in the discharge from the Waste Treatment Plant is unlikely to be acceptable to the local authorities or the general public in the longer term. It is recommended that a study is completed to determine the most cost effective method of phosphorus removal. Possible options are chemical dosing prior to discharge, luxury uptake of phosphorus by the biomass (requiring plant reconfiguration), or spray irrigation of the current Waste Treatment Plant discharge.

As higher dissolved oxygen levels in the aeration basins encourages denitrification in the clarifiers (conditions of low oxygen, more than 5 mg/l nitrates), it is recommended a dissolved oxygen level less than two mg/l is maintained in order to complete any denitrification within the aeration basins.

The ASIM model with the kinetic and stoicheometric coefficients and equations described in this thesis proved to ably model the Anchor Products Waitoa biological Waste Treatment Plant. It was able to predict well the final effluent COD and nitrogen concentrations in the discharge into the river. The model will be able to be utilised to predict the likely effects of large changes in influent characteristics on the discharge to the Waitoa River. The effects of future changes in the configuration of the wastewater treatment plant will also be able to be modeled.

LIST OF SYMBOLS

APHA	American Public Health Association	
ASIM	Activated Sludge SIMulation programme	
ASM1	Activated sludge Model Number one	
ASM2	Activated sludge Model Number two	
b	Yield Coefficient	per day
BOD_5	Biochemical Oxygen Demand	mg/l or kg/d
Ca	calcium	
Cl2	chlorine	mg/l
Co	Cobalt	
CO_3	Bicarbonate	
COD	Chemical Oxygen Demand	mg/l or kg/d
Cu	Copper	
DSS	Dispersed Suspended Solids	mg/l
Fe	Iron	
F/M	Food to microorganism ratio	per day
FSS	Flocculated Suspended Solids	mg/l
H_2O_2	Hydrogen Peroxide	
K	Potassium	
K_s	Coefficient	mg/l
MCRT	Mean Cell Retention Time	days
Mg	Magnesium	mg/l
MLSS	mixed liquor suspended solids	mg/l

MLVSS	Mixed Liquor Volatile Suspended Solids	mg/l
Mn	Manganese	
Mo	Molybdenum	
Na	Sodium	
NH_4^+	Ammonium	
NO_3^-	Nitrate	
O_2	Oxygen	
P	phosphorus	mg/l
PO_4	Orthophosphate	
Q	Wastewater Flow Rate	m^3/d
R	Return activated sludge flow	m^3/d
RAS	Return activated sludge	
SOC	Soluble Organic Carbon	mg/l
SSC	Suspended Sludge Concentration	mg/l
SSOC	Suspended solids Organic Carbon	mg/l
SVI	Sludge Volume Index	
TKN	Total Kjeldahl Nitrogen	mg/l
TP	Total phosphorus	mg/l
TS	Total Solids	mg/l
TSS	Total Suspended Solids	mg/l
V	Tank Volume	m^3
VSS	Volatile Suspended Solids	mg/l
WAS	Waste Activated Sludge	
WTP	Waste Treatment Plant	

Y_H	Yield Coefficient	mgVSS/mgCOD
Zn	Zinc	
μ_{max}	Coefficient	per day

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APPENDIX I. **Nutrient Requirements of the Anchor Waitoa Waste Treatment Plant.**

(Marshall, 1992; Task Force on Activated sludge, 1987)

Influent					Nutrient needed mg/l			Nutrient shortage mg/l			Weight of nutrients to be added, kg			Amount of chemical to be added, kg			
Date	BOD/N	BOD/P	BOD/Fe	BOD/COD	N	P	Fe	N	P	Fe	N	P	Fe	Urea		Ferric chloride	
														kg/d	$/day	kg/d	$/day
17/09/96	24	10	703	0.6	71	14	7	13	-108	5	80		33	374	175	329	207
18/09/96	25	12	1941	0.6	83	17	8	16	-99	7	110		51	510	238	510	320
19/09/96	23	13	2338	0.7	87	17	9	12	-113	8	98		65	458	214	653	410
20/09/96	37	21	235	0.8	55	11	6	25	-34	1	207		7	964	450	68	43
21/09/96	24	12	389	0.5	56	11	6	10	-77	3	77		21	358	167	209	131
22/09/96	24	13	1031	0.6	83	17	8	15	-96	7	123		55	572	267	552	346
23/09/96	36	15	577	0.7	101	20	10	45	-90	7	370		55	1721	804	553	347
24/09/96	30	10	739	0.6	78	16	8	27	-115	6	199		42	924	431	425	266
25/09/96	27	12	563	0.7	85	17	9	23	-102	5	195		47	909	424	475	298
26/09/96	27	14	1064	0.7	92	18	9	25	-98	7	175		53	813	380	537	336
27/09/96	27	17	888	0.9	111	22	11	30	-110	9	246		70	1144	534	708	444
28/09/96	24	16	957	0.7	89	18	9	16	-72	7	115		52	536	250	524	328
29/09/96	23	11	491	0.5	71	14	7	10	-96	4	71		30	328	153	297	186
30/09/96	27	11	440	0.6	73	15	7	19	-105	4	129		27	601	281	267	168
avg.	27	13	883	1	81	16	8	20	-94	6	157		43	729	341	436	274

COD	Flow	sol COD	BOD	SS	RG Fat	TKN	Nitrate	Nitrite	Ammonia	TP	DRP	Sulphur	Iron	Calcium	Sodium	Potassium	BOD:COD	COD:BOD
mg/l	m3/d	mg/l	mg/l	mg/l	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		
2800	7643																	
2000	8019																	
2800	8689																	
2040	8058																	
2580	7603																	
2440	7910																	
2800	7904																	
2640	8325																	
3100	7595																	
2640	7366																	
2600	7855																	
2240	7905																	
3100	7785																	
2600	8142																	
2600	8331																	
2380	8575																	
2640	7988																	
2440	6438	1240	1420	503	0.05	58.5	20.0	0.03	4.4	136	122	429	2.02				0.58	1.72
2640	6845	1280	1650	541	0.03	66.5	17.2	0.25	3.5	139	115	401	0.85				0.63	1.60
2620	8199	1500	1730	444	0.02	74.5	24.1	1.76	2.8	137	130	293	0.74				0.66	1.51
1400	8320	760	1100	344	0.02	30.1	8.9	1.20	2.9	52	45	209	4.69				0.79	1.27
2400	7695	960	1110	420	0.02	45.5	14.0	0.20	4.6	95	88	317	2.85				0.46	2.16
2600	8195	1300	1660	556	0.02	68.0	15.1	0.52	5.8	123	113	381	1.61				0.64	1.57
2800	8312	1600	2020	473	0.01	56.5	17.3	0.36	5.6	137	110	333	3.50				0.72	1.39
2460	7408	1000	1560	561	0.00	51.2	17.6	0.57	2.9	152	131	209	2.11				0.63	1.58
2420	8604	1200	1700	581	0.04	62.3	13.6	0.66	5.2	139	119	386	3.02				0.70	1.42
2500	7130	1200	1840	560	0.04	67.5	9.4	2.70	4.6	131	116	369	1.73				0.74	1.36
2580	8172	1580	2220	507	0.02	80.9	24.8	0.04	5.3	129	132	443	2.50				0.86	1.16
2620	7383	1560	1780	557	0.02	73.4	9.0	0.19	6.0	108	90	428	1.86				0.68	1.47
2820	7059	1420	1410	530	0.04	60.5	11.9	0.52	5.2	123	110	430	2.87				0.50	2.00
2360	6664	1240	1460	453	0.03	53.6	12.3	0.84	5.9	136	120	386	3.32				0.62	1.62
2260	8194	1580		354														
2580	7109	1800		389														
2820	8170	1580		697														
2960	9200	1600		692														
3040	8496	1800		599														
2600	9121	1440		520														
2640	9007	1580		481														
2200	7421	1400		327														
2180	7018	1080		440														
2000	8409	1200		425														
2400	8256	1480		398														
2600	7776	1420		538														
2620	7947	1640		512														
2400	7967	1400		591														
2360	7578	1440		412														
2240	8370	1220		430														
1960	8451	1020		383														
2460	8723	1400		437														
2400	8734	1560		583														
2200	7951	1180		473														
2000	7773	1160		412														
2260	8272	1260		268														
1800	7475	1020		267														
2040	7324	1200		633														
2180	7627	1000		495														
2640	7865	1100		709														
2160	7446	1220		447														
1960	8472	1180	1670	399	0.01	50.7	0.062	0.008	6.1	111	95.2	331	2.05				0.85	1.17
2640	8069	1220		588														
2460	7397	1340		436														
2220	6550	960		595														
2000	7815	1000		460														
2000	7653	1060		432														
2400	8214	1380		587														
2440	7227	1400		468														
3600	7210	1180	2340	1021		52.6	11.1	0.35	5.4	149	138	380					0.65	1.54
2200	7018	1420		390														
2960	7450	1580		663														
2580	7625	1260		647														
2200	6985	1300		371														
1800	6993	1120		334														
2337	8049																	
2200	7863	1000		502														
2620	7793	1400	1628	561		62	17.9	1	7.1	135	128	443		74.5	546	207	0.62	1.61
2000	8125	1360		335														
2980	7268	1420		679														
2800	7778	1180		731														
2000	7759	1000		462														
2600	7759	1360		640														
2600	7759	1360		661														
2600	7530	1240		709														
2600	7357	1400		543														
2640	7167	1450		584														
2880	8500	1600		755														
1840	8511	1200		333														
2580	7759	1600		458														
2337	7759	1313	1665	511	0.02	60	14	0.66	4.90	125	112	363	2.38	75	546	207	0.67	1.54
842	2156	218	330	132	0.01	12	6	0.70	1.25	24	23	73	1.03				0.11	0.26
3600	9200	1800	2340	1021	0	81	25	3	7	152	138	443	5	75	546	min	0.46	1.16
																max	0.86	2.16

Discharge from WTP

Flow	COD	sol COD	BOD	SS	RG Fat	TKN	Nitrate	Nitrite	Ammonia	TP	DRP	Sulphur	Iron	Calcium	Sodium	Potassium	Magnesium	BOD/N	BOD/P	BOD/Fe	BOD/COD
m3/d	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l				
1510	30	25	6.9	16																	0.23
1349	25	28	5.5																		0.22
996	28	18	4.1	15																	0.15
781	32	25	3.4	18																	0.11
239	40	28	4.5	18																	0.11
1196	22	25	15.0	18		2.10	18.90	0.13	0.16	89	82	220						7.14	0.17		0.68
1388	29	29	4.3																		0.15
1353	33	29	4.1	12																	0.12
1307	31	22	3.2	13																	0.10
1480	38	20	3.4	20																	0.09
290	35	28	4.1	30																	0.12
1906	48	37	9.0	34																	0.19
1753	50	30	6.0	40																	0.12
1721	65	30	5.9	33																	0.09
1648	42	20	4.4	36																	0.10
1565	32	20	4.3	30																	0.13
1841	41	29	5.1	33		1.40	35.50	0.01		70	68							3.64	0.07		0.12
1798	40	29	4.2	33																	0.11
1610	40		5.8	37																	0.15
60	62		9.8																		0.16
749	32	20	4.6	14																	0.14
987	40	30	6.8	32																	0.17
1400	39	22	6.1	23																	0.16
1789	45	32	7.0	28																	0.16
1668	48	28	8.8	31		2.80	37.80	0.09	0.05	61	58							3.14	0.15		0.18
1699	40	20	8.6																		0.22
1334	40	20	9.6	30																	0.24
1147	39	15	11.2	31																	0.29
1140	40	22	12.0	37																	0.30
1480	52	25	5.8	41																	0.11
1903	95	25	30.0	62		3.50	42.00	0.04	0.11	53	50	116						8.57	0.57		0.32
1990	92	20	36.0	68																	0.39
2049	102	28	37.0	81																	0.36
1664	88	20	28.0	70																	0.32
1748	103	24	39.0	78																	0.38
1547	98	28	26.0	80																	0.27
1440	108	38	18.6	90																	0.17
1770	100	28	32.0	74		4.80	28.10	0.03	0.11	48	43							6.67	0.67		0.32
2190	78	22	12.6	61																	0.16
2542	64	22	12.4	53																	0.19
3193	42	20	7.9	48																	0.19
3396	55	22		46																	0.00
3436	52	20	11.5	48																	0.22
3440	38	16	6.1	32																	0.16
3458	32	15	3.6	20		2.70	7.30	0.01	0.06	43	42							1.33	0.08		0.11
3430	30	20	6.4	26																	0.21
5222	32	30	4.5	22																	0.14
4726	35	32	5.2	22																	0.15
4260	40	30	5.3	11																	0.13
4837	40	28	6.0	15																	0.15
4824	35	22	6.9	18																	0.20
4175	50	34	5.7	20		2.10	0.00	0.00	0.00	46	46							2.71	0.12		0.11
4385	35	29	5.7	17																	0.16
4374	32	25	9.4	15																	0.29
6175	52	30	11.4	14																	0.22
6022	50	40	12.2	22																	0.24
5928	48	30	9.4	31																	0.20
6116	40	29	8.4	19		2.30	0.02	0.01	0.07	58	57							3.65	0.15		0.21
6312	31	22	8.4	26																	0.27
6207	29	28	5.7	21																	0.20
6087	38	25	6.1	12																	0.16
6085	50	30	6.9	12																	0.14
6183	42	38	13.3	26																	0.32
6183	62	40	13.6	31																	0.22
4637	50	32	15.3	31																	0.31
4515	56	40	13.3	35		3.50	0.01	0.01	0.19	80	78	302						3.80	0.17		0.24
6284	60	50	18.4	32																	0.31
7013	55	40	14.4	19																	0.26
7490	52	32	12.7	28																	0.24
7529	50	39	5.8	29																	0.12
7109	42	40	4.3	23																	0.10
6605	32	29	3.2	21																	0.10
6313	35	30	3.5	9		1.60	0.00	0.00	0.10	82	77							2.19	0.04		0.10
5572	42	40	5.2	16																	0.12
6117	50	40	6.7	29																	0.13
4105	38	35	5.3	25																	0.14
5684	35	33	5.2	22																	0.15
5509	33	30	4.1	19																	0.12
5572	40	22	5.0	15																	0.13
5462	30	28	5.7	10		2.80	0.05	0.04	0.70	88	90							2.04	0.06		0.19
6588	35	100	4.9	19																	0.14
6618	32	26	6.4	23																	0.20
6658	35	33	5.5	22																	0.16
6677	39	36	8.8	29																	0.23
7077	52	38	10.0	24																	0.19
5523	52	32	13.0	26																	0.25
7071	79		12.6																		0.16
6996	60	40	13.8	26		3.80	0.11	0.04		89	87							3.63	0.15		0.23
6482	48	37	8.7	22																	0.18
6641	47	36	11.0	25																	0.23
6319	42	38	12.3	20																	0.29
6299	46	38	8.1	24																	0.18
6618	49	44	14.7	30																	0.30
6881	49	30	14.6	24		5.00	1.06	0.14	2.40	101	94	283						2.92	0.14		0.30

Flow	COD	sol COD	BOD	SS	RG Fat	TKN	Nitrate	Nitrite	Ammonia	TP	DRP	Sulphur	Iron	Calcium	Sodium	Potassium	Magnesium	BOD/N	BOD/P	BOD/Fe	BOD/COD
m3/d	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l				
6976	53	33	15.3	33																	0.29
6859	84	38	29.2	31																	0.35
6704	88	49	17.6	46																	0.20
6611	80	63	14.0	50																	0.18
6741	62	50	14.8	31																	0.24
6714	58	38	13.8	28																	0.24
6549	47	32	15.5	33		2.70	0.06	0.01	0.06	97	93							5.74	0.16		0.33
6877	39	33	11.3	24																	0.29
7567	40	32	18.2	17																	0.46
7349	45	30	13.6	12																	0.30
7244	39	32	15.4	29																	0.39
7090	32	28	6.4	24																	0.20
6414	33	30	5	22	0.01	1.90	0.05	0.01	0.06	93	92	351	0.39					2.47	0.05	12.05	0.14
6358	37	30	4	18	0.00	1.60	0.05	0.01	0.10	105	97	357	0.37					2.50	0.04	10.81	0.11
5772	38	30	4	13	0.00	1.80	0.06	0.00	0.04	99	97	353	0.44					2.06	0.04	8.41	0.10
6137	35	28	3	11	0.01	1.80	0.00	0.00	0.01	103	97	355	0.45					1.83	0.03	7.33	0.09
6351	30	29	3	12	0.01	1.80	0.08	0.00	0.02	98	93	346	0.53					1.50	0.03	5.09	0.09
6321	22	28	3	8	0.00	1.90	0.17	0.01	0.08	94	95	341	0.62					1.79	0.04	5.48	0.15
6491	22	20	5	16	0.00	1.90	0.24	0.02	0.11	100	94	338	0.69					2.53	0.05	6.96	0.22
6644	22	22	5	15	0.00	2.00	0.19	0.02	0.11	94	92	322	0.65					2.60	0.06	8.00	0.24
6387	32	30	4	6	0.00	2.10	0.46	0.05	0.22	95	90	290	0.83					2.00	0.04	5.06	0.13
6622	32	32	6	11	0.02	2.30	0.65	0.05		97	93							2.61	0.06		0.19
6983	36	38	5	16	0.00	2.20	0.49	0.03	0.25	105	90	310	0.73					2.41	0.05	7.26	0.15
6722	32	30	6	22	0.01	2.10	0.29	0.02	0.18	106	85	182	0.44					2.67	0.05	12.73	0.18
7030	25	25	6	20	0.01	2.50	0.45	0.05	0.36	102	93	321	0.71					2.24	0.05	7.89	0.22
7389	28	28	8	20	0.01	2.70	0.58	0.17	0.50	89	91	334	0.61					2.85	0.09	12.62	0.28
7121	60	35	7	9																	0.11
6581	35	32	9	14		3.10	0.88	0.10	0.72	91	96							2.84	0.10		0.25
6608	38	32	12	24																	0.31
7113	30	25	13	22																	0.44
6886	33	28	7	15																	0.20
7420	58	30	11	46																	0.18
7009	60	30	19	34																	0.31
6839	48	32	10	22																	0.20
6657	38		15	29		3.00	0.59	0.07	0.52	79.3 0	75.4 0							5.00	0.19		0.39
6399	40	38	15	23																	0.39
6801	50	22	14	37																	0.28
6749	32	28	12	25																	0.39
7408	42	32	9	19																	0.21
7123	39	32	5	17																	0.12
7059	39	30	5	24																	0.13
6973	35	28	6	25		2.40	0.15	0.01	0.12	88.1 0	91.8 0							2.33	0.06		0.16
6971	32	23	4	21																	0.13
7203	32	24	4	28																	0.13
7393	32	25	4	18																	0.14
7097	32	22	5	14																	0.14
6987	30	22	6	16																	0.19
7216	32	23	6	19																	0.17
6989	31	24	5	26																	0.17
6865	30	27	6	18																	0.18
6236	32	20	6	12																	0.19
6492	32	22	5	17																	0.14
6610	29	20	5	27																	0.18
6851	32	28	4	27		2.30	0.35	0.01	0.19	91	90	318	0.71					1.70	0.04	5.49	0.12
6939	31	25	5	30																	0.16
7224	30	27	5	29																	0.17
7040	38	29	5	13																	0.14
6701	32	22	5	15																	0.15
6806	32	25	6	26																	0.18
7070	32	20	3.5	18																	0.11
6951	34	28	3.3	18																	0.10
6556	32	22	4.9	15		2.10	0.52	0.00	0.16	96	90	324						2.33	0.05		0.15
6265	30	26	5.6	14																	0.19
6170	32		4.2	26																	0.13
6272	32	30	3.6	14																	0.11
6261	28	22	4.0	8																	0.14
6296	22	18	3.2	18																	0.15
6420	20	22	3.6	20																	0.18
6415	20	20	5.3	15																	0.27
7238	49	35	2.6	5		1.10	0.03	0.01	0.02	83	84	369		42.80	561.00	145.00	5.94	2.36	0.03		0.05
6423	25	25	3.3	28																	0.13
6647	30	22	6.3	11																	0.21
6467	30	30	4.3	30																	0.14
6860	20	22																			
7335	28	30		20																	
6844	35	30		21																	
6825	32	29		17																	
6635	22	58		13																	
6621	20			24																	
6350	24	24		23																	
4287	111	22		89																	
5125	30	22		16																	
iore																					
6690	34	27	6.2	20	0.01	2.1	0.31	0.03	0.20	95	91	326	0.58	43	561	145	5.94	2.43	0.06	8.23	0.18
2230	18	9	6.7	15	0.01	0.9	11.98	0.04	0.44	18	17	64	0.15					1.66	0.14	2.76	0.09
7567	111	100	39	90	0.02	5.0	42	0.17	2.40	106	97	369	0.83	43	561	145	5.94				

Waste Activated sludge Trucking Over the Period Studied.

Date	TS % m/m	Sludge (m3/d)	TSkg/d	Date	TS % m/m	Sludge (m3/d)	TSkg/d	Date	TS % m/m	Sludge (m3/d)	TSkg/d
01/08/96		36		13/09/96	2.40	290	6960	24/10/96	2.32	445	10324
02/08/96		54		14/09/96	2.16	300	6480	25/10/96	2.22	460	10212
03/08/96		36		15/09/96	2.45	300	7350	26/10/96	2.18	455	9919
04/08/96		0		16/09/96	2.38	300	7140	27/10/96	2.22	450	9990
05/08/96		628		17/09/96	2.26	300	6780	28/10/96	2.21	450	9945
06/08/96		54		18/09/96	2.25	325	7313	29/10/96	2.22	450	9990
07/08/96		54		19/09/96	2.42	350	8470	30/10/96	2.43	575	13973
08/08/96		125		20/09/96	2.20	300	6600	31/10/96	2.00	325	6500
09/08/96		225		21/09/96	2.30	325	7475	01/11/96	2.08	450	9360
12/08/96		215		22/09/96	2.25	360	8100	02/11/96	2.07	450	9315
13/08/96		240		23/09/96	2.24	350	7840	03/11/96	2.39	450	10755
14/08/96		240		24/09/96	2.29	350	8015	04/11/96	2.46	475	11685
15/08/96		236		25/09/96	1.80	345	6210	05/11/96	2.54	475	12065
16/08/96		265		26/09/96	1.99	355	7065	06/11/96	2.35	475	11163
17/08/96		250		27/09/96	2.05	345	7073	07/11/96	2.64	475	12540
18/08/96		250		28/09/96	1.99	350	6965	08/11/96	2.44	490	11956
19/08/96		250		29/09/96	1.99	350	6965	09/11/96	2.19	475	10403
20/08/96		250		30/09/96	2.08	350	7280	10/11/96	2.52	475	11970
21/08/96		305		01/10/96	2.05	350	7175	11/11/96	2.20	490	10780
22/08/96		300		02/10/96	2.10	375	7875	12/11/96	2.26	475	10735
23/08/96		300		03/10/96	2.43	325	7898	13/11/96	2.15	515	11073
24/08/96		300		04/10/96	2.16	355	7668	14/11/96	2.25	530	11925
25/08/96		300		05/10/96	2.82	450	12690	15/11/96	2.08	475	9880
26/08/96		300		06/10/96	2.12	300	6360	16/11/96	2.26	480	10848
27/08/96		300		07/10/96	2.13	400	8520	17/11/96	2.26	475	10735
28/08/96		295		08/10/96	2.24	500	11200	18/11/96	2.03	455	9237
29/08/96	2.80	305	8540	09/10/96	2.66	425	11305	19/11/96	2.01	475	9548
30/08/96	2.62	300	7860	10/10/96	2.32	375	8700	20/11/96	1.96	525	10290
31/08/96	2.00	400	8000	11/10/96	2.18	430	9374	21/11/96	2.06	525	10815
01/09/96	2.30	375	8625	12/10/96	2.10	405	8505	22/11/96	2.13	375	7988
02/09/96	2.41	290	6989	13/10/96	2.23	375	8363	23/11/96	2.51	525	13178
03/09/96	2.77	300	8310	14/10/96	2.08	405	8424	24/11/96	2.47	455	11239
04/09/96	3.00	300	9000	15/10/96	2.33	400	9320	25/11/96	2.11	475	10023
05/09/96	2.66	295	7847	16/10/96	2.35	415	9753				
06/09/96	2.49	305	7595	17/10/96	2.23	450	10035	min	1.80	0	0
07/09/96	2.47	300	7410	18/10/96	2.17	475	10308	max	3.00	628	13973
08/09/96	2.44	305	7442	19/10/96	2.16	425	9180	avg	2.28	361	8997
09/09/96	2.50	305	7625	20/10/96	2.24	450	10080				
10/09/96	2.20	290	6380	21/10/96		450	0				
11/09/96	2.17	300	6510	22/10/96	2.42	470	11374				
12/09/96	2.24	300	6720	23/10/96	2.26	500	11300				

Sludge Trucking to Irrigation

5/08/96	6.48	1050	29022	2.6	526.7	195.5	40.1	33.3	1730	787.4	<0.04	162.8	0.6
19/08/96	6.59	2140	28702	2.6	644	191.6	185	33.2	1790	827.7	<0.34	166.4	0.6
2/09/96	6.73	2160	23400	2.3	598	211.1	48.1	32.3		677.4	<0.04	116.8	0.6
16/09/96	6.6	1530		2.4	692	254	60.2	36.8	1630	777	<0.03	191.2	0.6
30/09/96	6.9	1760	20814	2.2	624	223	52.1	26.2	1430	741	0	138.1	0.6
14/10/96	6.92	1320	21920	2.2									
29/10/96	6.96	2710	24545	2.5	531	313	45.9	21.7	1130	777	0	161	
11/11/96	6.75	3080	20909	2.2									
8/12/96	6.8	2300	19886	2.1	626	303	57.3	26.9	780	684	0.1	131	6.7
average	6.74	1969	24187	2.4	603	231	72	31	1542	764.6	0.03	156.1	0.6

Dynamic Sludge Age Report

Printed: 02/03/97 For Date Range: 19/09/96 to 25/11/96

Sample Date	Days Elapsed	Ponds One Volume m3	Ponds One Susp. Solids g/m3	Ponds Two Susp. Solids g/m3	Trucking Sludge m3	Trucking Total Solids %	Mass Sludge in System 1000s kgs	Mass Waste Rate 1000s kgs/day	Mass Sludge in System 1000s lbs	Mass Waste Rate 1000s lbs/day	Rate of Change in Mass K	Sludge Production Rate P	Dynamic Sludge Age DSA	Traditional Sludge Age TSA
19/09/96		43000	5905	5915	350	2.42	254	8	560	19			30.00	30.00
20/09/96	2	44000	5340	6000	300	2.20	249	7	550	15	-5.13	9.42	30.97	37.80
21/09/96	1	44000	6285	5655	325	2.30	263	7	579	16	29.10	45.58	29.53	35.14
22/09/96	1	44000	5435	5865	360	2.25	249	8	548	18	-31.04	-13.18	31.24	30.69
23/09/96	1	46500	5295	5070	350	2.24	241	8	531	17	-16.79	0.50	32.21	30.74
24/09/96	1	45500	5770	5230	350	2.29	250	8	552	18	20.42	38.09	30.99	31.22
25/09/96	1	45500	5255	5605	345	1.80	247	6	545	14	-7.02	6.67	31.61	39.79
26/09/96	1	45500	5580	5370	355	1.99	249	7	549	16	4.51	20.09	31.45	35.26
27/09/96	1	46000	5680	5690	345	2.05	262	7	577	16	27.33	42.92	30.10	36.98
28/09/96	1	46000	5270	5320	350	1.99	244	7	537	15	-39.55	-24.20	32.46	34.97
29/09/96	1	46000	5485	5560	350	1.99	254	7	560	15	23.07	38.43	31.23	36.47
30/09/96	1	44000	5465	5585	350	2.08	243	7	536	16	-24.11	-8.06	32.70	33.39
01/10/96	1	44000	5770	6025	350	2.05	259	7	572	16	36.13	51.95	30.73	36.17
02/10/96	1	44000	5700	5680	375	2.10	250	8	552	17	-20.13	-2.77	31.88	31.79
03/10/96	1	44000	5860	5905	325	2.43	259	8	571	17	18.67	36.08	30.86	32.77
04/10/96	1	44000	6045	6185	355	2.16	269	8	593	17	22.55	39.46	29.81	35.09
05/10/96	1	45000	5985	5800	450	2.82	265	13	585	28	-8.59	19.38	29.83	20.90
06/10/96	1	46500	6095	5930	300	2.12	280	6	616	14	31.79	45.81	28.60	43.96
07/10/96	1	46500	6190	6025	400	2.13	284	9	626	19	9.74	28.52	28.29	33.33
08/10/96	1	46500	6615	5890	500	2.24	291	11	641	25	14.86	39.56	27.55	25.96
09/10/96	1	46000	6125	6255	425	2.66	285	11	628	25	-13.23	11.69	28.04	25.19
10/10/96	1	46500	5950	5960	375	2.32	277	9	610	19	-17.27	1.91	28.95	31.83
11/10/96	1	46500	6230	5880	430	2.18	282	9	621	21	10.25	30.92	28.51	30.04
12/10/96	1	46500	5825	5545	405	2.10	264	9	583	19	-37.93	-19.18	30.45	31.08
13/10/96	1	46000	5945	5590	375	2.23	265	8	585	18	2.10	20.54	30.38	31.73
14/10/96	1	45500	5850	5645	405	2.08	262	8	577	19	-8.36	10.21	30.84	31.04
15/10/96	1	45000	6235	6055	400	2.33	277	9	610	21	33.10	53.65	29.13	29.67
16/10/96	1	45000	5695	5940	415	2.35	262	10	577	22	-32.49	-10.99	30.68	26.84
17/10/96	1	46000	5555	5710	450	2.23	259	10	571	22	-5.94	16.19	30.81	25.82
18/10/96	1	46000	5675	5570	475	2.17	259	10	570	23	-1.01	21.71	30.65	25.09
19/10/96	1	45500	5340	5425	425	2.16	245	9	540	20	-30.27	-10.03	32.21	26.68
20/10/96	1	46000	5410	5720	450	2.24	256	10	564	22	24.44	46.66	30.56	25.40
21/10/96	1	46000	5740	5580	450	0.00	260	0	574	0	9.63	9.63	31.04	#DIV/0!
22/10/96	1	46500	5510	5540	470	2.42	257	11	566	25	-7.60	17.47	31.09	22.59
23/10/96	1	46500	5470	5630	500	2.26	258	11	569	25	2.56	27.48	30.60	22.84
24/10/96	1	46000	5750	5680	445	2.32	263	10	580	23	10.62	33.38	29.84	25.46
25/10/96	1	45500	5415	5430	460	2.22	247	10	544	23	-35.64	-13.13	31.56	24.16
26/10/96	1	46000	6515	5790	455	2.18	283	10	624	22	80.01	101.88	27.42	28.53
27/10/96	1	46000	5685	5515	450	2.22	258	10	568	22	-56.03	-34.01	30.06	25.79
28/10/96	1	46500	5515	5500	450	2.21	256	10	565	22	-3.31	18.62	30.07	25.75
29/10/96	1	46500	5370	5490	450	2.22	252	10	557	22	-7.94	14.08	30.31	25.27
30/10/96	1	47000	5600	5500	575	2.43	261	14	575	31	18.42	49.22	28.74	18.67
31/10/96	1	44500	5905	5690	325	2.00	258	7	569	14	-6.31	8.02	29.34	39.69
01/11/96	1	44500	5605	5740	450	2.08	252	9	557	21	-12.26	8.37	29.90	26.97
02/11/96	1	44000	5645	5825	450	2.07	252	9	556	21	-0.19	20.35	29.80	27.09
03/11/96	1	44000	5700	5570	450	2.39	248	11	547	24	-9.70	14.01	30.04	23.05
04/11/96	1	44000	5645	5685	475	2.46	249	12	550	26	2.91	28.67	29.49	21.33
05/11/96	1	43500	5915	5605	475	2.54	251	12	552	27	2.87	29.46	28.93	20.77
06/11/96	1	43500	5875	5770	475	2.35	253	11	558	25	5.99	30.60	28.35	22.69
07/11/96	1	44000	6100	5865	475	2.64	263	13	580	28	21.94	49.58	26.94	20.99
08/11/96	1	44000	5850	5795	490	2.44	256	12	565	26	-15.52	10.84	27.43	21.43
09/11/96	1	44000	5835	5835	475	2.19	257	10	566	23	1.21	24.15	27.26	24.68
10/11/96	1	42000	6000	5910	475	2.52	250	12	551	26	-14.62	11.77	27.68	20.89
11/11/96	1	44000	5820	6085	490	2.20	262	11	577	24	26.01	49.78	26.30	24.30
12/11/96	1	45000	5845	5975	475	2.26	266	11	586	24	8.91	32.57	25.84	24.77
13/11/96	1	44500	5630	5645	515	2.15	251	11	553	24	-33.25	-8.84	27.25	22.66
14/11/96	1	45500	5895	5770	530	2.25	265	12	585	26	31.99	58.28	25.55	22.25
15/11/96	1	45500	6155	5820	475	2.08	272	10	601	22	15.55	37.33	24.96	27.57
16/11/96	1	44000	5740	5390	480	2.26	245	11	540	24	-60.78	-36.87	27.66	22.57
17/11/96	1	45500	5870	5165	475	2.26	251	11	553	24	13.64	37.30	26.80	23.39
18/11/96	1	46500	5730	5545	455	2.03	262	9	578	20	24.47	44.83	25.72	28.38
19/11/96	1	47500	5500	5610	475	2.01	264	10	582	21	3.79	24.84	25.62	27.64
20/11/96	1	46500	6095	5555	525	1.96	271	10	597	23	15.43	38.12	24.99	26.32
21/11/96	1	46000	5650	5645	525	2.06	260	11	573	24	-24.42	-0.58	26.01	24.02
22/11/96	1	44000	6085	5850	375	2.13	263	8	579	18	6.14	23.75	25.94	32.87
23/11/96	1	45000	5935	6130	525	2.51	271	13	598	29	19.60	48.66	24.84	20.60
24/11/96	1	55000	4675	5325	455	2.47	275	11	606	25	7.80	32.58	24.51	24.47
25/11/96	1	54000	5345	5135	475	2.11	283	10	624	22	17.55	39.64	23.95	28.23

APPENDIX III. **Cleaning Chemical Balance**

Site Chemical usage - (bulk)										
Date	Hypochlorite Cheese factory	Ammonia Cheese factory	Caustic Milk reception	Triplex Milk reception	C20 Main compd	Chlorosolv Main compd	Nitric Main compd	Caustic Main compd	Triplex Main compd	Sulphuric Main compd
Sodium g/l	27		437		8	119		437		
chlorine g/l	41					6				
nitrogen g/l		117					213			
Sulphur g/l										589
Phosphorus g/l				31					31	
Actual usage (litres)										
17/9/96-31/9/96	3000	6950	1800	9400	50530	7000	3700	91815	59460	41950
1/10/96-31/10/96	7900	13250	4990	14550	104420	11655	5700	247625	125060	107630
1/11/96-25/11/96	2000	9800	6950	13620	72200	7470	1300	175415	86260	78055
Nutrients to Plants										
	17/9/96-31/9/96									
Sodium kg	81		786		419			40116		
chlorine kg	124					45				
nitrogen kg		816					790			
Sulphur kg										24688
Phosphorus kg				294					1861	
	1/10/96-31/10/96									
Sodium kg	213		2180		866			40116		
chlorine kg	328					74				
nitrogen kg		1556					1217			
Sulphur kg										63340
Phosphorus kg				455					3914	
	1/11/96-25/11/96									
Sodium kg	54		3037		599	890		76642		
chlorine kg	83					48				
nitrogen kg		1151					277			
Sulphur kg										45935
Phosphorus kg				426					2700	

Total to Plants	**17/9/96-31/9/96**	**1/10/96-31/10/96**	**1/11/96-25/11/96**	**Total**
Sodium kg	41402	43375	81221	165998
chlorine kg	169	402	131	702
nitrogen kg	1606	2772	1428	5806
Sulphur kg	24688	63340	45935	133963
Phosphorus kg	2155	4370	3126	9651
Total to WTP				
Sodium kg	62258	65564	62626	190449
chlorine kg				
nitrogen kg	8667	6096	8235	22998
Sulphur kg	40837	39747	47199	127783
Phosphorus kg	14150	13329	16287	43766
Total to WTP/d				**average**
Sodium kg/d	4151	4371	4175	4232
chlorine kg/d				
nitrogen kg/d	578	406	549	511
Sulphur kg/d	2722	2650	3147	2840
Phosphorus kg/d	943	889	1086	973
Unknown source to WTP				
Sodium kg/d	20856	22190	-18595	24451
chlorine kg/d				
nitrogen kg/d	7061	3323	6807	17192
Sulphur kg/d	16150	-23593	1264	-6180
Phosphorus kg/d	11994	8959	13161	34115

APPENDIX IV. **ASIM Variation Data**

Variation data for INFLUENT for the ASIM model: Waitoa

Date	Influen Vol m3/day	RAS vol m3/day	Dx day-1	SI mg/l	Ss mg/l	Snh mg/l	Sno mg/l	Xs mg/l	XI mg/l	Tem °C
Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.62
S.E.	0.09	0.04	0.17	0.15	0.19	0.23	0.19	0.24	0.15	1.31
17-Sep-96	0.845	0.910	0.745	0.994	0.915	1.130	1.409	1.091	0.994	1.6
18-Sep-96	0.899	0.919	0.687	1.076	0.944	1.284	1.228	1.238	1.076	1.6
19-Sep-96	1.076	0.924	0.842	1.068	1.110	1.439	1.820	1.015	1.068	-0.2
20-Sep-96	1.092	0.922	0.791	0.570	0.562	0.581	0.711	0.581	0.570	-1.6
21-Sep-96	1.010	0.920	0.740	0.978	0.705	0.879	0.999	1.314	0.978	-1.3
22-Sep-96	1.076	0.925	0.905	1.059	0.959	1.313	1.099	1.182	1.059	0.1
23-Sep-96	1.091	0.918	0.888	1.141	1.184	1.091	1.243	1.088	1.141	1.6
24-Sep-96	0.973	0.923	0.851	1.002	0.734	0.989	1.278	1.332	1.002	1.9
25-Sep-96	1.130	0.934	0.869	0.986	0.885	1.203	1.003	1.110	0.986	1.2
26-Sep-96	0.936	0.941	0.697	1.019	0.885	1.303	0.851	1.183	1.019	0.1
27-Sep-96	1.073	0.932	0.713	1.051	1.171	1.562	1.748	0.904	1.051	1.4
28-Sep-96	0.969	0.919	0.800	1.068	1.155	1.417	0.643	0.959	1.068	1.7
29-Sep-96	0.927	0.918	0.745	1.149	1.048	1.554	0.874	1.273	1.149	0.1
30-Sep-96	0.875	0.943	0.778	0.962	0.916	1.035	0.925	1.018	0.962	0.1
01-Oct-96	1.076	0.924	0.762	0.921	1.173	0.847	1.000	0.610	0.921	0.9
02-Oct-96	0.933	0.937	0.834	1.051	1.337	1.035	1.000	0.700	1.051	1.6
03-Oct-96	1.073	0.939	0.716	1.149	1.169	1.175	1.000	1.125	1.149	1.5
04-Oct-96	1.208	0.965	0.871	1.206	1.183	1.257	1.000	1.235	1.206	1.3
05-Oct-96	1.115	0.979	0.996	1.239	1.333	1.304	1.000	1.123	1.239	1.3
06-Oct-96	1.198	0.962	0.676	1.059	1.065	1.046	1.000	1.052	1.059	1.0
07-Oct-96	1.183	0.956	0.811	1.076	1.170	1.070	1.000	0.959	1.076	1.1
08-Oct-96	0.974	0.981	0.995	0.896	1.038	0.812	1.000	0.722	0.896	-0.2
09-Oct-96	0.921	0.994	0.908	0.888	0.797	0.800	1.000	1.001	0.888	0.2
10-Oct-96	1.104	0.987	0.979	0.815	0.889	0.695	1.000	0.724	0.815	0.8
11-Oct-96	1.084	0.990	0.963	0.978	1.097	0.929	1.000	0.832	0.978	1.2
12-Oct-96	1.021	1.001	0.907	1.059	1.050	1.046	1.000	1.071	1.059	2.3
13-Oct-96	1.043	1.009	0.808	1.068	1.216	1.058	1.000	0.885	1.068	1.5
14-Oct-96	1.046	1.015	0.938	0.978	1.036	0.929	1.000	0.906	0.978	0.4
15-Oct-96	0.995	1.009	0.817	0.962	1.067	0.906	1.000	0.832	0.962	1.4
16-Oct-96	1.099	1.004	1.003	0.913	0.902	0.835	1.000	0.926	0.913	0.9
17-Oct-96	1.110	0.995	1.109	0.799	0.753	0.671	1.000	0.854	0.799	1.5
18-Oct-96	1.145	1.003	1.113	1.002	1.036	0.964	1.000	0.961	1.002	1.7
19-Oct-96	1.147	1.015	1.023	0.978	1.157	0.929	1.000	0.757	0.978	1.7
20-Oct-96	1.044	1.003	1.032	0.896	0.872	0.812	1.000	0.926	0.896	1.9
21-Oct-96	1.021	1.005	1.052	0.815	0.859	0.695	1.000	0.761	0.815	2.7
22-Oct-96	1.086	1.004	1.153	0.921	0.932	0.847	1.000	0.907	0.921	2.9
23-Oct-96	0.981	1.000	1.274	0.733	0.755	0.577	1.000	0.707	0.733	2.2
24-Oct-96	0.962	1.013	1.039	0.831	0.889	0.718	1.000	0.761	0.831	2.0
25-Oct-96	1.001	1.013	1.175	0.888	0.737	0.800	1.000	1.075	0.888	1.5
26-Oct-96	1.033	1.014	0.970	1.076	0.808	1.070	1.000	1.405	1.076	2.9
27-Oct-96	0.978	0.999	1.035	0.880	0.903	0.788	1.000	0.852	0.880	2.7
28-Oct-96	1.112	0.993	1.060	0.799	0.874	0.979	0.005	0.706	0.799	3.1
29-Oct-96	1.059	1.006	1.070	1.076	0.899	1.070	1.000	1.293	1.076	3.6
30-Oct-96	0.971	1.019	1.330	1.002	0.991	0.964	1.000	1.017	1.002	2.7
31-Oct-96	0.860	1.010	0.832	0.905	0.706	0.824	1.000	1.149	0.905	0.4
01-Nov-96	1.026	1.020	0.969	0.815	0.738	0.695	1.000	0.910	0.815	1.0
02-Nov-96	1.005	1.037	1.008	0.815	0.783	0.695	1.000	0.854	0.815	1.8
03-Nov-96	1.078	1.030	1.021	0.978	1.021	0.929	1.000	0.924	0.978	1.2

04-Nov-96	0.949	1.027	1.237	0.994	1.036	0.953	1.000	0.943	0.994	1.5
05-Nov-96	0.947	1.035	1.267	1.467	0.861	1.020	0.806	2.213	1.467	0.2
06-Nov-96	0.921	1.032	1.294	0.896	1.053	0.812	1.000	0.703	0.896	1.0
07-Nov-96	0.978	1.006	1.152	1.206	1.168	1.257	1.000	1.253	1.206	0.3
08-Nov-96	1.001	1.032	1.372	1.051	0.929	1.035	1.000	1.201	1.051	-0.3
09-Nov-96	0.917	1.023	1.226	0.896	0.963	0.812	1.000	0.815	0.896	-0.3
10-Nov-96	0.918	1.035	1.130	0.733	0.830	0.577	1.000	0.614	0.733	-0.5
11-Nov-96	1.057	1.041	1.281	0.896	0.782	0.812	1.000	1.038	0.896	0.3
12-Nov-96	1.032	1.030	1.068	0.896	0.736	0.812	1.000	1.093	0.896	0.7
13-Nov-96	1.023	1.034	1.254	1.068	1.035	1.197	1.330	1.108	1.068	0.0
14-Nov-96	1.067	1.032	1.167	0.815	1.009	0.695	1.000	0.575	0.815	1.1
15-Nov-96	0.954	1.030	1.066	1.214	1.047	1.269	1.000	1.420	1.214	1.8
16-Nov-96	1.021	1.033	1.108	1.141	0.867	1.164	1.000	1.477	1.141	1.5
17-Nov-96	0.959	1.024	1.162	0.815	0.738	0.695	1.000	0.910	0.815	1.5
18-Nov-96	0.959	1.032	1.066	1.059	1.005	1.046	1.000	1.127	1.059	2.3
19-Nov-96	0.959	1.034	0.993	1.059	1.005	1.334	0.531	1.127	1.059	0.8
20-Nov-96	0.989	1.024	1.015	1.059	0.914	1.046	1.000	1.238	1.059	0.9
21-Nov-96	0.966	1.028	1.076	1.059	1.035	1.046	1.000	1.090	1.059	1.2
22-Nov-96	0.941	1.032	0.807	1.076	1.072	1.070	1.000	1.080	1.076	1.0
23-Nov-96	1.116	1.027	1.120	1.173	1.183	1.210	1.000	1.161	1.173	0.2
24-Nov-96	1.117	1.023	1.171	0.750	0.890	0.601	1.000	0.577	0.750	0.8
25-Nov-96	0.959	1.024	1.085	1.051	1.186	1.035	1.000	0.886	1.051	1.4
26-Nov-96	1.020	1.022	0.981	0.978	1.036	1.348	0.578	0.906	0.978	1.9
27-Nov-96	0.934	1.009	1.062	1.059	1.020	1.046	1.000	1.108	1.059	0.8
28-Nov-96	0.877	0.994	0.933	1.157	1.259	1.187	1.000	1.032	1.157	1.9
29-Nov-96	0.788	1.009	1.173	1.027	0.945	0.999	1.000	1.127	1.027	0.3
30-Nov-96	1.050	1.025	1.250	1.059	1.352	1.046	1.000	0.700	1.059	3.1
01-Dec-96	1.049	1.029	0.883	0.807	0.738	0.683	1.000	0.891	0.807	2.8
02-Dec-96	0.800	1.039	1.003	1.059	1.261	1.046	1.000	0.811	1.059	3.0
03-Dec-96	1.038	1.033	1.029	0.970	1.052	0.942	0.948	0.869	0.970	3.1
04-Dec-96	0.899	1.020	0.724	1.059	0.899	1.046	1.000	1.257	1.059	3.2
05-Dec-96	0.866	1.027	0.799	0.823	0.798	0.706	1.000	0.854	0.823	3.3
06-Dec-96	0.887	1.023	1.128	0.978	0.720	0.929	1.000	1.296	0.978	3.4
07-Dec-96	0.932	1.033	0.946	0.962	0.931	0.906	1.000	0.999	0.962	3.5
08-Dec-96	0.805	1.041	0.931	0.896	1.023	0.812	1.000	0.741	0.896	3.7
09-Dec-96	0.867	1.028	1.036	0.856	0.873	0.753	1.000	0.834	0.856	3.9
10-Dec-96	0.935	1.029	1.315	1.059	1.035	0.965	0.975	1.090	1.059	4.4
11-Dec-96	0.946	1.025	0.969	0.896	1.023	0.812	1.000	0.741	0.896	5.0
12-Dec-96	0.840	1.028	1.137	0.962	0.961	0.906	1.000	0.962	0.962	4.0
13-Dec-96	0.866	1.029	1.139	1.100	1.049	1.105	1.000	1.163	1.100	4.1
14-Dec-96	1.224	1.030	0.860	1.263	1.544	1.339	1.000	0.918	1.263	3.8
15-Dec-96	0.924	1.041	1.179	1.141	1.486	1.164	1.000	0.716	1.141	3.9
16-Dec-96	0.997	1.019	0.946	1.230	1.484	1.293	1.000	0.919	1.230	2.7
17-Dec-96	1.013	1.028	1.019	1.308	1.415	1.404	1.000	1.177	1.308	2.5
18-Dec-96	1.031	1.020	1.141	1.385	1.345	1.515	1.000	1.435	1.385	2.1