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Nutrient removal from abbatoir wastewater

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Nutrient Removal From Abattoir Wastewater

MRC Project : M.478 / CRC WMPC Project 10.2

EXECUTIVE SUMMARY

Project M.478 for the Meat Research Corporation, involved the development and testing of a treatment pond and a pilot scale Sequencing Batch Reactor (SBR) for the improved removal of nutrients, specifically nitrogen and phosphorous, from abattoir wastewater.

The project was undertaken during 1995-1996 by the CRC for Waste Management and Pollution Control through the Advanced Wastewater Management Centre at the University of Queensland. The work was based at the Dinmore abattoir of Australia Meat Holdings Pty. Ltd. in Queensland. It incorporated two independent treatment methods, which were both investigated over a period of approximately one year.

The two methods researched through this project were the use of:

- an experimental pond, targeting a 60-70% removal of nitrogen from abattoir wastewater to produce effluent suitable for discharge onto land; and
- a transportable sequencing batch reactor (SBR) with the objective of maximising nitrogen and phosphorus removal, to produce effluent suitable for discharge to waterways.

The experimental pond was 1 Megalitre (ML) in size and operated for 12 months on a continuous basis. It comprised a single pond consisting of three zones - an anoxic/anaerobic zone, an aerated zone and a settling zone. Experiments performed using this pond showed that the design was technically feasible and successful in achieving bulk nitrogen removal of 60 - 70% at a hydraulic retention time of 8 days to give effluent total nitrogen concentrations of 70 mg/l or less. . The effluent produced was suitable for irrigation and associated storage purposes and would reduce the land requirement for most abattoir irrigation systems by 2 - 3 times. It was found that the pond only required a minimum of supervision with operator attendance on a weekly to fortnightly basis. Due to the relatively high hydraulic residence time, variations in feed quality and quantity did not ultimately affect the overall performance of the pond.

Key features of the pond can be summarised as a high level of operational robustness, consistent nitrogen removal and excellent reduction in total suspended solids in the effluent from more than 1,500 mg/l in the pond basin to less than 150 mg/l in the effluent. No phosphorus removal was observed (or expected).

The SBR consisted of two identical, six cubic meter tanks, each a self contained sequencing batch reactor, allowing independent operation from each other and permitting a greater coverage of experimental parameters throughout the test period. Operated in an intermittent fashion with six hour cycle times, the different phases of

cyclic operation of the SBR provided the conditions necessary for the removal of both nitrogen and phosphorus. Experiments performed over the test period confirmed the ability of the SBR to remove total nitrogen up to 90%, achieving effluent concentrations of 10 - 20 mg/L total N. Solids removal was also shown to be very effective with the majority of samples achieving effluent TSS of 20 mg/L or less, despite mixed liquor suspended solids (MLSS) concentrations of up to 20,000 mg/L in the reactor. It was found that nitrification and denitrification (essential steps in the removal of nitrogen) was successfully achieved simultaneously at low dissolved oxygen levels.

Nitrogen removal in the SBR was influenced by two key process variables, these being:

- MLSS (required for nitrification)
- COD:TKN ratio (for denitrification)

The experiments also showed that phosphorus removal in the SBR was poor throughout the study period. The cause for such low phosphorus removal in the SBR can be attributed to the extremely low level of soluble COD in the effluent from both anaerobic ponds used as influent to the SBR.

As opposed to the experimental pond findings and due to the short hydraulic residence time of the SBR, variations in feed compositions and flow were found to adversely affect the operation of the SBR on a weekly basis.

Recommendations for further work required, based on the conclusions drawn from the study, are:

- Demonstration and optimisation of the nitrogen removal performance in a full scale abattoir pond.

- Determining the effect of intermittent operation of aerators on nitrogen removal over a longer test period in the experimental pond and exploring means by which variations in levels of suspended solids associated with this mode of operation can be prevented or overcome

- Targeting of operational strategies and modifications to the feed composition to encourage stable phosphorous removal from the SBR.

- Identification and implementation of strategies to minimise the effects of feed variation on SBR performance.

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Abbreviations

AMH	Australia Meat Holdings Pty Limited
BOD	Biological oxygen demand (5 day at 20°C)
COD	Chemical oxygen demand
CODs	Soluble COD
CODt	Total COD
DO	Dissolved oxygen
HRT	Hydraulic retention time
ML	Megalitre (1 million litres)
MLSS	Mixed liquor suspended solids
MRC	Meat Research Corporation
N	Nitrogen
P	Phosphorous
PHB	Polyhydroxybutyrate (cell internal carbon storage product)
SBR	Sequencing batch reactor
TKN	Total Kjeldahl nitrogen
TSS	Total suspended solids
VFA	Volatile fatty acids

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Chapter 1

Introduction

The Australian red meat industry is currently under increasing pressure from community groups, government departments and environmental regulatory agencies to address environmental issues related to the industry. In particular, authorities are questioning the classical methods of meat process industry wastewater treatment and disposal.

Until recently, the responsible treatment of abattoir wastewater to remove fats, solids and BOD were of greatest concern to the industry. However, more recently, the focus has shifted to the removal of the nutrients - nitrogen and phosphorus, both of which are present in meat process wastewater at levels approximately 4 times greater than domestic sewage. The two major disposal routes for treated meat process effluent are

- to water-courses (rivers, estuaries, etc)
- and, more commonly, to land (via irrigation).

It has been found that excessive nutrient loading is detrimental to both destinations. Problems related to irrigation include:

- rising saline water tables,
- nitrate contamination of ground water,
- the flushing of nutrients from soil into rivers, creeks and waterways.

Once in waterways, nutrients have been proven to promote algal growth, both green and toxic blue-green forms, fish kills and subsequent odorous pollution.

The first point of call for the industry is to achieve radical reductions in the release of nutrients. The Meat Research Corporation publication "Identification of Nutrient Source Reduction Opportunities and Treatment Options for Australian Abattoirs and Rendering Plants", November 1995 is a pivotal report in this regard and provides information which can assist nutrient reduction, although realistically not to "zero discharge" levels.

The second strategy, is appropriate treatment and disposal. For the two disposal routes different effluent qualities are required. For effluent discharged into waterways, any input of nutrients needs to be minimised. Current nutrient levels typically permitted for discharge to rivers in Australia are 5 - 10 mg/litre of total nitrogen (ammonia +organic + nitrate + nitrite) and 0.05 - 2 mg P/litre. There are many technologies available to achieve this, but they have only rarely been applied to meat process wastewater and so there is little experience available. Further detail is available in the Meat Research Corporation publication "Developments in waste treatment in the meat processing industry", July 1993.

Effluent discharged to land can contain reasonably high values of nutrients since the land is capable of substantial remediation and nutrient removal. This has been well described in the Meat Research Corporation publication "Effluent Irrigation Manual for Meat Processing Plants", 1995. Unfortunately, meat process wastewater contains levels of nitrogen (150 - 300 mg N/l) well in excess of that permitted for irrigation at a suitable hydraulic loading (approx. 50 - 70 mg N/l). Consequently, the level of nitrogen needs to be reduced to the latter concentration. However, full removal of nitrogen is inefficient and wasteful when irrigating, since it is a valuable nutrient for plant growth. The problem for the industry is that all nutrient removal technologies currently available are designed for nitrogen removal to very low levels (suitable for release to rivers) - eg. overkill.

Project M.478 for the MRC and Project 10.2 for CRC for WMPC were a joint venture between the Meat Research Corporation and the CRC for Waste Management and Pollution Control Ltd. The objective of this report is the investigation and assessment of two innovative technologies to provide appropriate nutrient removal for meat process industry wastewater. These methods were:

- the use of an aerated pond to biologically remove nitrogen from abattoir wastewater; This technology is aimed at treatment for use where wastewater is irrigated;
- the use of an intermittent portable sequenced batch reactor (SBR) to biologically remove nitrogen and phosphorus nutrients from abattoir wastewater. This SBR system was aimed at disposal to waterways and other environments requiring minimisation of nutrient release.

These methodologies are discussed at depth in Chapter 4. The project, undertaken by two research assistants and one research fellow, spanned approximately two years (1995 - 1996), with experimental work being undertaken on the Dinmore abattoir site of Australia Meat Holdings Pty Ltd., in South East Queensland.

During the experimental period, effluent data were collected on both systems under varying conditions and with the constant fine-tuning of experimental parameters. A description of the Aerated Pond is given in Chapter 7, while that for the SBR is given in Chapter 9. Summaries of operating conditions have been included in the appendices. Methods used are discussed in Chapter 5. Since the feed to both systems was similar and comprised anaerobic pond treated wastewater, details of these feeds are given in Chapter 6.

The data collected was subsequently tabulated and analysed. The results from the aerated pond are presented in Chapter 8. Those for the SBR are given in Chapter 10. Based on these results, conclusions were drawn and a series of recommendations made.

It is hoped that from the knowledge gained from this exercise, the meat industry has been brought closer to finding environmentally satisfying solutions to the challenge of nutrients in industry wastewater.

Chapter 2

Conclusions

2.1 Experimental Pond

- A multi-zone experimental pond was trialed for 12 months and confirmed the technical feasibility of achieving consistent nitrogen removal of 60 - 70% at a hydraulic retention time (HRT) of 8 days to yield effluent nitrogen concentrations of 70 mg/l or less, principally in the nitrate form.

- No phosphorus removal was observed under any conditions of operation. It is believed that this is due to a lack of sufficient readily degradable COD in the feed.

- The effluent produced from the experimental pond was of sufficiently reduced nitrogen and COD content and levels of suspended solids to be suitable for irrigation and associated storage purposes.

- The pond was operationally robust with variations in the feed quality and flowrate having minimal effect on overall performance. Pond operation required minimum supervision with associated activities such as sludge recycling and wastage requiring only manual operation once every 1-2 weeks.

- The turnover baffle and associated settling zone and sludge recycling pump was an outstanding feature of the pond, permitting effluent with TSS concentrations of less than 150 mg/l, despite operating TSS in the pond basin of up to 2,500 mg/l.

- Excellent nitrification (>90%) was correlated to a sufficient HRT (8 days), sufficient levels of TSS in the aerated zone (minimum of 500 mg/l, preferably 1,500 - 2,000 mg/l) and the use of the partial baffle. The ability to activate a sludge recycle occasionally from the settling basin was a useful feature of the system. In contrast, the location of the feed inlet had little effect.

- Good denitrification, and total nitrogen removal, was associated with the provision of sufficient COD in the feed stream and a low dissolved oxygen concentration in the pond (preferably less than 2 mg/l).

- Initial studies show that intermittent control of aerators leads to the best N removal (85% removal was achieved at best performance). However, it was found that subsequent resuspension of suspended solids was difficult.

- The capital cost of the pond was approximately $0.5 million per ML/day treated, however given its small scale (only 0.1 ML), considerable economies of scale can be expected for a larger pond. Operating costs comprise mainly aerator power, which is estimated at $0.14/kL treated at $0.1/kWh power costs.

2.2 Portable Sequencing Batch Reactor

- The portable SBR unit demonstrated the capability of such a system to remove up to 90% of nitrogen from a beef abattoir wastewater (minimum levels of 15-20 mg/l total N in effluent). This can be achieved with a short hydraulic retention time of 1 day in a single tank system.

- The nitrogen removal efficiency was strongly influenced by two key process variables. These were the Mixed Liquor Suspended Solids (MLSS) (for nitrification) and the COD:TKN ratio in the wastewater (for denitrification).

- Complete nitrification was achieved at MLSS levels higher than 5000 mg/l whereas more than 80% denitrification was possible if the wastewater COD:TKN ratio was above 6.

- To optimise both nitrification and denitrification good control of the dissolved oxygen (DO) concentration is critical. The optimal range found in this study was 0.2-0.4 mg/l O_2 which is very low compared to typical concentrations of 2 mg/l.

- The very low soluble COD concentration in the Dinmore abattoir wastewater during the study did not allow any biological phosphorus removal to develop. The minimum SCOD:Total P recommended for successful P removal is around 20, while the SCOD:TP ratio in the wastewater present only rarely exceeded 10.

- The effluent produced was consistently low in suspended solids (SS) with most samples recording an effluent SS of 20 mg/l or less.

- The SBR process achieved an extremely well settling sludge allowing successful operation with MLSS concentrations up to 20,000 mg/l while maintaining a low effluent SS.

- The SBR, with its short hydraulic residence time, was more adversely affected than the pond by daily variations in the feed streams - in particular the carbon content of the feed.

Chapter 3

Recommendations

Recommendations for further experimental work include :-

Experimental Pond

- The pond should be built full-scale at an abattoir and proved at full-scale to ensure that there are no scale-up difficulties in its performance.

- Intermittent operation of aerators achieved a very high level of nitrogen removal, however the time available to test this mode of operation was limited and there is some suspicion that suspended solids level in the pond were falling due to this mode of operation. Testing over a longer period than was possible in this test programme would be useful to explore means by which the fall-off in the levels of suspended solids can be prevented or overcome and to fully define the performance.

- Operational strategies which would encourage phosphorus removal from the pond should be tested. This would largely relate to providing a stronger source of soluble carbon to the pond than was possible at Dinmore.

- Intensification of the pond, such as the use of attached growth films would be a longer term interest to try and reduce the overall size of the pond.

Portable Sequencing Batch Reactor

- To minimise the effect of variations in feed composition on the nutrient removal performance, an optimisation of the operational strategies on a daily basis should be undertaken. This could include the use of direct measurements such as the Oxygen Uptake Rate (OUR) or on-line ammonium sensors to determine the optimal anoxic and aerobic sequence times on a cycle-by-cycle basis.

- Methods to increase the concentration of soluble COD in the abattoir wastewater should be explored to enable biological phosphorous removal as has been demonstrated in bench-scale experiments.

- Spatial variations in DO concentrations are likely in full scale systems, in particular if surface aerators are used. The effect of these, and the implications on the selection of DO measurement points, should be studied carefully in a large scale system operating in a similar way as the pilot scale SBR.

- The benefits of the (patented) feed distribution system in achieving a very dense, well settling sludge should be demonstrated on a full scale system. This can be attained by modifying the inlet configuration to enable intensive contacting between the incoming wastewater and the settled sludge in the reactor.

Chapter 4

A Brief Theory Of Biological Nutrient Removal

4.1 Introduction

The high concentration of nitrogen (N) and phosphorus (P) in abattoir wastewater after primary treatment (in the absence of chemical dosing), requires their removal by a series of bacterial (biological) steps. These are described briefly below. Since each step has very different operational requirements, and often these are contradictory, the process can not be achieved successfully either in existing anaerobic or facultative ponds, or in a simple, well-mixed tank.

Consequently, most biological nutrient removal systems comprise either:

1. A series of tanks, or zones, in which different conditions exist (e.g. air/no air) and with streams recycled between the zones; or
2. A single tank (often called a Sequencing Batch Reactor, SBR) in which conditions are systematically changed on a time basis, to provide suitable conditions for each reaction.

In this MRC study, the pond is based on the first design, the SBR on the second.

Note: the biological reactions and their requirements are the same in both. The systems are engineered differently to meet these requirements.

4.2 Biological Nitrogen Removal

The mechanism by which nitrogen is biologically removed from wastewater can be considered a two stage process involving:

1. nitrification of the ammonium (NH_4^+) to nitrate (NO_3^-) or nitrite (NO_2^-), which is an intermediate product in the conversion of ammonium to nitrate, followed by
2. denitrification of the nitrate and nitrite to nitrogen gas (N_2) which bubbles from the wastewater into the atmosphere. Air consists of 79% N_2, so this seems a harmless and sustainable end-product of the nitrogen removal process.

In raw, or primary-treated, meat processing plant wastewater, the nitrogen is initially present as either:

- organic nitrogen, especially blood proteins, or
- ammonium which comes either from urine, or as the result of decomposition of proteins during rendering processes.

Subsequent treatment of the wastewater in an anaerobic pond, results in the conversion of virtually all the organic nitrogen into ammonium nitrogen due to bacterial breakdown of proteins.

Bacterial Nitrification

Nitrification is carried out under aerobic conditions (oxygen rich) in the presence of two groups of bacteria species:

1. *Nitrosomonas* for reaction of ammonium to nitrite,
2. *Nitrobacter* for the reaction of nitrite to nitrate.

These bacteria obtain carbon from carbon dioxide dissolved in wastewater, not digestion of organic compounds (BOD/COD) and tend to be slow growers. The bacteria exist in the suspended solids in the pond or tank. The supply of the oxygen can be achieved through either mechanical aeration of the wastewater (as is the case with the experimental pond), or by the bubbling of compressed air through the wastewater (as is the case with the portable Sequencing Batch Reactor).

The main requirements for bacterial nitrification can be summarised as:

- nitrogen is present as ammonium ions (NH_4^+);
- BOD/COD concentrations are low;
- there is an abundance of molecular oxygen (O_2) present;
- the pH is about neutral.
- the temperature is above about 8°C.

Bacterial Denitrification

Bacterial denitrification is carried out under anoxic conditions (zero oxygen, high nitrate/nitrite concentrations). The bacteria responsible simultaneously degrade organic compounds and are relatively fast growers. The key requirements for denitrification are the

- presence of biodegradable organic carbon material (BOD, or RBCOD - readily biodegradable COD) which provides the "fuel' for the heterotrophic bacterial denitrification process. It is essential that the carbon source be present - and be in a form readily available for the reaction.
- the nitrogen must be in the form of nitrate ion (NO^-_3), or nitrite (NO_2^-).

pH Control

Nitrification is accompanied by the generation of hydrogen ions (H^+) which consumes alkalinity (a measure of the ability of wastewater to resist pH change) and lowers the pH of the wastewater. Consequently, meat processing plant wastewater treatment systems where only nitrification occurs, produce wastewater with low pH, typically pH 4 or less. Subsequent denitrification consumes hydrogen ions thereby returning some alkalinity to the wastewater and moving the pH back toward neutral pH. The pH of the wastewater can therefore be used as a quick indication of the extent of imbalance between nitrification and denitrification.

Oxygen and Power Consumption

Approximately 50% extra aerator power and oxygen is required relative to BOD removal alone, to nitrify wastewater, if there is no accompanying denitrification. Subsequent denitrification, however, reduces the additional power required to about 10% more than BOD removal alone, since nitrate, rather than oxygen, is used to degrade some of the BOD during the denitrification reaction. Consequently, it is more economical to design and operate a plant for total nitrogen removal, than for nitrification only.

Importance of COD in the Wastewater

A key feature of the operation of both test units is the use of a high carbon strength feed stream. It is this feed stream, high in organic carbon content (or COD), which provides the carbon source for the denitrification reaction. In the case of the experimental pond, this feed stream is fed directly to the anoxic zone of the pond.

The percentage of this high carbon stream in the overall feed, therefore, becomes a key process variable in optimising nitrogen removal in both the experimental pond and the portable SBR unit. A large part of the test program on both units involved quantifying the effect of the variations in the feed ratio had on performance.

Summary

In conclusion, there are three benefits from achieving biological nitrogen removal. These are:

1. total nitrogen content of the wastewater is reduced;
2. the pH of the wastewater remains approximately neutral, rather than going acidic if nitrification occurs.
3. the energy and oxygen requirements for total nitrogen removal are substantially less than those for nitrification only (eg. only going "half-way").

4.3 Biological Phosphorus Removal

Biological removal of phosphorus from wastewater is not as nearly well understood as biological nitrogen removal. The process essentially involves the uptake of the phosphorus into the bacterial sludge which is then wasted from the system as a sludge stream. The process is a two-stage process involving an anaerobic period followed by an aerobic period.

Anaerobic Period

In the anaerobic period, the level of the soluble phosphorus (as orthophosphate ($PO^{3-}{}_4$)) in the wastewater actually increases as the P is released by the bacteria in preference for carbon uptake. The conversion of the soluble fraction of the incoming COD into volatile fatty acids (VFA) is essential for VFA uptake by the biological P storing organisms which produce an energy-rich carbon polymer (Polyhydroxy butyrate or PHB) for internal storage. These steps are absolutely crucial to the success of biological P removal.

Aerobic Phase

In the aerobic phase, the PHBs previously synthesised are oxidised and the soluble P in the wastewater is now taken up by the bioP bacteria, which store it in the form of polyphosphate compounds within the cell. In the P-removal process, the P-rich bacterial cells (sludge) are collected after the aerobic phase and recycled back to the anaerobic zone, with a fraction of the sludge recycle being wasted. It is through this stream of waste sludge that the phosphorus actually leaves the system. The sludge must be handled carefully to avoid subsequent release of soluble phosphate.

In summary, the main known requirements for biological phosphorus removal are:

- presence of P-removal bacteria;
- an anaerobic stage/zone in the presence of high levels of short chain VFA's and low nitrate;
- a subsequent aerobic phase with phosphorus present as soluble orthophosphate;
- rapid removal of a fraction of the P-rich bacterial sludge from the wastewater.

Chapter 5

Project Methodology

5.1 The Site

The experimental program was based at the Dinmore meat processing plant of Australia Meat Holding Pty Limited (AMH) based just east of Ipswich in SE Queensland. The work was directed from the offices of the Queensland Node of the CRC for Waste Management and Pollution Control Ltd. (CRC WMPC) at The University of Queensland's Department of Chemical Engineering.

At the time of this program, the Dinmore meat processing plant processed approximately 1,000 head of grass-fed cattle per day, 5 days a week with a single shift operation. Generally there was no processing on weekends. In addition to slaughtering, evisceration and boning operations, rendering and blood processing was performed, the former using continuous Keith rendering equipment typical of the Australian industry. A small low temperature rendering facility also operated, but had little effect on the overall strength of the wastewater. Extensive offal processing occurs at Dinmore and paunch was wet dumped.

5.2 The Dinmore Wastewater Treatment System - Overview

The wastewater treatment system of Australia Meat Holding's Dinmore meat processing plant comprised the following main units during the study period (refer to attached sketch MRC-028).

- primary treatment using screens, savealls and occasionally a dissolved air flotation unit (DAF). For some of time, chemical dosing occurred. Subsequently this was stopped, since it interfered with nutrient removal.
- anaerobic pond (Pond 1);
- a second anaerobic pond (Pond 2) in series with the first;
- an activated sludge Sequencing Batch Reactor (Pond 4) - this is used for final organic removal and for partial nutrient removal;
- a final maturation pond (Pond 5).

The dual anaerobic ponds in series was the preferred start format preceding both M-478 experimental units.

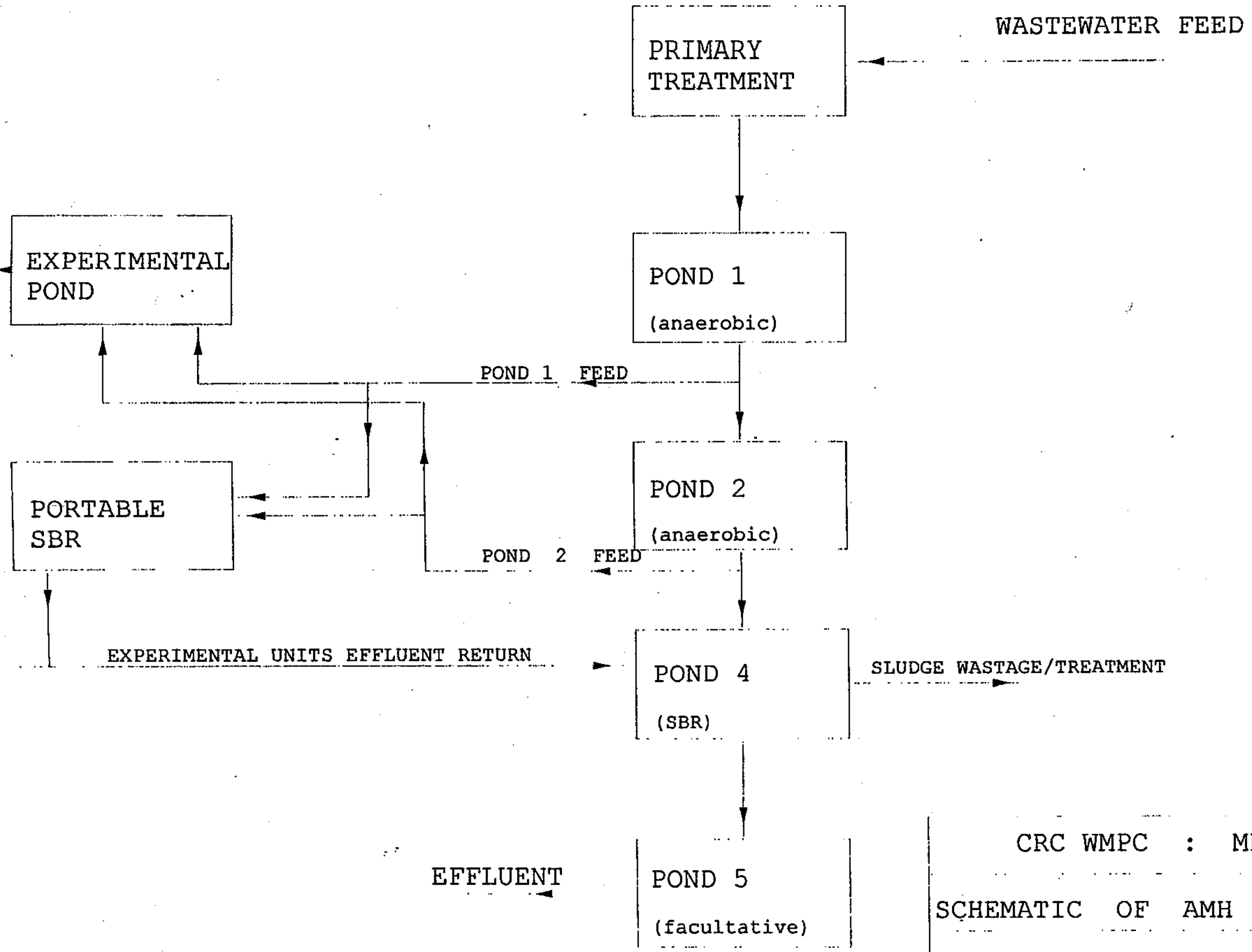
5.3 Flow Measurement

Feed to the M.478 units was drawn from both anaerobic ponds. It was important to be able to control the relative proportion of each feed. This was achieved by the installation of magnetic flowmeters (TechFluid) on the feed lines from both anaerobic ponds.

5.4 Analytical Techniques

A wide range of analytical testing was performed on samples drawn from anaerobic ponds, the M.478 pond and the SBR.

- The tests used are outlined in Table 5.1.
- Some difficulties were experienced when applying standard wastewater methods for nutrient analysis of meat processing wastewater - these are covered in Appendix 5.1.



CRC WMPC : MRC PROJECT

SCHEMATIC OF AMH DINMORE POND

DRAWING MRC-028 REV 1 16/12

5.4.1 Sampling

All samples were taken as grab samples from locations which were well-mixed so as to provide representative samples. Composite sampling was not considered, since numerous grab samples were taken.

For the pond, key sample locations were:
- the effluent weir from the settling basin prior to discharge into the sump tank.
- the main aeration basin in the pond;
- sample valves on the two feed lines from anaerobic ponds 1 and 2.

Samples were analysed immediately at the on-site CRC laboratory, or frozen rapidly where storage, or travel was necessary (for analyses performed by PEAC).

For the pond and feeds from the anaerobic ponds, samples were taken three times a week. Samples taken from the effluent weir and the main aeration basin were found to be identical in terms of soluble pollutant concentrations, consequently only samples from the effluent weir were used to assess removal performance.

5.4.2 Analysis

Table 5.1 lists the analyses performed on waste water samples. Methods followed those given in "Standard Methods for Examination of Water and Wastewater, 18th edn., 1992". Dissolved oxygen and pH measurements were taken by portable apparatus, previously calibrated in accordance with manufacturer's instructions. Temperature was read using a thermometer.

In addition to the analyses below, most samples were tested with the rapid RQFlex portable nutrient testing instrument (Merck). This instrument permitted rapid analysis of ortho-phosphate, nitrite, nitrate and ammonium concentrations and is based on the colorimetric determination of pollutants using paper test strips. The expression of N and P pollutants is readily confused. In this report, all concentrations of nitrogen and phosphorus chemical species are expressed as mg of N, or P/litre.

Nitrogen concentrations (all as mg N/l) were defined as follows:

- TKN = organic N + NH^{+}_{4}-N

- Total Nitrogen = TKN + NO^{-}_{3}-N + NO_{2}^{-}-N

Phosphorus concentrations (all as mg P/l) were defined as follows:

- Total Phosphorus = organic P + PO^{3-}_{4}-P

A number of issues arose from the work:

1. All tests were performed on filtered samples (through GF/C filter paper and 0.45 μm Millipore filter) except COD total; TSS, RQFlex tests and TKN determinations.

2. Some tests (COD; nitrate) are vulnerable to nitrite interference. Consequently, sulfamic acid or similar chemicals were added to eliminate the interference where required (as shown by RQFlex analysis).

3. Testing was performed using a Merck SQ118 instrument and Merck methods as per the manufacturers manual.

4. Difficulties were experienced with the accuracy of some tests on meat processing wastewater. These are discussed in Appendix 5.1.

Table 5.1 Analysis methods performed.

Analysis	Method	Operator
Total Suspended Solids (TSS)	gravimetric	CRC
Chemical Oxygen Demand - total (COD)	Merck SQ118 method	CRC
Chemical Oxygen Demand - soluble (CODs)	Merck SQ118 method	CRC
Total Kjeldahl Nitrogen (TKN)	Digestion/distillation	PEAC, UQ
Ammonia (NH_4^+)	distillation	PEAC, UQ
Ammonia (NH_4^+)	Merck SQ118 method	CRC
Nitrite (NO_2^-)	Merck SQ118 method	CRC
Nitrate (NO_3^-)	Merck SQ118 method	CRC
Ortho-phosphate (PO_4^{3-})	Merck SQ118 method	CRC
Total phosphorus (TP)	Merck SQ118 method	CRC

- Operator: PEAC, UQ: Process and Environment Analytical Centre, University of Queensland.
- The Merck SQ118 is a laboratory unit which measures concentration using colorimetric, or spectrophotometric, methods.

5.4.3 Calculation of Values

A large number of concentration data were obtained during the approximately 50 weeks of operation. The results for each week were tabulated in Excel (Microsoft) spreadsheets and averaged. All calculations used the weekly average value.

- <u>Pollutant removal</u> (%) was calculated as (where I = a given pollutant):

$$\%\ removal_i = (load_i\ in - load_i\ out) / load_i\ in$$

Loads were used rather than concentration to calculate removal, since two feeds were used containing different concentrations of most pollutants. Load in was calculated as:

$$load_i\ in = F_1 c_{i1} + F_2 c_{i2}$$

where F - flow from anaerobic pond 1 or 2.
c - concentration of pollutant I in feed from anaerobic pond 1, or 2.

Load out was the flow out of the pond times the concentration of pollutant in the pond effluent.

- <u>Hydraulic Retention Time (HRT)</u> (days, or hours) was calculated as:

$$HRT = Flowrate\ [m^3/day] / Tank,\ or\ basin\ volume\ [m^3]$$

5.5 Pond Surveys

To establish the nature of the environment in different parts of the M.478 pond, a YSI 3800 submersible multiprobe instrument was used. The probe detected pH, DO, turbidity, salinity and temperature at various depths at selected transects throughout the pond.

Chapter 6

The Composition of the Anaerobic Feed Streams

During the research program, the pond and the SBR were fed with anaerobic-treated feed streams from both of the anaerobic ponds at Dinmore. The composition of these streams was critical to the outcome of the project and is detailed below.

6.1 Feed from Anaerobic Pond 1.

The composition of the effluent of pond 1, as determined during the life of the project is presented in Table 6.1. The variation in nitrogen and phosphorus concentrations are illustrated in Figure 6.1 during 1996, whereas the variation in COD and TSS concentrations are given in Figure 6.2.

Most of the parameters demonstrated no trend with time during the year. The pH and nitrogen concentrations were particularly constant, as can be seen by the similarity of the mean and 50 percentile values and the reasonably low standard deviation value. The TKN concentration always exceeded the ammonium-N value, as is expected due to the presence of organic nitrogen in the wastewater. Unfortunately there was a discrepancy between values of ammonium-N analysed by distillation and titration (PEAC) and RQFlex. This is covered in Appendix 5.1. The former value is more accurate.

Phosphorus and soluble COD concentrations, however, showed a step fall in average value, which occurred at the end of April (Table 6.2 and Figs 6.1, 6.2). The reason for this is unclear, but it corresponds to a major flood experienced at the end of April/early May. Nevertheless, the concentrations did not come back up after this time. A more feasible reason is that soluble COD and phosphate concentrations are increased by higher water temperatures in summer (Jan - Mar) due to enhanced microbial action. The temperature of the effluent varied between an average of 32.7^{o}C for summer (Jan-Mar) and 27.4^{o}C for winter (Jun-Aug).

The ammonia nitrogen concentration represented an average of 77% of the nitrogen exiting the pond. All the phosphorus was in the orthophosphate form.

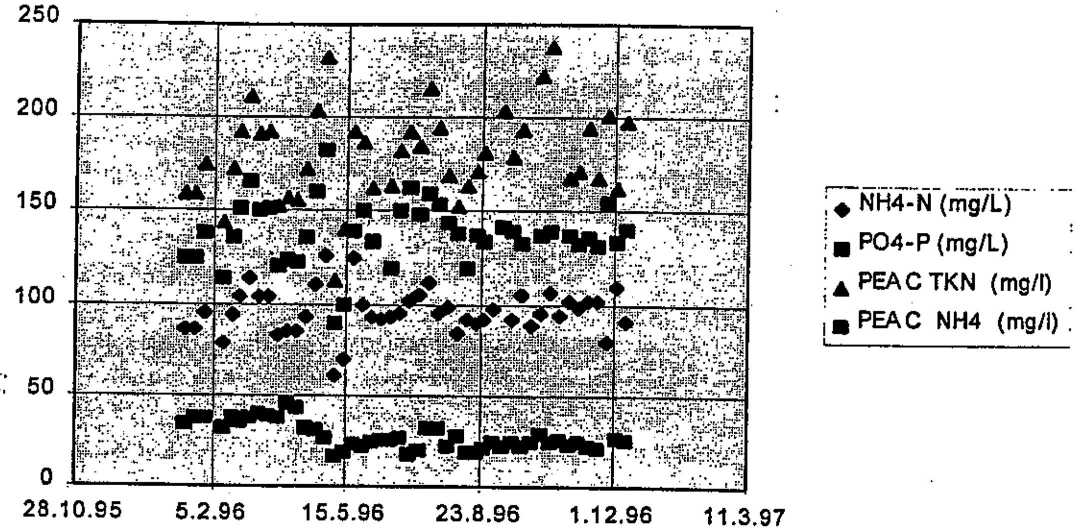
Table 6.1 Characterisation of Effluent from first Anaerobic Pond at Dinmore

Parameter	Units	Mean	Std Dev.	50 percentile	min value	max value
pH	-	6.6	0.1	6.6	6.45	6.82
TSS	mg/l	810	375	725	245	2005
COD soluble	mg/l	235	115	200	128	789
COD total	mg/l	1680	510	1555	525	2856
TKN	mg/l	180	25	180	113	238
NH_4-N	mg/l	138	17	137	89	183
PO_4-P	mg/l	28	7	25	17	46

Notes:

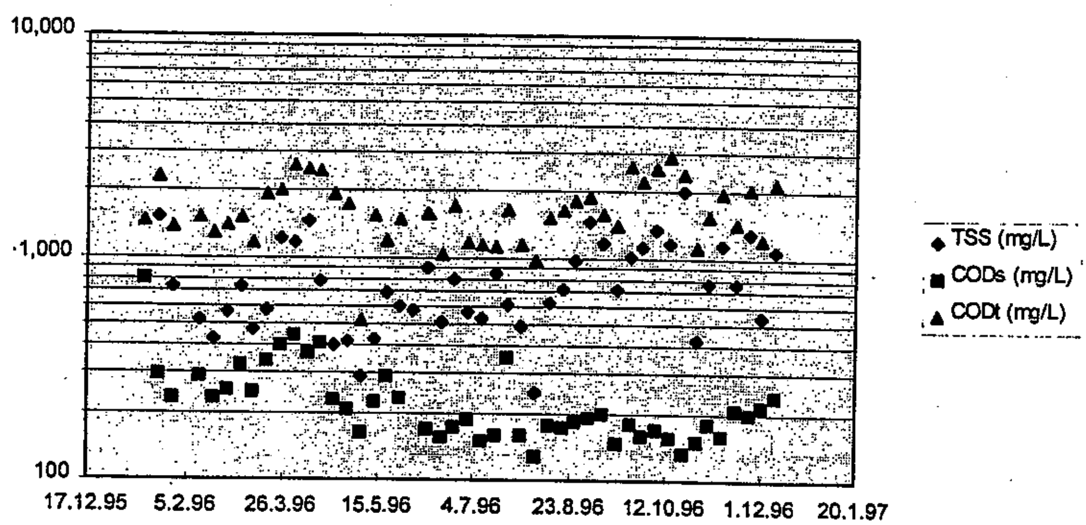
1. The values are derived from weekly averages for the period 1 January - 15 December, 1996.
2. Nutrient concentrations are reported as mgN/litre, or mgP/litre.
3. Oxidised forms of nitrogen were below the limit of detection.
4. 50 percentile and mean values correspond when there is a normal distribution of values. 50 percentile values are less affected by extreme values.

Figure 6.1 Nutrient concentrations with time for effluent from pond 1.



Note:
1. PEAC NH_4-N concentration is more accurate than the NH_4-N value.

Figure 6.2 COD and TSS concentrations with time for effluent from pond 1.



Note:
1. The vertical axis is a log scale to more conveniently illustrate the large range in values. Each horizontal line above the value given on this axis represents an increment of that value.

Table 6.2 Step change in average orthophosphate and soluble COD concentrations during 1996.

Parameter	Units	Jan-April	May-Dec
COD soluble	mg/l	306	185
PO_4-P	mg/l	36	24

6.2 Feed from Anaerobic Pond 2.

The composition of the effluent of pond 2, which received effluent from pond 1 as feed, is presented in Table 6.3. The variation in nitrogen and phosphorus concentrations are illustrated in Figure 6.3 during 1996, whereas the variation in COD and TSS concentrations are given in Figure 6.4. There was little difference between mean and 50 percentile (not shown) values.

The parameters demonstrated no trend with time during the year, except for orthophosphate concentrations, which showed the same trend observed in effluent from Pond 1. Unlike Pond 1, soluble COD showed no trend. Whereas TSS and COD concentrations were much less in Pond 1 effluent compared to Pond 1, little change occurred in nutrient values.

The ammonia nitrogen concentration represented a higher fraction of the nitrogen exiting pond 2 (93% of total N) compared to an average of 77% for Pond 1 effluent. All the phosphorus was in the orthophosphate form. The temperature of the effluent varied between an average of 30.9°C for summer (Jan-Mar) and 25.4°C for winter (Jun-Aug) - approximately 2°C cooler than Pond 1.

Table 6.3 Characterisation of Effluent from Second Anaerobic Pond at Dinmore

Parameter	Units	Mean	Std Dev.	min value	max value
pH	-	6.7	0.2	6.35	6.93
TSS	mg/l	103	545	10	343
COD soluble	mg/l	153	21	95	186
COD total	mg/l	344	51	246	480
TKN	mg/l	163	13	132	196
NH_4-N	mg/l	151	13	117	183
PO_4-P	mg/l	30	8	20	46

Notes:

1. The values are derived from weekly averages for the period 1 Jan - 15 Dec, 1996.
2. Nutrient concentrations are reported as mgN/litre, or mgP/litre.
3. Oxidised forms of nitrogen were below the limit of detection.

Figure 6.3 Nutrient concentrations with time for effluent from pond 2.

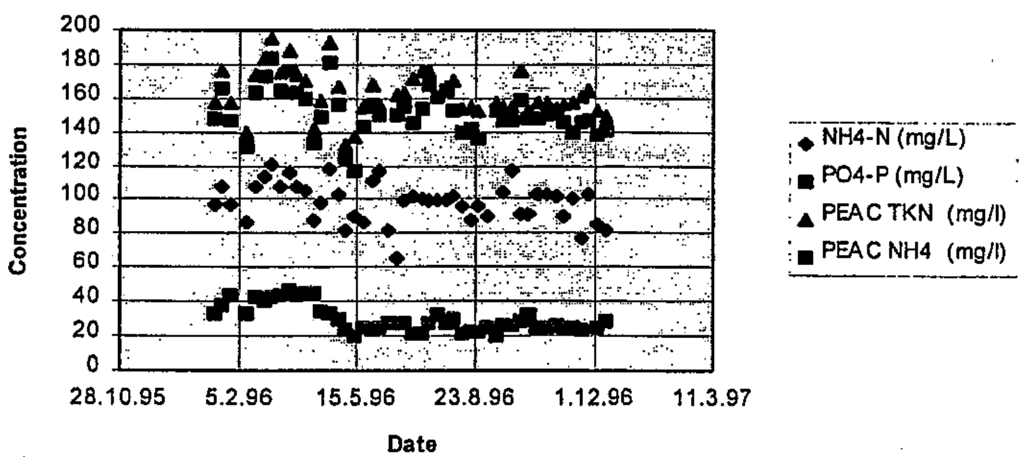
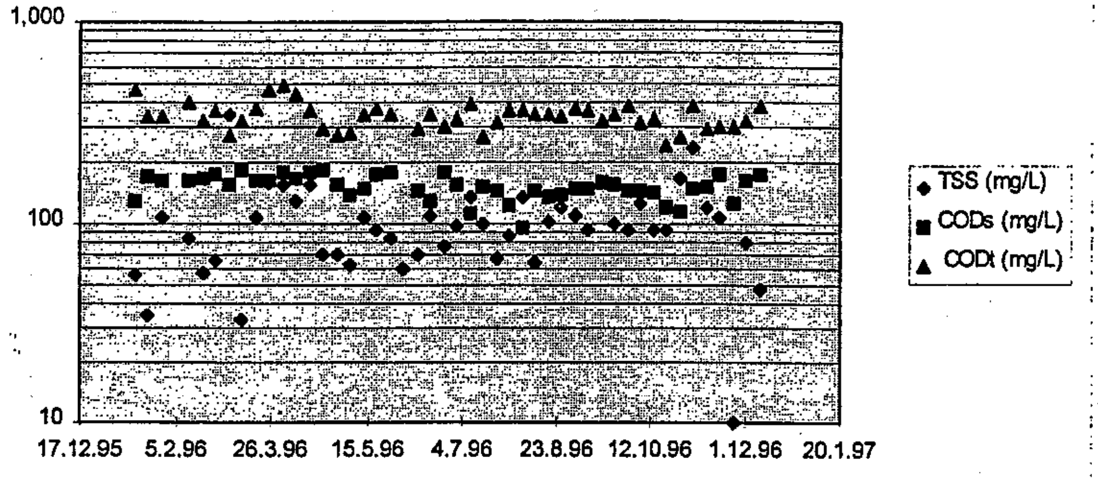


Figure 6.4. COD and Total Suspended Solids concentrations with time for effluent from pond 2



Note:

1. The vertical axis is a log scale to more conveniently illustrate the large range in values. Each horizontal line above the value given on this axis represents an increment of that value.

Chapter 7

Pond Design and Costing

7.1 Context and Objective

The purpose of the pond is to provide a cost-effective and robust pond technology capable of reducing nitrogen levels in abattoir wastewater to those suitable for subsequent irrigation of the pond-treated effluent on to land. The key concepts are:

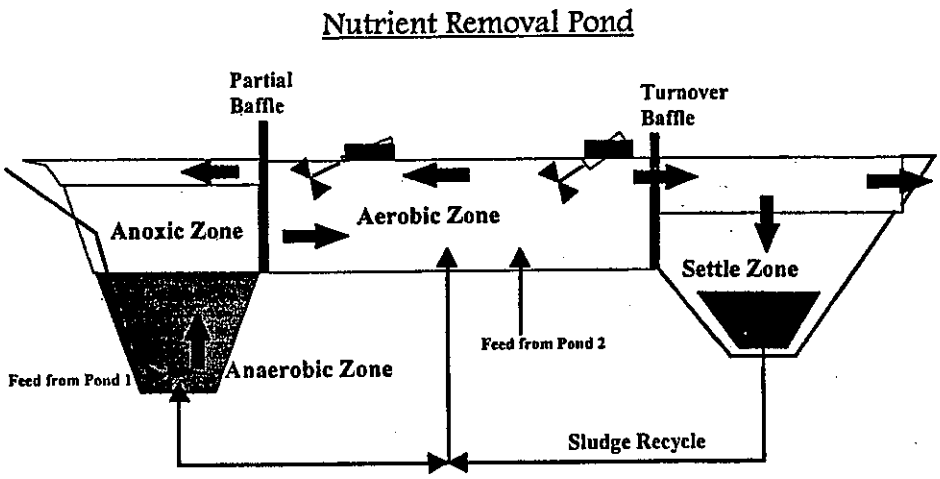
- the pond should reduce nitrogen levels and load to an extent that the irrigation area required for disposal of the treated wastewater (as calculated for N load according to currently accepted Australian Environment Authority calculation protocols) would not exceed the land area needed on the basis of hydraulic load.

- prior anaerobic pond treatment of the primary-treated wastewater should be maintained to permit cost effective removal of COD.

- the pond should consist of a single, mechanically aerated system, but with multiple zones.

The pond concepts are illustrated in Figure 7.1.

Figure 7.1 Schematic of the Experimental Pond



Concept 1: Appropriate Nitrogen Removal

The first concept above is important and novel. Nitrogen and phosphorus in abattoir wastewater is actually a valuable resource. Pond systems traditionally used in Australian abattoirs remove little N and P. Consequently, the high nitrogen concentrations in the final wastewater dictate that large land areas necessary for disposal, often 2 - 3 times larger than the land area needed when only water balance calculation is performed. More information is given in the MRC "Effluent Irrigation Manual for Meat Processing Plants" from project

M.476 in November 1995. Consequently high and untreated nitrogen concentrations in treated wastewater penalises meat processors by requiring the purchase, fitout and maintenance of land areas larger than would be needed if nitrogen levels in the wastewater were lower.

Modern biological nitrogen removal plants are designed to remove nitrogen to low levels (10 mgN/l or less). While these low levels are critical for disposal to rivers and estuaries, they are needlessly low for use in irrigation., for which 50 - 70 mgN/l are typically suitable. Consequently, meat processors who irrigate, would over-invest in capital and operating costs to achieve an effluent which is actually N-deficient for pasture irrigation.

The MRC pond is designed to achieve "just-enough" N removal. This ensures that minimum land area is required for irrigation, and that the irrigated effluent is a rich source of nitrogen for irrigated pasture to permit optimal pasture development. This pasture can be harvested and sold.

Concept 2: Anaerobic Pre-Treatment

Anaerobic ponds achieve highly cost-effective BOD reduction for meat process plants. Although this could also be achieved in an aerated pond, this is expensive in terms of aerator costs. Consequently, the retention of prior anaerobic treatment was a crucial start-point for this project.

Concept 3: A Single Pond, but Multi-Zone

A single basin with multiple zones in which the different reactions could occur was the preferred design. Aerators and baffles provided the recycling of water between zones and the means of achieving different zones, respectively.

Phosphorus removal

The project focused on nitrogen removal over that for phosphorus because:

- Nitrogen is currently the nutrient which most defines irrigation areas for meat processors under current Australian guidelines for irrigation of effluent.

- There is no economic alternative to biological N removal whereas phosphorus can be chemically precipitated if necessary.

In the final outcome, P removal was never observed in the M.478 pond, probably due to an insufficiency of readily biodegradable carbon compounds.

7.2 Description of Final Constructed Version of the Pond

- Figure 7.2 clearly illustrate the three separate zones characteristic of the pond. This is discussed in Section 7.3.1.
- Table 7-1 summarises the design parameters for the pond.
- Drawing MRC 001 shows the final "as built" dimensions of the pond. The design basis is the treatment of 100 m^3/day of total wastewater feed. Further drawings of the detail of each zone are given in Appendix 7.1.

- Drawing MRC-005 shows the location of the feed and sludge withdrawal points (See Section 7.3.3).
- Drawing MRC 006 reveals the piping and instrumentation details for the pond.
- An equipment schedule is given as Appendix 7.2.

The experimental pond had a total volume of 940m^3, and consisted of three distinct zones:
- an anoxic/anaerobic zone,
- an aerobic zone,
- and a settling zone.

The overall design hydraulic retention time (HRT) was 9.1 days. It was intended that the pond achieve a target of 66% nitrogen removal based on an initial total nitrogen level of 200 mg/l in the feed streams, with final BOD_5 and suspended solids concentrations to be compatible with irrigation end use.

Pond zone depths were chosen from experience and after considering the scour/fetch characteristics of the aspirators. The depth of the anaerobic zone was constrained by the small size of the pond. The anoxic and aerobic zones were sized based largely on the procedure described by Eckenfelder (1989). Surface aspirators were selected to provide aeration, because they provide a unique way of directing flow within the pond. The settle basin nominal HRT of 24 hrs was designed to give adequate size for solid settling and sludge storage, while minimising the likelihood of algal growth.

The pond was operated in a continuous mode. The two feed streams were fed continuously to the aerobic zone (AMH Pond 2 feed) and the anoxic zone (AMH Pond 1 feed), respectively, as shown in Drawing MRC-005.

Three directional aspirating aerators on the pond circulated the water in the aerobic zone around in anti-clockwise manner. The partial baffle between the aerobic and anoxic zones allows partial exchange of wastewater between the two zones and is described in Section 7.3.4. The settling zone is separated from the aerobic zone by a full width turnover baffle described in Section 7.3.5.

7.3 Design Concepts

A number of design concepts play a significant part in the operation and performance of the pond. These are explained below:

7.3.1 Heterogeneous Zones

The key design feature of the pond is the use of separate heterogeneous zones within the pond - namely aerobic, anoxic/anaerobic & settling zones. These zones are obtained by the use of baffles, directional aerators and variations in the depth of the pond.

- **Zone 1: Anoxic/Anaerobic**

This zone (Fig 7.3) comprised a 4 m deep well at the southern end of the pond and was separated from the shallower, but larger aerated zone by the partial baffle. The role of this zone was to provide conditions suitable for denitrification of the nitrate formed in the aerated zone. This was aided by delivery of anaerobic feed from AMH pond 1 into the base of the zone. The bottom of this zone was designed to also be sufficiently anaerobic to enable P release if sufficient readily degradable carbon was present.

Figure 7.2: Top - a view from the settling basin end showing the middle aerated zone with counter-clockwise flow and the anoxic zone behind the far, partial baffle. Bottom: The view from the anoxic zone end.

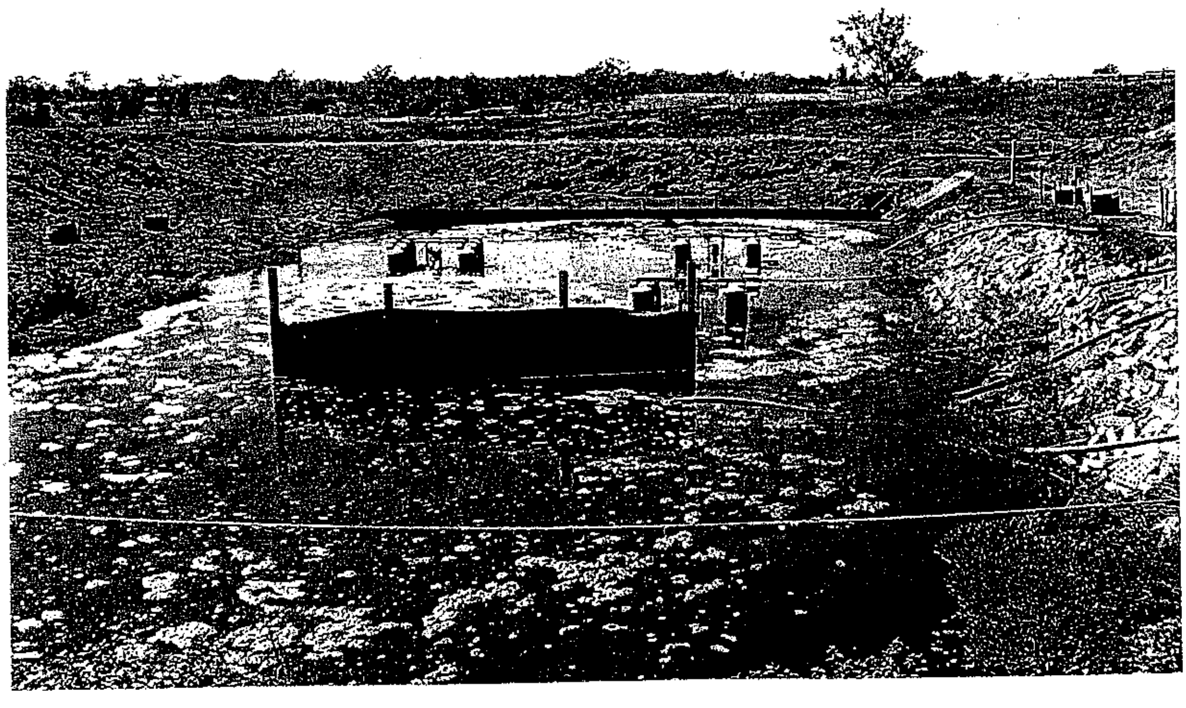


Table 7-1 : Summary of Pond Design

	Design HRT	Volume (m^3)		Area (m^3)	Batter	Base (m)		Water Level (m)		Top (m)		Max. Depth
	(days)	Design	Actual	top	L:Ht	Width	Length	Width	Length	Width	Length	(m)
Anoxic	2.9	290	320	210.7	1.5:1	3.2	3.0	15.2	11.25	17.2	12.25	4
Aerobic	5.2	520	520	350.9	2.1:1	5.2	20.4	15.2	20.4	17.2	20.4	2.5
Settle	1.0	100	100	98.9	1.5:1	1.6	1.6	10.6	6.85	12.6	7.85	3
TOTAL	**9.1**	**910**	**940**						38.5		40.5	

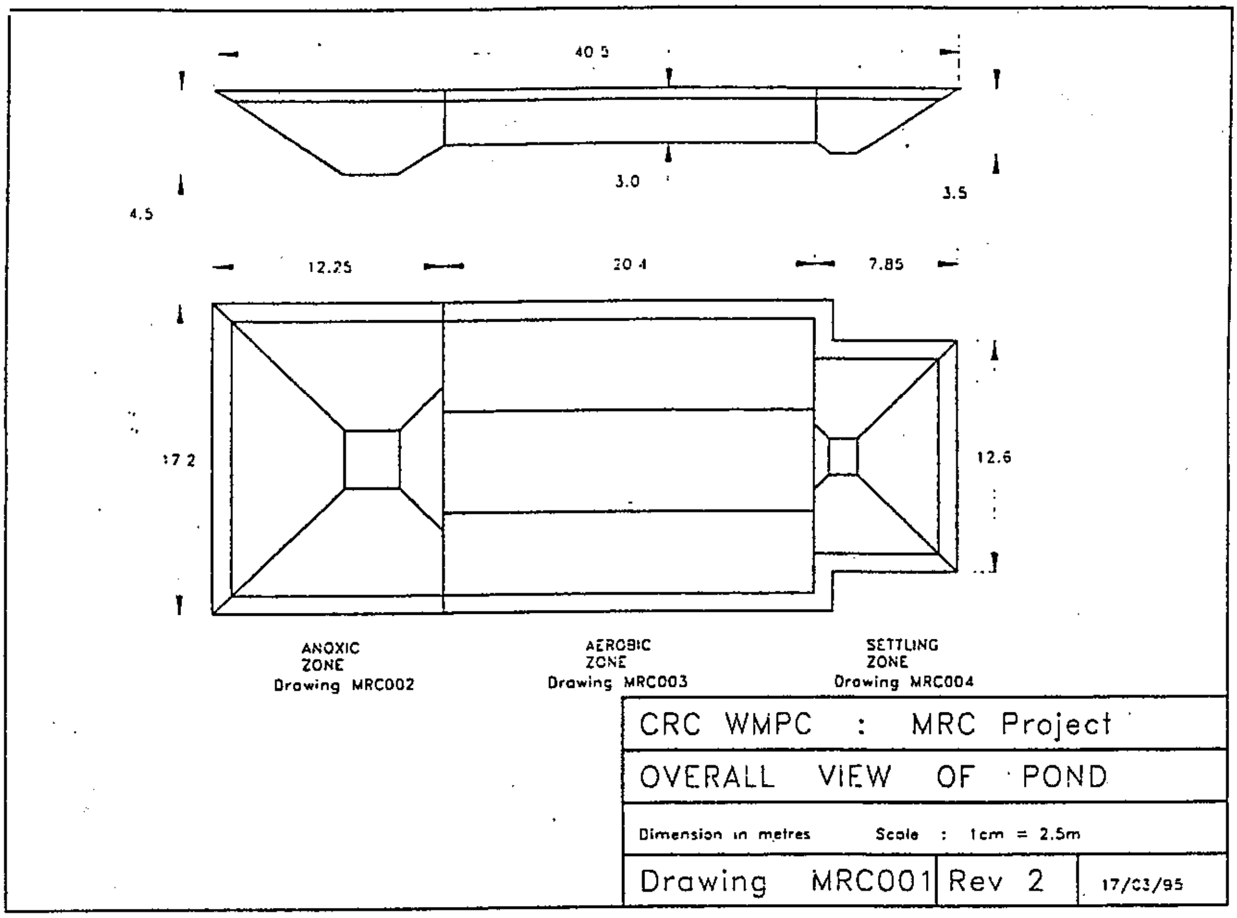
Design : Flowrate: 100 m^3/day
From Pond 1: 34 m^3/day
From Pond 2: 66 m^3/day
TKN: 180 mg/l
NH_4-N: 180 mg/l
NO_3+NO_2-N: 0 mg/l
BOD_5^{20}: 600 mg/l
PO_4-P: 40mg/l

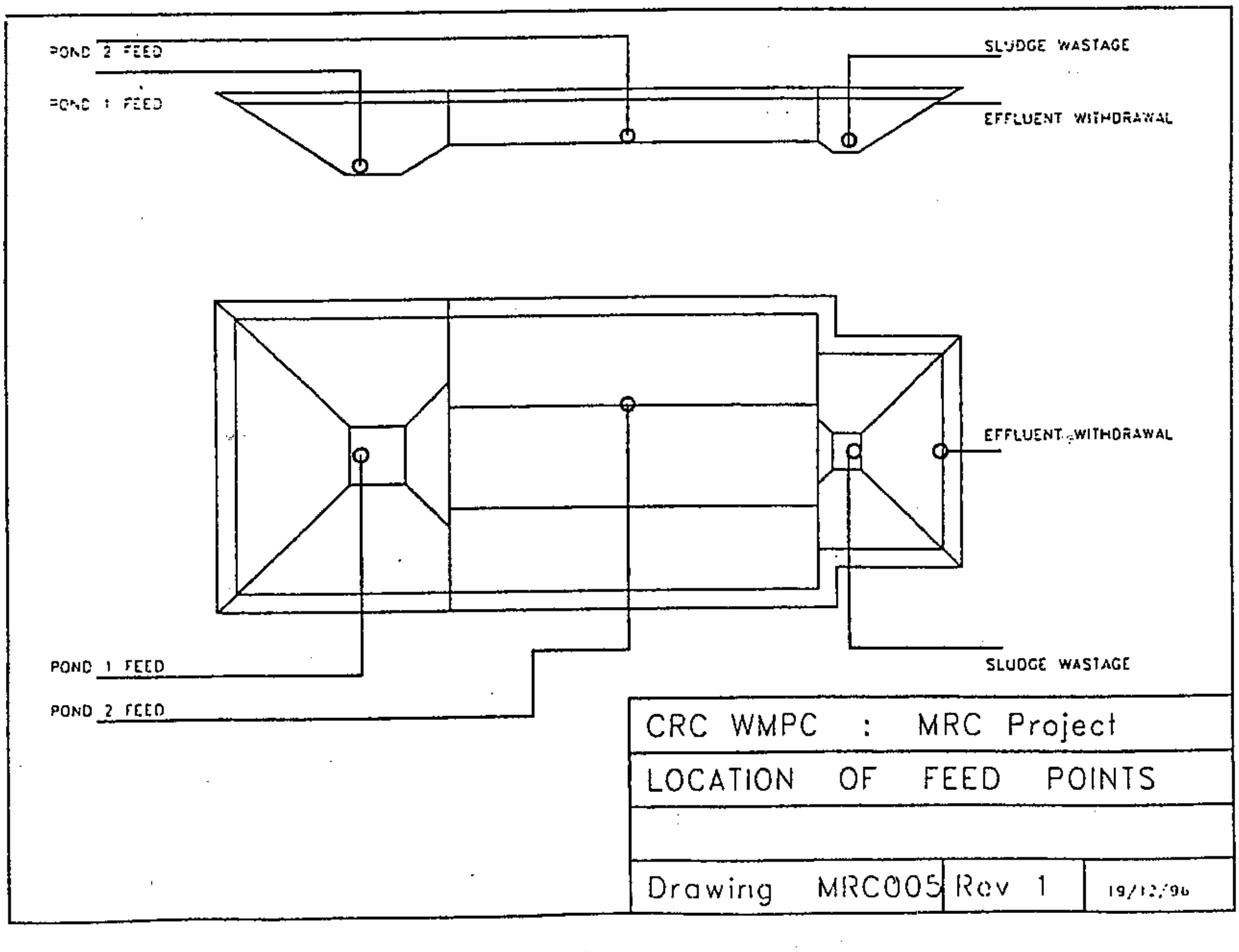
Design Effluent : BOD_5^{20}: 20 mg/l
Acrators: 2 @ 2.2kW & 1 @ 3.7kW aspirator in aerobic zone

Baffles: 1 partial between anoxic @ aerobic zones
1 turnover between aerobic & settle zones
Freeboard: 0.5 m
Wave Protection: reject bricks in wire netting

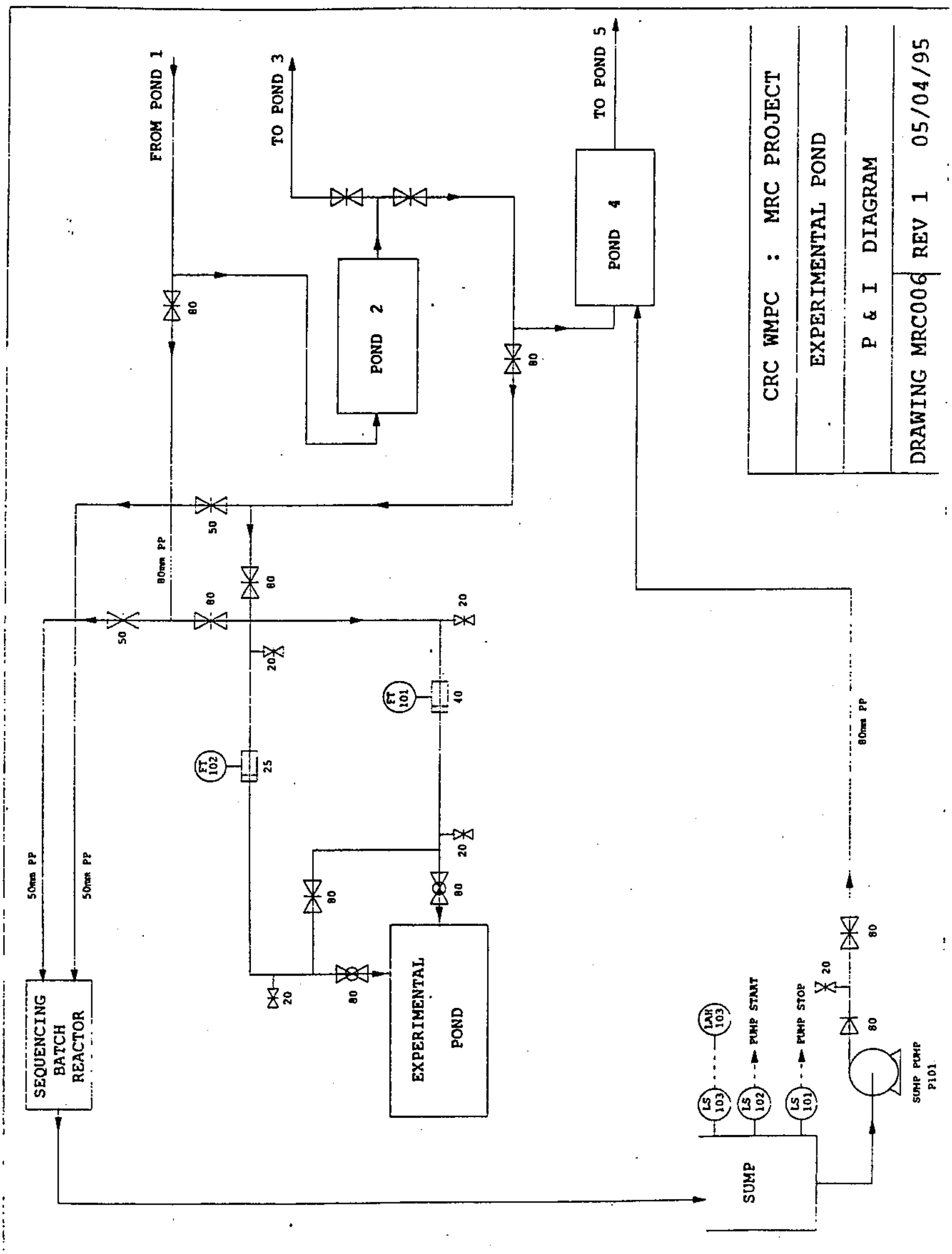
Inlet: From Pond 1: into anoxic zone, 0.5m off base
From Pond 2: into aerobic zone, 0.5m off base plus connection to anoxic zone inlet.
Outlet: 1 at surface, settle zone.

- Drawing MRC 001





- Drawing MRC-006



Zone 2: Aerated
The aerated zone (Fig 7.4) supplied oxygen for nitrification and BOD removal and bacterial growth. The aspirators ensured delivery of nitrified-effluent to the anoxic zone and mixing to ensure suspension of the bacterial floc. The aerated zone had 16 W/m^3 of aeration power, although generally only two aerators were found necessary (eg. 11 W/m^3).

- **Zone 3: Settling**

This zone permitted settling of the high suspended solids concentration in the water from the aerated zone (typically 1,000 - 2,500 mg/l) prior to discharge via the weir located at the centre of the pond wall opposite the Turnover Baffle (Fig 7.5). A sludge removal system was fitted and is described in Section 7.3.6.

7.3.2 Directional Aerators

The use of directional aspirators (Fig 7.4) served the dual purpose of both aeration and creating a circulation pattern for exchange between the aeration and anoxic zones of the pond. They also keep the pond solids in suspension and distribute them around the pond. This is important, particularly for effective nitrification. The anti-clockwise flow direction is clearly seen in Fig 7.4. Other types of aerators or aeration systems could be used, but there would also be the need for additional mixing and circulation units - all of which would add to the capital and operating cost of the pond.

7.3.3 Anaerobic Feed Mix and Placement

Two anaerobic feeds of differing COD strengths (see Chapter 6) were fed to the pond. One was a higher strength (higher organic content) drawn from Pond 1 and fed to the bottom of the anoxic/anaerobic zone. This feed supplied the organic carbon load required to obtain denitrification of the nitrate and nitrite to nitrogen gas.

The second feed (lower strength organic feed - but with higher ammonium levels) consisted of effluent from the second anaerobic pond (Pond 2) and was fed to the bottom of the aerobic zone of the pond. The purpose was to nitrify the ammonium present to nitrate or nitrite. The ratio of the feed rate of the two anaerobic feed streams then becomes a major operational variable in optimising the performance of the pond. The effect of varying this feed ratio is discussed in the results below.

7.3.4 Partial Baffle

Computational Fluid Dynamic (CFD) simulations suggested that a Partial Baffle would permit a split of flow between the aerated and anoxic and anoxic zones. Some fraction of flow impinging on the baffle would be recirculated to the aerated zone, while the remainder moved through the anoxic zone. The anoxic region behind the baffle should be highly anoxic permitting denitrification to occur. Fig 7.6 shows the Partial Baffle.. The baffle dimensions are detailed in Appendix 7.3. The baffle width was approximately one third the top water level width of the pond, although the cross-sectional area obstructed by the baffle was approximately 58%.

7.3.5 Turnover Baffle

Between the aerated and settling zone a novel turnover baffle was constructed, which is a key design element in ensuring the good operation of the settling zone in removing solids from the effluent. It consisted of two full width baffles in parallel with a gap between them of 50 mm (Fig. 7.7a). The first baffle, the over baffle, faced the aerated zone and was sealed on the bottom and sides with its top edge 100-150 mm below the water level (Fig. 7.7b). The second baffle, the under baffle, faced the settling zone and was open at the bottom (gap 1-1.5 m) with its top edge above the water level (Fig. 7.7c).

This arrangement forced the water leaving the aerated zone for the settling zone to travel over the top of the over baffle and into the base of the settle zone via the under-baffle. In doing so, the velocity of the water is greatly reduced (to less than 10 cm/min @ $100m^3$/day total feed) allowing the suspended solids in the water to settle into the sludge blanket at the base of the settling zone. The existence of the sludge blanket was confirmed by turbidity measurements using the YSI multi-probe.

Additionally, by maintaining a sludge blanket on the bottom of the settling zone, the arrangement of the baffles forces the effluent from the aerated zone to pass upwards through this sludge blanket, thereby further reducing the solids content of the effluent by this 'filtering' action. The effectiveness of the baffle in providing still water conditions for settling, despite its close proximity to the aerated zone, shown in Fig 7.6d, where a thin film of duckweed, which inadvertently colonised the zone for some time, is undisturbed at full operation.

7.3.6 Sludge Recycle and Wastage

The formation of the above mentioned sludge blanket in the settling zone also allowed for convenient collection of sludge for either sludge recycle or sludge wastage. Strictly speaking the pond is not an activated sludge process and the only sludge recycle required is that to maintain a reasonable level of solids in the aerated zone (minimum 500 mg/l TSS) in order to facilitate complete nitrification. The operational experience was such that all this required was an occasional recycle - usually once/week for less than an hour using a pump with a capacity 400% of the total feed rate (ie an overall 'recycle ratio' of 2.4% - compare this with the 50-200% recycle ratio of a conventional activated sludge plant).

Likewise with sludge wastage. Sludge was only wasted on an as required basis, in order to maintain the sludge blanket depth in the settling zone at between 1 and 2 meters depth. This was carried out on a less than weekly basis, again usually for less than an hour using the pump referred to above. Typical concentration of the wasted sludge is 25-30,000 mg/l TSS, ideal for a belt filter press or similar. This ease of operation is a major operational advantage requiring minimal operator attention.

Figure 7.3: Top - The anoxic zone under construction, showing the baffle support poles and brick erosion protection. Bottom - the filled zone.

Figure 7.4: Top - The aerobic zone under construction, showing the baffle support poles for both baffles and brick erosion protection. Bottom - the filled zone with 2 x 2.2 kW units closest and the 3.7 kW unit facing the opposite direction to provide counter-clockwise flow.

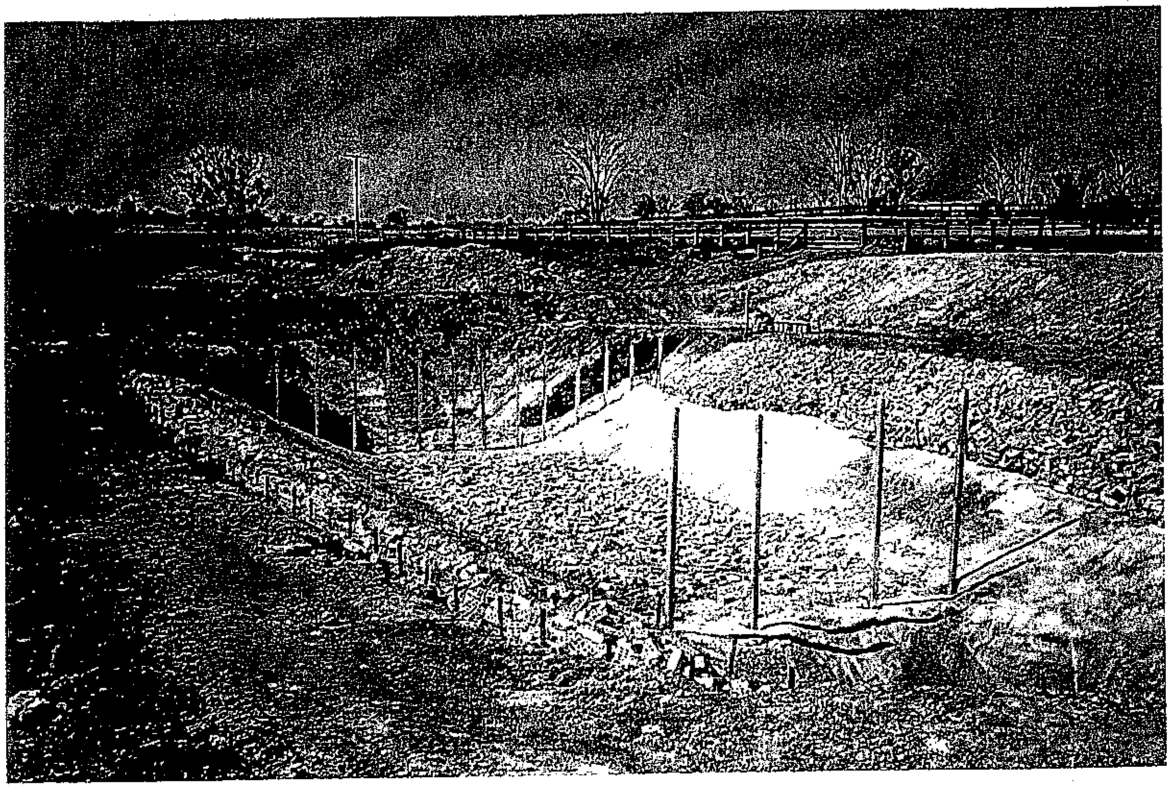


Figure 7.5: The settling zone showing the turnover baffle and the effluent weir (left). Over time there was some grass growth over the zone, but this did not affect performance.

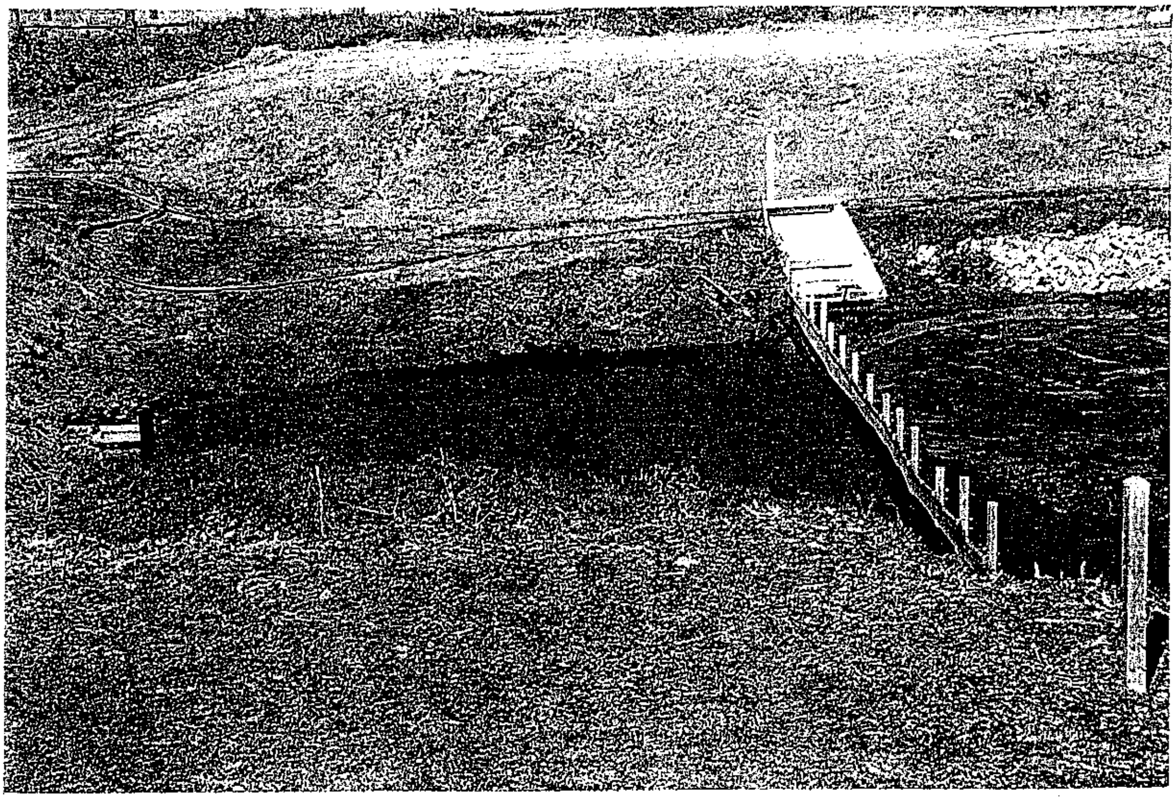


Figure 7.6: View of Partial Baffle showing the cross-sectional area obstructed.

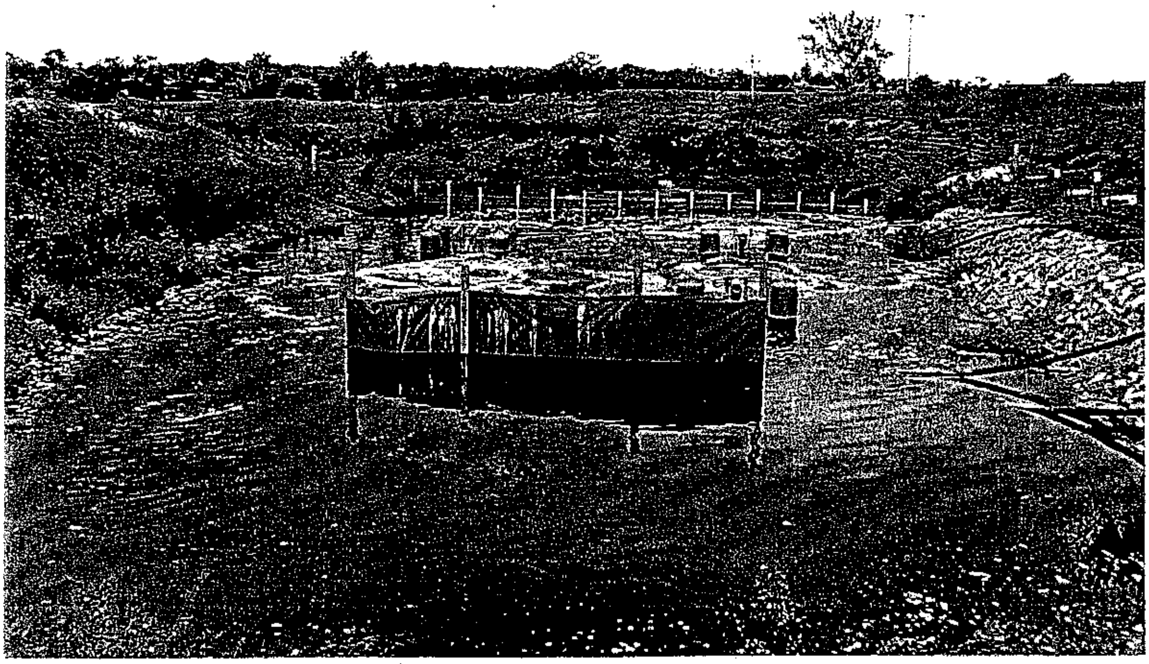
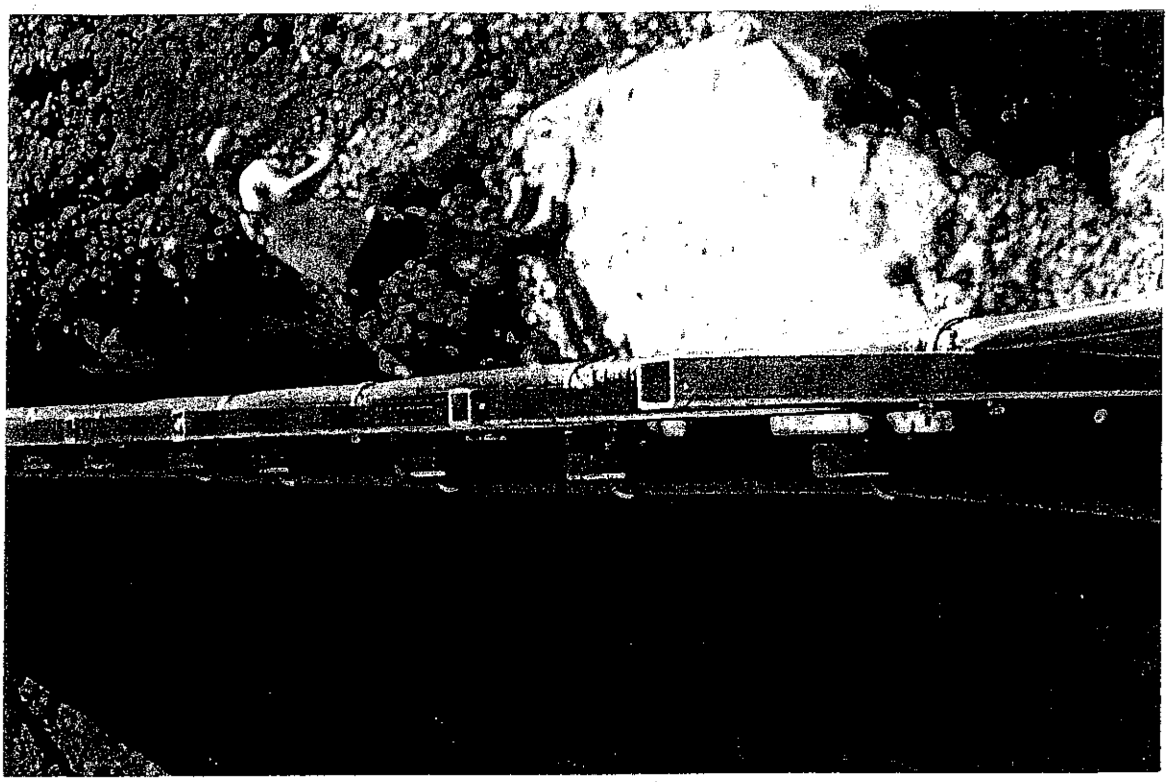


Figure 7.7: a, Top - Top view of the turnover baffle with the over baffle on left, under baffle on right. b, bottom - view showing the over baffle, the top of which set water level in the aerated zone.



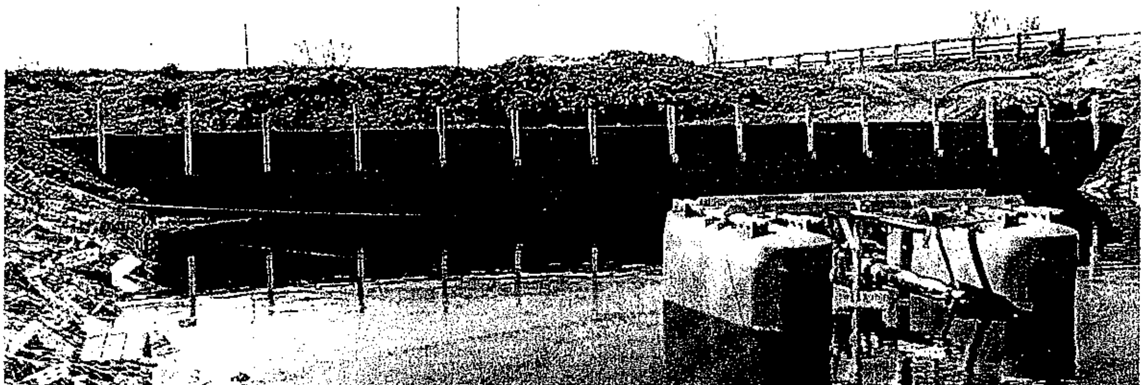
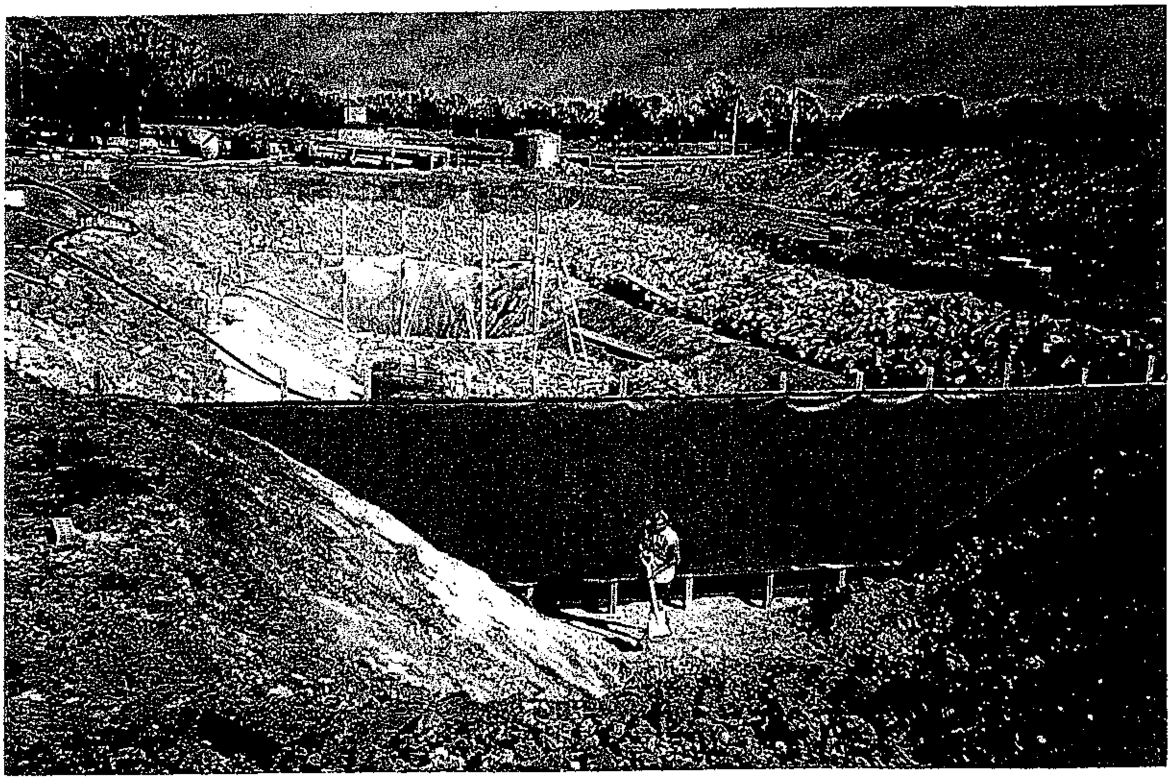
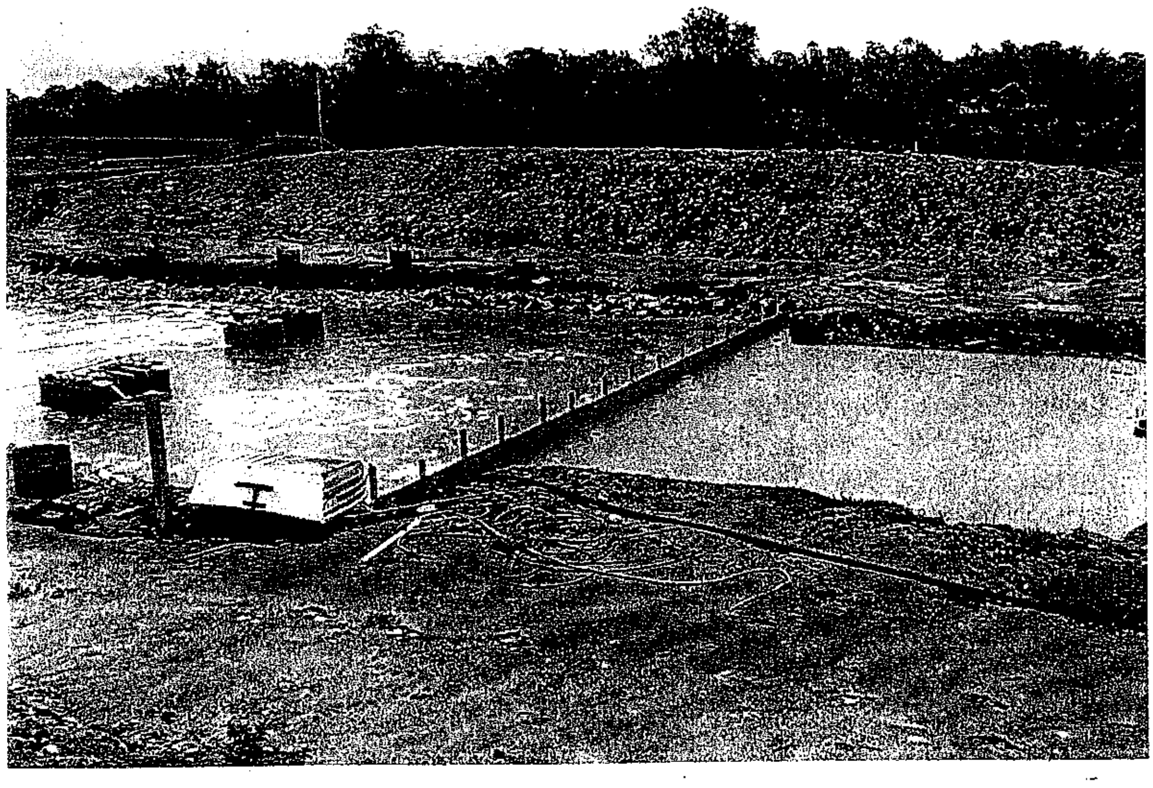


Figure 7.7: c, Top - View of the under baffle and settling zone. The water exits at the base of the zone. d, bottom - Quiescent conditions in the settling zone (right of baffle).





7.4 Capital and Operating Cost of Pond

7.4.1 Capital Cost

The capital costs (both equipment and labor components) contained here are based upon the design, construction and fitting out of the pond. It includes:

- the three aerators
- baffles and their support systems
- and the feed flowmeters.

It does not include:

- (buried) feed and return lines
- the (2) feed pumps
- the effluent return pump and their associated control equipment.

These items are not included as they will obviously depend upon the individual circumstances.

Based on these guidelines, the total cost (both equipment and construction labor) for the 940 m^3 experimental pond was \$56,328 (\$60/m^3). For the design 100 m^3/day feed rate, the capital cost represents \$0.15/kL treated for a 10 year pond life. This cost is high due to the small size of the pond and its experimental nature.

7.4.2 Operating Cost

The pond was originally equipped with three directional aspirating aerators - two 2.2 kW units with a single 3.7 kW unit. Operational experience demonstrated that the pond could operate with just two units - one of the 2.2 kW aerators and the 3.7 kW unit. Dissolved oxygen levels could be kept around 0.5 - 1 mg/l in the aeration and settling zones and almost total nitrification (>95%) could be maintained (provided the suspended solids was kept above 500-800 mg/l in the aeration zone).

Based on the 100 m^3/day throughput with just these two aerators operating, this is a power load of 5.9 kW/100KL/day of treated wastewater. Based on aeration requirements only, this is equal to a power consumption of 1.4 kWh/kL. At a nominal power cost of 10c/kWhr, this is an operating cost of \$0.14/kL.

In contrast to the capital cost for the construction of the pond, the operating cost of the aerators will not be as effected by economics of scale. The aerator power required is more directly related to load and therefore any significant variation on this operating cost of 1.4 kWh/kL, will largely depend on the selection of the aerators (or aeration system) and their oxygen transfer efficiency.

Chapter 8

Pond Performance

This section describes the performance of the M.478 pond under a variety of test regimes which were designed to assess the effect of critical operating variables on the robustness and effectiveness of its nitrogen removal performance.

8.1 Pond Commissioning and Summary of Operations.

The major activities of the M.478 pond project are outlined below:

- Design and Construction: April - 14 September 1995
- Pond Commissioning: 13 November 1995 - 5 February 1996
- Pond Trials: 13 February 1996 - 18 December 1996.

8.1.1 Pond Commissioning

The main events during the approximate 3 month commissioning of the pond are detailed below. A fuller description is given in Appendix 8.1.

- The Pond was filled to 75% full initially with treated wastewater from Pond 5;
- Since a nutrient removing SBR was located at Dinmore (Pond 4), the mixed liquor from this pond was pumped into the M.478 pond to provide the remaining 25% volume and the seed.
- Pond 2 anaerobic feed was begun at 100 kL/day (design load);
- Pond 1 feed was initiated 12 days later at a ratio of 2:1 Pond 2:Pond 1 feed at a total of 100 kL/day.

Initial TSS were low (<100 mg/l), DO levels were high (7-8 ppm) and nitrification was immediately experienced on feeding Pond 2 effluent to the pond. Levels of ammonium-nitrogen were less than 20 mg/l, with nitrate-N concentrations of 50 - 80 mg/l. The pond pH reflected extensive nitrification with little denitrification, with pH in the range 5 - 6.

When pond 1 effluent feeding was begun (29/11/95), the DO fell to 5-6 ppm and pH increased to 6-7 within 2 weeks. Increased ammonia-N concentrations (30 - 50 mg/l) and reduced nitrate levels (30 - 40 mg/l) resulted. Consequently start-up, when BNR sludge is used, is rapid.

8.1.2 Summary of Operations

Pond operation occurred over the period 13 February - 18 December 1996. A description of the operation plan is given in Appendix 8.2. Two major interruptions to operation occurred during the project. The principal ones were:

1. A shutdown at AMH Dinmore for a week in February 1996 interrupted feed to the system.

2. 29 April - 13 May 1996: Record rainfall in the SE Qld corner flooded the region and shutdown the Dinmore operation temporarily. Approximately 800 mm rain was received in 2 weeks. Although the pond site was not flooded, the rainfall washed much of the solids from the pond. Due to inability to bring in stock, Dinmore was shutdown until 13 May.

8.2 Pond Test Program

The test programme involved:

- testing the ability of the pond to remove nitrogen and COD;
- investigating the effect of changes in pond operation on effluent quality. The changes tested are detailed in Table 8.1.
  Unfortunately, trial times for the later conditions were usually only three weeks duration due to the requirement to finish the project. However, the pond appeared to give stable performance within this time for all trials.

Table 8.1 Testing of pond performance during 1996.

Period tested	Variable tested	Ratio (%) P1:P2 feed*	Flow m^3/day	Comments
13 Feb - 20 Mar	Feed rate	33:67	200	2x design flow
21 Mar - 17 Apr	"	"	150	
18 Apr - 1 Jul	"	"	100	design flow
2 Jul - 9 Aug	Feed ratio	50:50	100	
10 Aug - 10 Sep	"	33:67	"	
11 Sep - 2 Oct	"	67:33	"	Best performance
3 Oct - 22 Oct	Feed point	67:33	100	Into anoxic zone
23 Oct - 29 Nov	Intermittent aeration	"	"	2.2 kW on/3.7 kW intermittent
30 Nov - 18 Dec	Partial baffle	"	"	

* P1: Pond 1 feed; P2: Pond 2 feed.

Given the relatively large hydraulic residence time of the pond (9.4 days at the design 100 m^3/day), a minimum of 2-3 weeks was required for the pond to obtain steady operation after each change of conditions.

8.3 Overall Results of the Pond Testing

The removal of pollutants by the pond for each of the trials listed in Table 8.1 above are given below in Table 8.2 and the mean and min/max values of pollutants exiting the pond are listed in Tables 8.3 and 8.4, respectively. Due to the low retention time in the settling zone, pollutant concentrations in the aerated basin and exiting the settling zone (and the pond) were identical, except for dissolved oxygen (typically 2 mg/l less in the settle zone) and TSS levels.

Table 8.2 Removal of pollutants during pond trials and values of important pond measures.

Trial	Removal (%)			Concentration in basin		Pond pH
	CODsol	CODtot	Nitrogen	TSS (mg/l)	DO (mg/l)	
1	34.8	66.9	19.8	low	2.7	7.5
2	42.6	76.3	25.7	240	2.3	7.2
3	19.7	66.7	54.7	140	4.9	7.3
4	24.8	71.7	54.5	1060	2.9	6.3
5	26.0	73.8	55.1	1350	2.5	5.7
6	30.6	85.0	62.5	1720	3.6	6.2
7	28.0	91.0	64.1	2530	2.6	6.2
8	36.9	88.1	75.1	1020	0.9	6.6
9	36.7	85.6	67.1	280	2.2	6.7

Legend: Trials 1-3: Feed flow: Trial 1, 200 m^3/day; Trial 2, 150 m^3/day ; Trial 3, 100 m^3/day
Trials 4-6: Feed ratio (Pond 1: Pond 2): Trial 4, 1:1; Trial 5, 1:2; Trial 6, 2:1.
Trial 7, feed to anoxic zone; Trial 8, intermittent aerator operation; Trial 9, removal of partial baffle & continuous aeration.

Table 8.3 Effluent concentrations of pollutants from the pond.

Trial	TSS (mg/L)	CODs (mg/L)	CODt (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	TKN (mg/l)	NH_4-N (mg/l)	TN (mg/l)
1	61	134	232	17	24	43	140	84	181
2	73	144	255	26	8	39	85	51	119
3	45	139	216	7	14	24	53	39	73
4	82	117	214	2	47	27	31	21	80
5	80	117	218	1	63	24	12	2	74
6	102	111	219	0	51	24	15	3	66
7	79	105	165	0	52	27	13	4	65
8	34	105	137	0	32	25	11	2	43
9	12	131	172	2	36	30	19	10	56

Legend: Trial numbers as per table 8.2.

Table 8.4 Minimum & maximum concentrations of pollutants in pond effluent.

Trial		DO (mg/L)	TSS (mg/L)	CODs (mg/L)	CODt (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TKN (mg/l)	NH_4-N (mg/l)	TN (mg/l)
1	Min	0.4	10	114	156	3	9	42	25	108
	Max	5.1	93	158	274	38	111	192	115	225
	Min	2.0	50	138	216	22	1	81	48	104
2	Max	2.5	95	151	278	34	17	90	54	134
	Min	2.9	20	123	188	2	3	39	23	58
3	Max	5.3	67	163	251	10	25	69	57	86
	Min	2.1	127	72	151	0	14	10	1	72
4	Max	3.2	147	161	242	4	72	74	58	93
	Min	2.3	40	99	186	0	55	10	1	70
5	Max	3.8	113	145	247	1	68	15	5	80
	Min	3.5	40	94	169	0	46	13	1	65
6	Max	5.0	147	135	305	0	54	20	5	67
	Min	1.8	43	96	131	0	35	9	1	49
7	Max	4.0	80	111	184	1	63	18	10	67
	Min	1.3	20	91	113	0	17	7	0	25
8	Max	2.2	40	130	165	0	55	19	6	64

Legend: Trial numbers as per table 8.2. Note that Trial 9 had too few values to make data relevant.

The nine trials demonstrate that pond performance is sensitive to several operating and design factors. This is discussed further below.

8.3.1 Recommended Pond Operation

1. Intermittent Aerator Operation:

The best nitrogen removal from the pond was achieved during the intermittent operation of the aerators with a 2:1 pond 1:pond 2 feed. During this time, the total nitrogen removal peaked at relatively steady 75% over the two week testing period. However at the same time it was observed that the pond suspended solids steadily declined.

This suggested that intermittent operation of the aerators was dropping out the suspended solids during the idle periods, but failing to re-suspend the solids once full aeration started again. If the trial with intermittent aerator operation had been allowed to continue, it is likely that the suspended solids would have fallen to a level (less than 600 mg/l TSS) where the degree of nitrification would have been adversely affected - thereby harming the level overall nitrogen removal.

Therefore, while this mode of operation did achieve the maximum nitrogen removal, it cannot be recommended for long term operation until the settling problem is overcome. This trial (no. 8) is discussed further below.

2. High Pond 1 Feed Operation:

The recommended mode of operation is that performed as trial 6, namely a higher proportion of stronger anaerobic feed. The performance of the pond under these conditions is highlighted in the shaded rows of tables 8.2 and 8.3. During this time, overall nitrogen removal was approximately 63% with a total nitrogen concentration in the pond effluent of 66 mg/l, which is in the range in which the nitrogen and water demands of the pasture are simultaneously met, which is the preference for irrigation.

The forms of nitrogen present in pond effluent include:

51 mg/l nitrate-N
3 mg/l ammonium-N
12 mg/l organic nitrogen
and zero nitrite.

Total COD removal was 85% with the final total COD concentration of 220 mg/l being suitable for irrigation and corresponds to a BOD_5 of approximately 30 - 40 mg/l. TSS in pond effluent were 100 mg/l, reduced by the turnover baffle from 1,720 mg/l present in the aerated basin.

Therefore, the recommended operating conditions are as follows ;

Feed Rate : 100 m^3/day - equivalent to a design hydraulic retention time of 9.1 days.

Feed Ratio : 67% Pond 1 - fed to bottom of anoxic zone
33% Pond 2 - fed to bottom of anoxic zone (See Section 8.6.3),
Where two anaerobic ponds are not operated in series, a suitable ration of primary-treated and anaerobic treated feed could be used.

Aeration : One (1) 3.7 kW aspirating unit plus one (1) 2.2 kW aspirating unit operating continuously - positioned to create circular exchange of wastewater between aeration & anoxic zone. This amounts to 11.5 W/m^3 of aerated basin, or 6.4 W/m^3 total pond volume.

Sludge Recycle : minimum to maintain 2,000-3,000 mg/l TSS in aeration zone (from settling zone to aeration zone).

Sludge Wastage : minimum to maintain 1-2 metre depth of settled sludge in settling zone

Partial Baffle : Sufficient width to provide around 40% open cross-sectional area (ie 60% closed off).

8.4 Removal of Phosphorus, Suspended Solids & COD

8.4.1 Phosphorus

The removal of phosphorus in the experimental pond was not specifically targeted. A comparison of the mean phosphorus concentrations in the pond effluent with those in both anaerobic feeds, shows that no P removal was obtained. Any variation in the PO_4-P concentration in Table 8.3 is explained by the seasonal variation observed in pond 1 (see Table 6.2).

The lack of P removal is not surprising. No P removal was observed in the pilot scale SBR trials associated with this project, nor does the full-scale SBR at Dinmore achieve P removal. The literature suggests that the ratio of soluble COD: TP concentrations needs to be of the order of 20, before appreciable biological P removal is achieved. Unfortunately, the anaerobic feeds were deficient in soluble COD. Furthermore, P removal in the pond would necessitate sludge wasting on a more deliberate scale. While this is possible, it was not performed. A recommendation for future work is that phosphorus removal be more closely investigated. The pond infrastructure for this to occur is already in place.

8.4.2 Suspended Solids

Aeration of meat processing wastewater inevitably generates high levels of suspended solids, which include the bacterial population responsible for COD and nutrient removal. During the testing program it became apparent that in order to maintain good nitrification (>95%), the level of suspended solids in the aeration zone had to be kept above 500-800 mg/l TSS. In fact it was found that stable operation was achieved with the solids in the 1500-2000 mg/l range. One of the concerns in operating with such relatively high level of solids in the aeration zone was its impact on the performance of the settling zone and the resultant level of solids in the effluent.

The performance of the turnover baffle and the settling zone proved to be one of the highlights of the pond's operation. These provided pond effluent with an average 100 mg/l or less TSS despite large variations in the pond TSS - some over 2,000 mg/l (Figure 8.1). The maximum TSS in the pond effluent over 1996 was 150 mg/l (Table 8.4).

8.4.3 COD (organics)

In addition to the removal of most nitrogen from the wastewater, the pond consistently removed between 66-90% of the incoming total COD (See figure 8.2). It produced an effluent with typically 220 mg/l of total COD, although levels as low as 137 mg/l average were attained with intermittent aerator operation (trial 8). Values of soluble COD between 105 - 140 mg/l were achieved during all trials at design feed rate of 100 m^3/day (trials 3-9).

Figure 8.1 Efficiency of the pond in removing TSS from pond effluent.

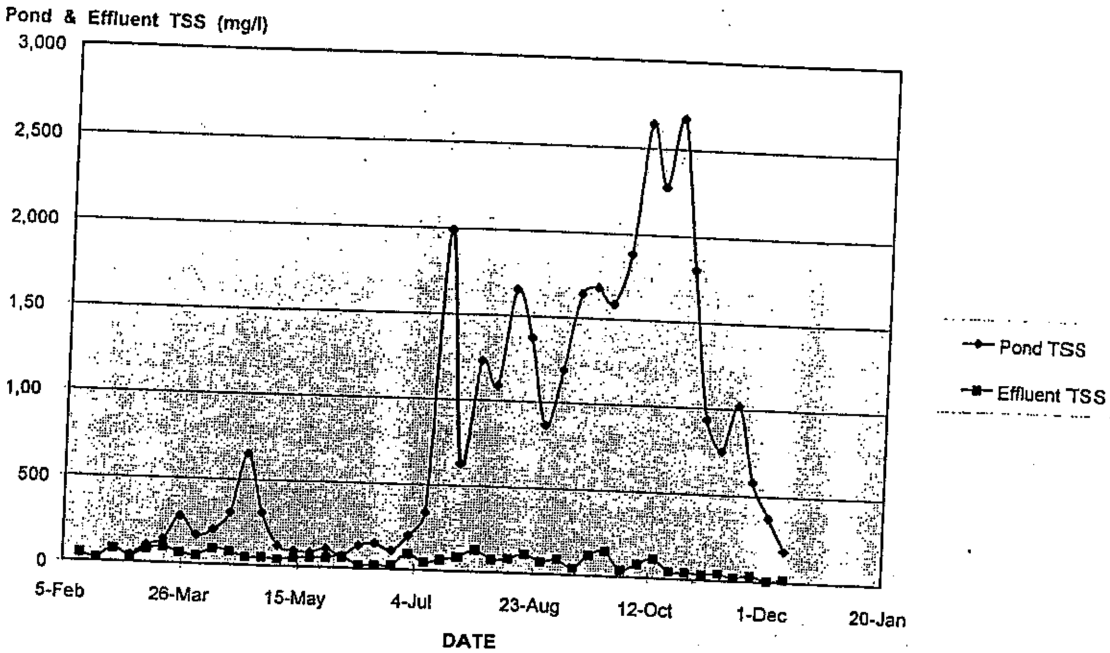
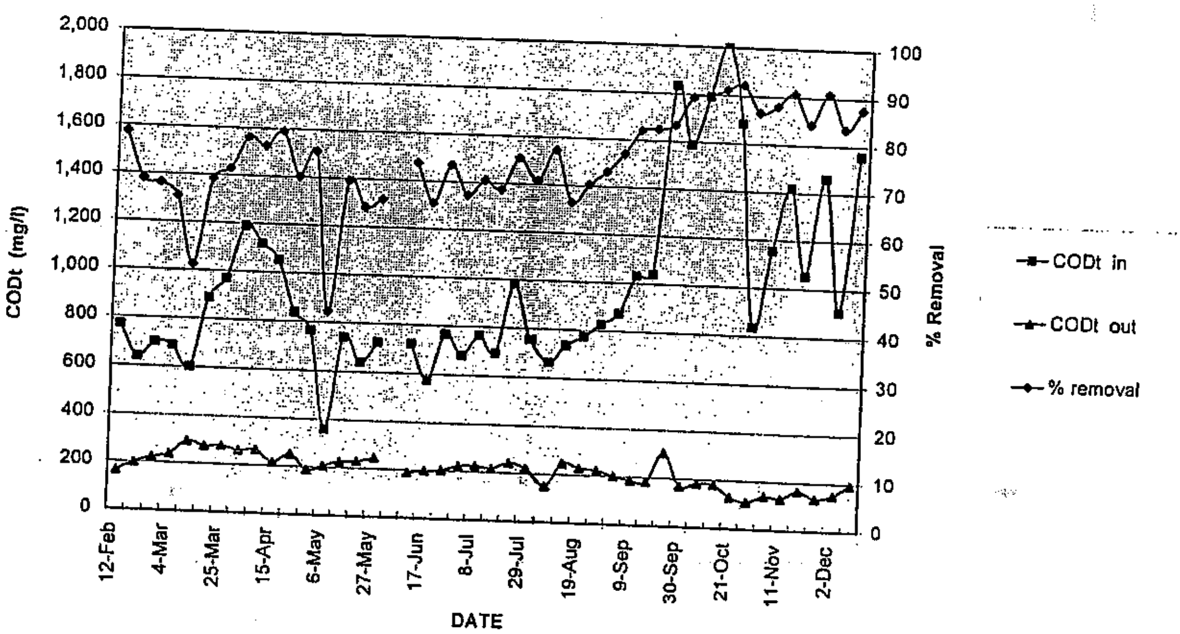


Figure 8.2. Total COD concentration in the feed and COD removal by the pond.



Interestingly enough, the data would indicate that the best performance was obtained with an increase of COD in the feed. The answer to this observation probably lies with the increased COD leading to improved denitrification, which besides consuming COD, also releases more oxygen to the wastewater for activities such as the reduction of COD. High levels of incoming COD (Figure 8.2) and nitrification (Figure 8.3) permit high quantities of nitrogen removal by denitrification.

8.5 Nitrogen Removal

The removal of nitrogen was successfully achieved in the pond to the levels required. A graph of nitrogen removal through the duration of the trials, indicating percentage nitrification and denitrification, and the values of critical parameters, is given as Figure 8.3. The effect of the various factors tested on nitrogen removal are discussed in Section 8.6 below. Rates of nitrification and denitrification are given as Appendix 8.3.

Overall, several trends were observed:

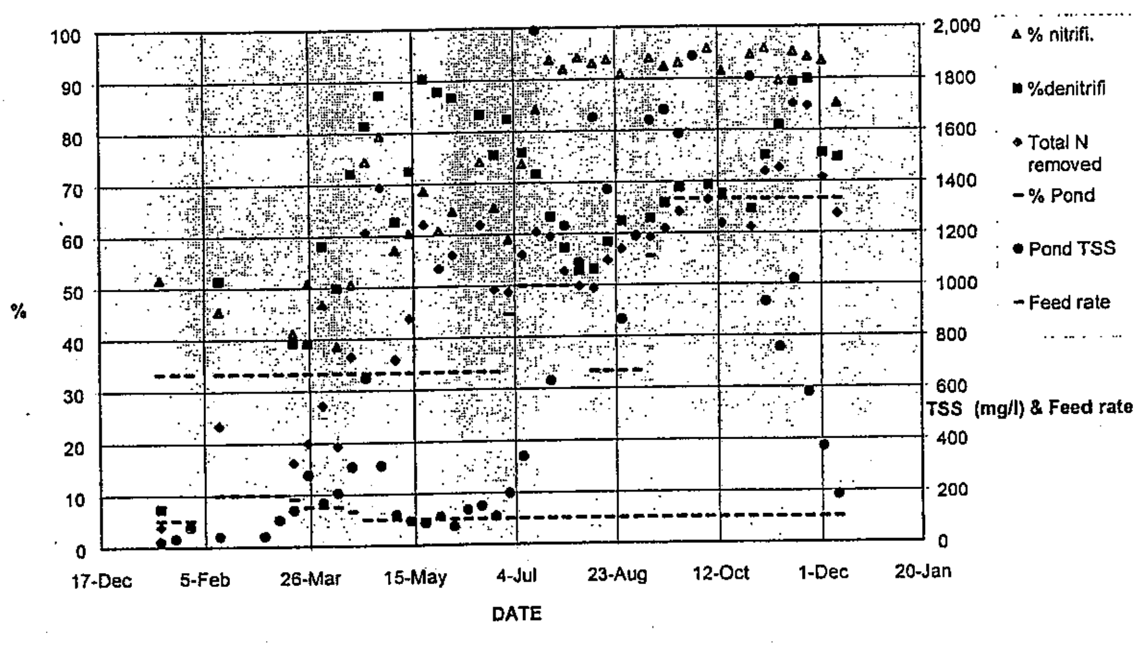
8.5.1 Nitrification

Full nitrification was achieved from early July onwards and was consistently attained until mid-December when the project ended (Fig 8.3). Nitrification is defined in this report as % ammonia-N in feed converted to either nitrite-N or nitrate-N and is critical to nitrogen removal. Full nitrification correlated especially to:

- Sufficient retention time (HRT):

A HRT of about 8 days in the anoxic and aerated zones seems about right for the pond to achieve full nitrification. Lower values of HRT resulted in poor nitrification. Trial 1 (HRT = 4 days) and trial 2 (HRT = 6 days) gave nitrification values of only about 50% and lead to very poor N removals of 20 and 26% respectively.

Figure 8.3. Effect of critical operating factors on nitrogen removal.



- Sufficient TSS in the aerated zone:

Getting the HRT to 8 days in trial 3 improved nitrification to 60 - 70%, however TSS concentrations in the aerated zone were low (only 140 mg/l ave.). When sludge was recycled into the aerated zone from the settle zone in July to increase TSS to over 1,000 mg/l, there was an immediate and sustained improvement in nitrification to more than 95%. Interestingly, relatively high concentrations of nitrite were measured, in addition to ammonia, in trials 1 - 3, despite abundant DO levels. Nitrite was not measured in subsequent trials (4-8) when TSS concentrations increased, but appeared in trial 9, which also experienced low TSS levels.

- Presence of the partial baffle:

The removal of the partial baffle in trial 9, resulted in a fall in nitrification, despite reasonable DO levels in the aerated basin (Table 8.2). It is possible that it enhanced settling out of TSS in the deeper anoxic zone, to the detriment of the nitrifier population.

Nitrification was insensitive to the feed ratio.

8.5.2 Denitrification

Denitrification varied considerably during the trials (Figure 8.3), but reached a maximum of 90% during trials 3 and 8. Generally, however, large quantities of nitrate remained in the pond. Denitrification is defined as % of the nitrified N removed. Denitrification correlated especially to:

- Sufficient COD:

The lowest nitrate nitrogen values correlated best with high ratio of pond 1 feed when full nitrification was achieved. It is well known that COD:TKN values of 7:1 are required for denitrification, and this was only achieved when feed from pond 1 was high.

- Low DO values in the aerated zone:

Denitrification is inhibited by the presence of DO levels. In trial 8, the DO fell to 0.9 mg/l, due to the intermittent operation of the aerators and this correlated to excellent denitrification and low nitrate and nitrite concentrations in the pond effluent. The additional denitrification had a side-benefit of lowering COD values.

Denitrification was unaffected by feed point location.

8.6 Effect of Factors on Nitrogen Removal

The trials investigated the effect of various operating and design factors on the removal of nitrogen. The results are briefly described below.

8.6.1 Effect of Total Feed Rate on Nitrogen Removal (Trials 1-3)

Following the installation of the two feed pumps in February, the total feed rate was raised to 200 m^3/day which is 200% of the design feed rate. This was done in order to increase the solids content of the aerobic & anoxic zones of the pond and to counter a lower-than-design COD in both the two feed streams. Three trials (1-3; see Table 8.1) were performed at 3 different feed rates.

The effect of variation in the feed rate on the percentage nitrification, denitrification, and overall nitrogen removal is shown in Figure 8.3. There is a trend for an improvement in total nitrogen removal as the feed rate was reduced. This is replotted as Figure 8.4 to show the effect of HRT. The percent nitrification increased from 30-50% during the 200 & 150m^3/day feed rates, to a fairly consistent 60-70% at 100m^3/day feed rates. Likewise percent denitrification (% of the nitrified N removed to nitrogen gas) rose from around 50% to 80-90%. Overall nitrogen removal rose from less than 20% to 50-60%.

The amounts (in terms of kg/day) of nitrification and denitrification exhibited a general trend upward in the amount nitrified, the amount denitrified is fairly constant at 10-12 kg/day, irrespective of the feed rate. The effect of HRT on the concentration of nitrogen species in pond effluent is depicted in Figure 8.5.

Figure 8.4 Effect of hydraulic retention time on N removal.

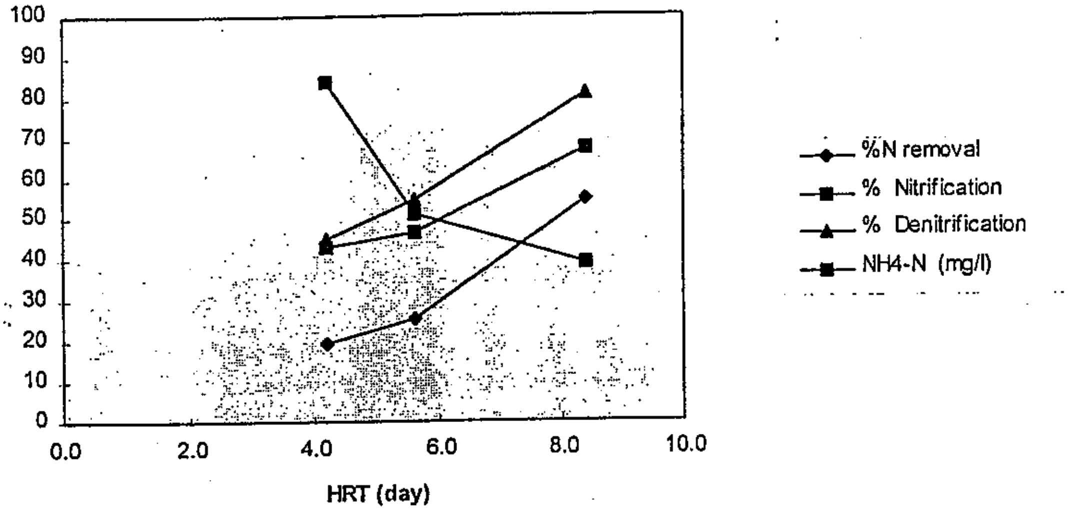
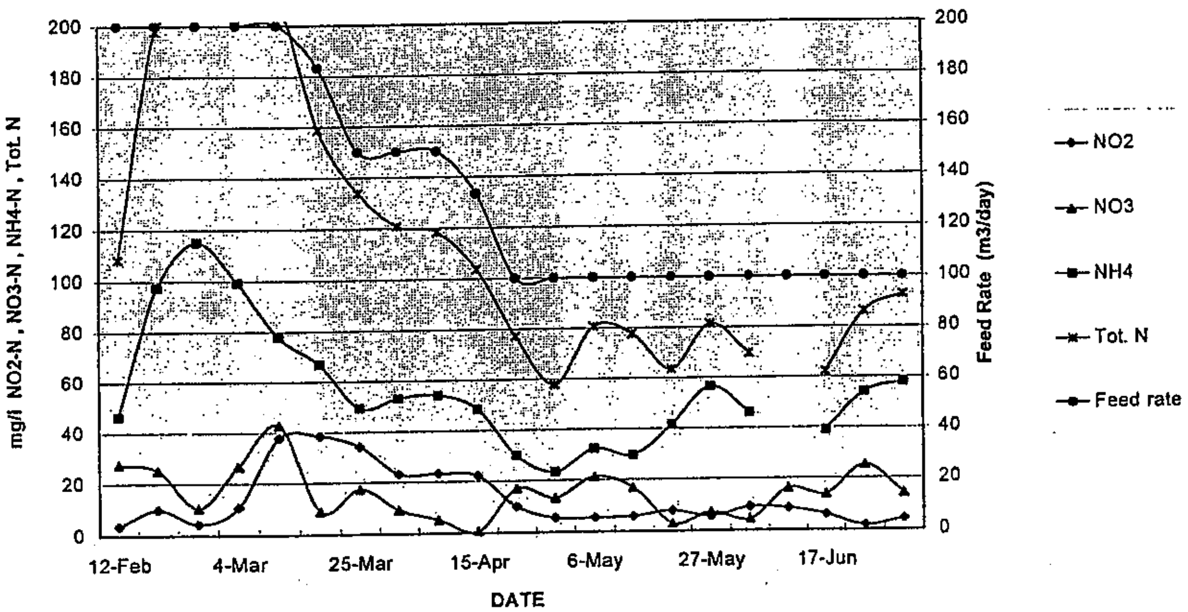


Figure 8.5 Effect of HRT on nitrogen forms in pond effluent



Legend:	Trial 1: HRT, 4.2 days, 13 Feb - 20 Mar; Trial 2: HRT, 5.6 days, 21 Mar - 17 Apr; Trial 3: HRT, 8.4 days, 17 Apr - 7 Jul.

Two interrelated factors can be identified to account for the low N removal.

- <u>low solids content in the pond</u> - the total suspended solids (TSS) in the aeration basin of the pond rarely rose above 200 mg/l during this period. Typically, the volatile fraction of these solids (those solids containing the nitrifying and denitrifying bacteria) is less than 80% of the TSS. The design MLVSS was 500 mg/l. This low level of MLVSS can adversely effect both nitrification and denitrification.

- low carbon content in the feed stream - the denitrification of the nitrified nitrogen is dependant upon carbon in the feed stream to "fuel" the denitrification reaction. The design BOD of the feed was 600 mg/l. Typically, for the abattoir wastewater used, this would correspond to a COD level of 1,200 to 1,500 mg/l. The level of COD in the combined feeds over this period was typically 600 - 800 mg/l, with soluble COD at 200 mg/l. The feed COD:TKN ratios were 4-6 for total COD, and less than 2 for soluble COD. It is recognised that a minimum COD:TKN ration of 7:1 is required for complete denitrification to occur.

8.6.2 Effect Of Feed Ratio On Nitrogen Removal (Trials 4-6) (02/07/96 - 02/10/96)

Following on from trials 1-3 above, the percent of Pond 1 feed in the total overall feed was increased, but the total feed was maintained at the design 100 m^3/day. At the same time, steps were taken to increase the level of solids in the aeration zone of the pond by regular batch recycling of settled sludge from the settling zone of the pond to the aeration zone (as opposed to simply wasting the sludge). The feed ratios used are given in Table 8.1.

The data are given in Figure 8.3. The most striking feature of this period is in early July when both the Pond 1 feed ratio was increased from 33% to 50%, and (perhaps more significantly) the solids levels in the pond was also increased from less than 200 mg/l to over 1000 mg/l TSS. Almost immediately nitrification increased sharply from 60-70% to over 90% - where it remained. Mirroring this was a corresponding decrease in the percent denitrification from 80% to 50-55%.

There was a sharp rise in the amount nitrified from 11-12 kg/day during trial 3 to 16-17 kg/day during trial 4, most probably due to the higher TSS levels. During trial 5, it reduced slightly to 15 kg/day at the lower pond 1 feed ratio, but picked up to 16-17 kg/day again for trial 6. On the other hand, the amount denitrified (which is equal to the total nitrogen removed) rose only slightly from 8-9 kg/day to a peak of 12 kg/day before falling back below 10 kg/day.

From these observations, a number of conclusions can be drawn.

- the effect of solids concentration on nitrification - there is a clear connection between the levels of TSS in the aeration basin and both the percent and amount of incoming nitrogen that is nitrified - specifically the feed ratio has little if any effect on nitrification. In fact, the increase in the percentage of Pond 1 feed would actually increase the total nitrogen in the feed.

  This conclusion was confirmed during August when the feed ratio was reduced back to 33% Pond 1 but the solids content of the pond kept over 1000 mg/l TSS. Both the percent and amount of nitrogen nitrified remained at their late July levels. In September when the feed ratio was changed to 67% Pond 1 there was relatively little change in the extent of nitrification. In fact the amount of nitrogen nitrified rose slightly as the amount of nitrogen in the feed would have increased.

- the amount of denitrification is affected by feed ratio - the amount of nitrogen denitrified remained relatively stable over the June-September period. Interestingly, the various small peaks and troughs all match perfectly the increases and decreases in percent Pond 1 feed. While the carbon in the feed stream remains below optimum, the clear indication is that as the percent Pond 1 feed increases (ie increased COD in the feed), both the percentage, and particularly the amount, of denitrification also increases.

8.6.3 Single Feed Point (Trial 7) (03/10/96 - 22/10/96)

During this period both the two anaerobic feed streams were directed to the bottom of the anoxic zone (ie the Pond 1 feed point). The purpose of this trial was to determine what effect - if any - the scheme of separate feed points had on the performance of the pond. Both the feed rate and percent Pond 1 feed were kept constant at 100 m^3/day and 67% respectively.

Overall the results indicate little change in the nitrogen removal from the pond. This is probably not too surprising considering prior to this change, 67% of the total feed was fed to this point. Nevertheless, it suggests that there is little value in separating the feed points.

Because of time constraints it was not possible to examine the other option of putting both feeds to the Pond 2 feed point in the aerobic zone.

8.6.4 Intermittent Operation of the Aerators (Trial 8) (23/10/96 - 29/11/96)

The levels of DO measured in the pond were generally quite high (Tables 8.1 and 8.4), which might discourage denitrification. Consequently, the purpose of the intermittent operation of the aerators was to effectively increase the anoxic volume of the pond. While aerators are off, the level of dissolved oxygen in the pond is reduced, thereby encouraging anoxic conditions. This should assist in with the denitrification reaction. The possible downside of this mode of operation is that overall DO levels could fall enough to adversely effect nitrification.

After some experimentation, the final configuration of the aerators adopted was:

- one 2.2 kW unit on full-time,
- with the 3.7 kW unit on a 1 hour ON/1 hour OFF operation.
- the second 2.2 kW unit was not used at all (that closest to the anoxic zone in Figure 7.1).

During this period both the feed rate and percent Pond 1 feed were kept constant at 100 m^3/day and 67% respectively

The intermittent operation of the aerators produced the best nitrogen removal performance of the testing programme. During this period the percent of overall nitrogen removal rose steadily from around 65% to a steady 85% removal. While nitrification remained steady at around 95%, denitrification rose from 65-70% to 90%. Total nitrogen in the effluent was 20-25 mg/l N.

However one clearly apparent side-effect of the intermittent operation of the aerators was the fall-off in the level of suspended solids in the pond. As can be seen from Figure 8.1, almost from the moment the intermittent operation began, the TSS dropped steadily from over 1200 mg/l, to less than 600 mg/l by the end of this period of operation. Furthermore, there was a noticeable reduction of solids in the settling zone of the pond (both visually and by analysis). The conclusion was that during the idle periods in the operation of the aerator, the solids were dropping to the floor of the pond and clearly not re-suspending when the aerators came back on.

This reduction in TSS, while not effecting performance during this period, was to begin to have an effect during the next phase of operation.

8.6.5 Removal of Partial Baffle (Trial 9) (30/11/96 - 18/12/96)

The final study involved the removal of the partial baffle in order to observe its effect on the formation of an anoxic zone - and in turn the effect on denitrification. During this period both the feed rate and percent Pond 1 feed were kept constant at 100 m^3/day and 67% respectively and the same intermittent aerator operation used in trial 8 was continued.

The removal of the baffle had an immediate effect on denitrification. On the Monday following the removal of the baffle on the Friday, the nitrate levels both in the mixed pond and in the effluent had doubled from 17 to 34 mg/l NO_3-N. In the following days the level of nitrate continued to rise steadily - although at a slower rate.

However the most interesting trend which started to come through after a week was a small, but significant rise in both ammonium and nitrite - indicating a falloff in nitrification. This falloff in nitrification also means an even greater decrease in the amount of denitrification than is indicated above.

The reason for the reduction in nitrification was a decrease in the solids content of the aerobic zone of the pond - largely as a continuation of the reduction of solids during the intermittent operation of the aerators.

This reduction of nitrification was countered by turning on additional aeration capacity and by recycling sludge from the settling zone of the pond. By the end of the testing period the solids content of the pond had started to improve and with it, a return to 95%+ nitrification. Unfortunately, time did not allow a continuation of the study.

Chapter 9

Sequencing Batch Reactor Pilot Plant Design and Costing

9.1 Objective and Concept

The purpose of the Sequencing Batch Reactor (SBR) pilot plant is the determine the maximal level of nitrogen and phosphorus removal achievable from abattoir wastewater. The aim is to achieve a water quality suitable for discharge to inland waterways without detrimental environmental effects. This would be required in situations where there is insufficient land available for irrigation (eg in semi-urban environments) or other constraints exist that leave discharge to waterways as the only viable option (eg groundwater related limitations).

The underlying concepts of the SBR approach are:

- Implement a biological nutrient removal (BNR) process in the most effective way, both in terms of construction/capital costs and operation.
- Use prior anaerobic treatment as the most efficient COD removal stage while still supplying sufficient and suitable COD required for the BNR process.
- To demonstrate a BNR technology that can be optimally incorporated into existing abattoir treatment systems using ponds.

Concept 1: Cost-effective BNR process

Complete BNR processes are inherently complex due to the various conditions required to achieve both nitrogen and phosphorus removal by biological means (see Chapter 4). The selection of the SBR process has been based on the relative simplicity how the integration of all these processes is being achieve into a **single tank operation.** This has a number of advantages such as

- Reduction in capital costs based on the elimination of a large part of external piping and pumping requirements and the fact that for a given volume a single tank is considerably cheaper to construct than multiple tanks.
- Simplification of tank construction since the SBR can be built in the form of an earthen pond and thereby largely utilise existing pond construction technology.
- Higher degree of operational flexibility due to the time-based process operation. This is of particular importance in industrial and indeed abattoir wastewater treatment since changes to abattoir operation and primary treatment systems are quite frequent and can change the composition of the wastewater considerably.
- Ease of operation based on the limited number of sensors, pumps and valves which require regular maintenance to ensure full reliability of the process. This also offers opportunities for remote operation of the process (combined with regular site visits), possibly even by external contractors.

This concept has been proven to work on abattoir wastewater during several years of research at small scale within the Department of Chemical Engineering at The

University of Queensland (UQ). The results achieved in these studies have been very encouraging with over 90% elimination of both nitrogen and phosphorus compounds being achieved on actual abattoir wastewater. Additionally, similar concepts have been demonstrated to achieve high levels of nutrient removal at full scale from domestic and industrial wastewaters.

Concept 2: Optimise use of anaerobic and aerobic COD removal

As mentioned in Chapters 4 and 7, the optimal integration of the BNR process into the existing anaerobic pond treatment is important to minimise operating costs for the BNR stage while still achieving the full nutrient removal potential.

Much of the previous research at UQ has been focused on this aspect and good prior knowledge of the required anaerobic pre-treatment has been gained through this work.

Concept 3: Demonstrate integration into existing abattoir treatment system

The single tank operation is dependent on an intermittent influent stream since water is only flowing into the tank for a limited time (usually about 50% of time). Using the anaerobic ponds, however, the intermittent influent characteristic can easily be achieved. The storage capacity for wastewater is usually well in excess of the amount required during the non-feed period (typically 2-3 hours).

Additionally, the SBR could well be retrofitted instead of an aerobic or aerated pond since the required hydraulic retention time (HRT) in the pond is likely more than sufficient for operation in the SBR mode. Therefore, the SBR is likely the most effective and cost-efficient process to achieve a high effluent quality with a minimum in capital and operating costs.

9.2 Description and Design of Portable SBR Pilot Plant

- Figure 9-1 shows the two SBR tanks and the adjacent control building as seen from the top.
- The unit is fully self-contained and portable and its installation at the Dinmore abattoir is shown in Figure 9-2.
- The diagram in Figure 9-3 shows the schematic layout of the control room and the two SBR tanks.
- SBR design parameters are summarised in Table 9-1.

Further details of the SBR design and operation are given in Appendices 9.1 and 9.2.

9.2.1 Description of SBR Pilot Plant

The sequencing batch reactor (SBR) pilot plant, as shown in Figures 9-1 and 9-2, consists of two 6000 litre fibreglass tanks placed side by side with an adjacent control room, all of which is mounted on a steel skid. Overall dimensions are 6.4m (length) x 2.4m (width) x 2.5m (height). The control room contains all the process and control equipment necessary to operate both SBR tanks.

Each of the two tanks is an independently operated SBR. Both are equipped with two feed pumps, one for each feed source (anaerobic ponds 1 and 2). The pumps are positive displacement (MONO) type pumps, which are operated through variable speed controllers, allowing full adjustment of both the filling time and ratio between the two feed streams.

Two centrifugal air compressors are also installed in the control room and provide the air for aeration of the tanks. Only one blower is operated at a time (being sufficient in capacity for both tanks), with the second blower on standby. Air is dispersed in the two tanks via membrane diffusers which are positioned at the bottom of each tank. Besides providing a good oxygen transfer efficiency, the membrane diffusers also mix the tanks very effectively.

During the aeration phase, the dissolved oxygen level in the tanks is maintained between the upper and lower dissolved oxygen (DO) control limits. This is achieved by opening and closing solenoid valves in the air lines to the tanks and exhaust lines to the atmosphere.

Solenoid valves are also used to control effluent withdrawal and sludge wastage. During the effluent withdrawal phase, the effluent is decanted from the top water level using a floating decanting mechanism.

The whole process is controlled with a computer based control system, located in the control room adjacent to the SBR tanks. This system was selected for the pilot plant operation as it allows large flexibility in adjusting various operating parameters and treatment strategies. For a full-scale installation, a PLC based control system is likely sufficient for the operation of the plant.

More detail on the design and set-up of the SBR and its control system is contained in Appendix 9-2.

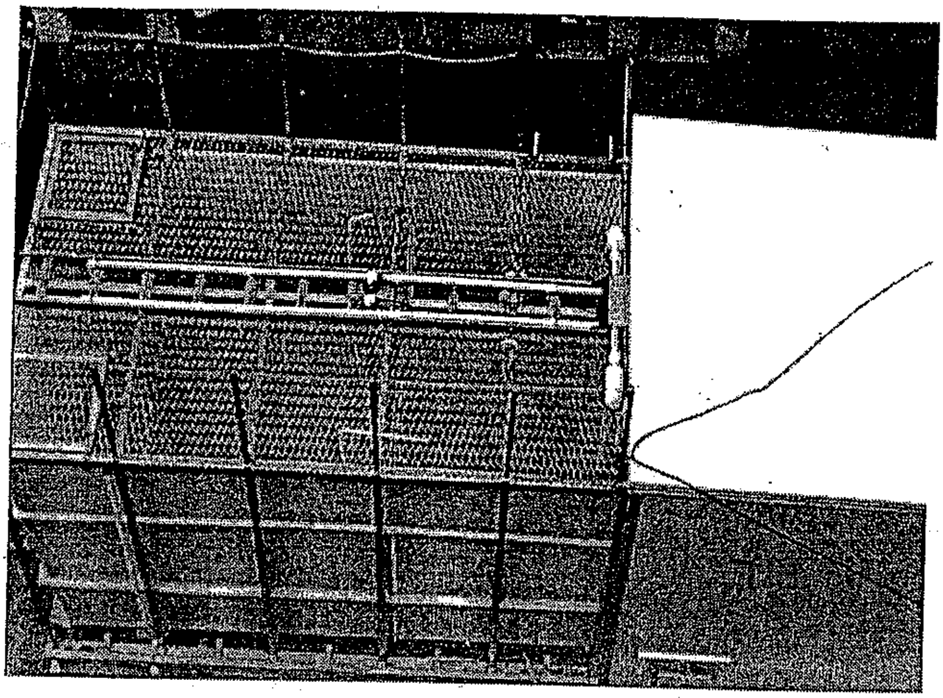


Figure 9-1: View from top onto the two SBR tanks and the control building

Figure 9-2: Installation of portable SBR unit at Dinmore abattoir

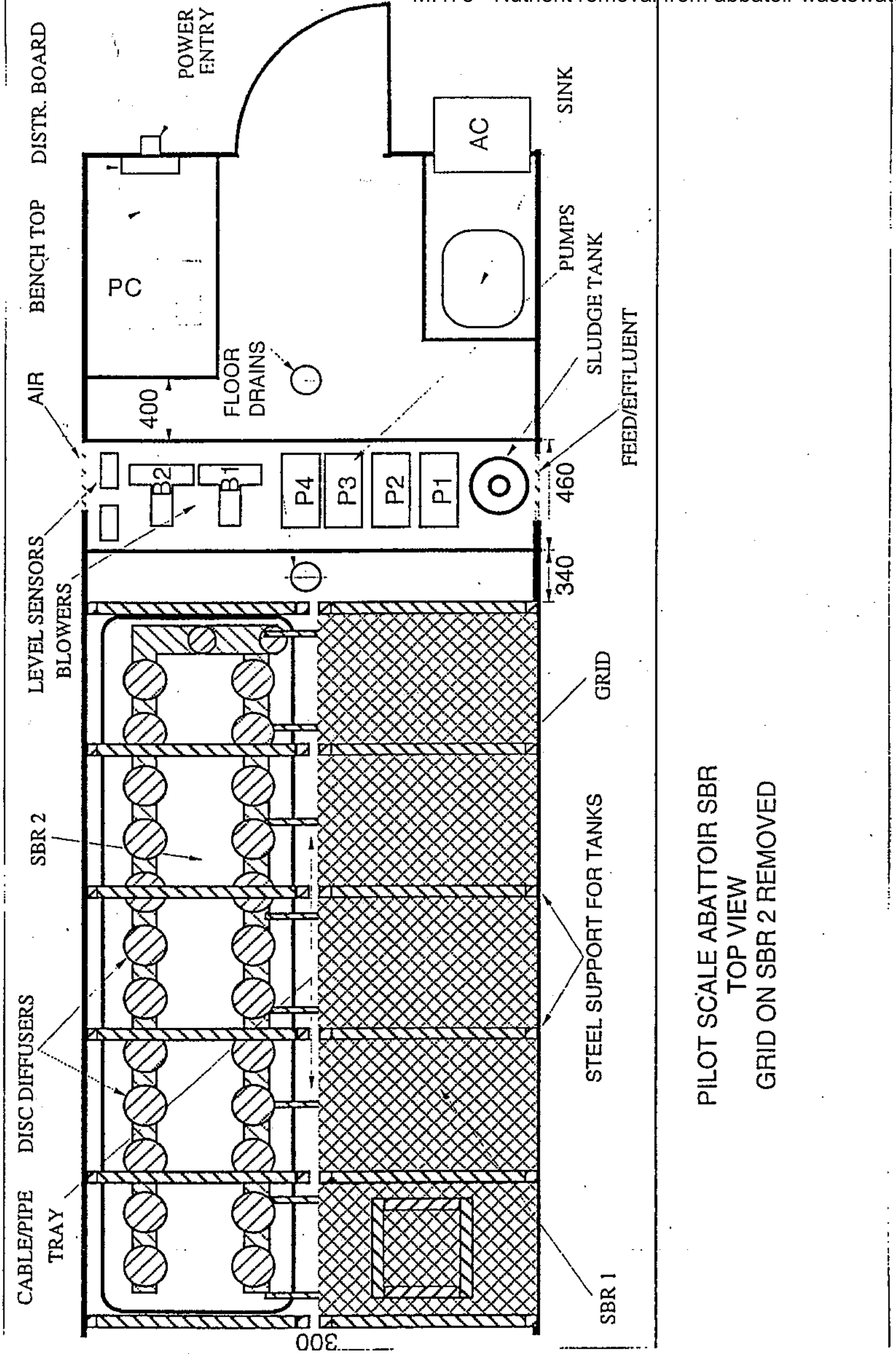


Figure 9-3: Schematic diagram of SBR control room and tank layout

9.2.2 SBR Overall Design Parameters

A summary of the basic design and operating parameters of the two SBR tanks is contained in Table 9-1, shown below. These parameters represent mostly optimal operating conditions. However, several changes to a number of control variables have been made during the experimental stage to optimise the performance of the system. These changes and the resulting effects are further discussed in the following sections and a detailed events summary is given in Appendix 6-3.

Table 9-1. Basic Design and Operating Parameters of SBR Tanks

DESIGN PARAMETER	SBR 1	SBR 2
Design throughput (m^3/day)	6	6
Hydraulic retention time HRT (hrs)	24	24
Percentage of feed from Pond 1	60	80
Fill volume per cycle (m^3)	1.5	1.5
Total cycle time (hrs)	6	6
Feed (hrs)	1.8	1.8
Mixed React (hrs)	0.3	0.3
Aerated React (hrs)	2.7	2.7
Settle (hrs)	0.5	0.5
Draw (hrs)	0.7	0.7
Aeration control limits[1] (mg/L O_2)	0.2 - 0.4	0.2 - 0.4
Estimated oxygen requirement[2] (kg/d)	6.4	7.5
Sludge age[3] or SRT (days)	15	15

[1] The DO control range 0.2 - 0.4 mg/L O_2 was found to be the optimum for nitrification/dentrification. The initial control range was 0.5 - 2.5 mg/L O_2.

[2] Based on average COD concentration during operating period (1150 mg/l and 1410 mg/l, respectively), includes effect of denitrification.

[3] A 15 day sludge age was found to be optimum. On occasions, in order to control the level of MLSS in the reactors, the sludge age was varied to between 10 and 30 days.

As shown in Table 9-1, the major difference between SBR 1 and SBR 2 was the fraction of feed to each SBR from Pond 1. Because feed from Pond 1 contains a high

COD concentration, which is necessary for denitrification to proceed, the percentage of feed from Pond 1 affects the extent to which denitrification occurs in each reactor.

9.2.3 Specific Design Features

This SBR pilot plant incorporates a number of specific design features which are unique to this type of BNR process. These are briefly outlined below.

Influent distribution system

The influent from Ponds 1 and 2 are mixed and evenly distributed in the bottom of each tank. This is achieved by a four separate feed supply lines in each tank which extend across the entire tank floor and have numerous outlets at the bottom. Additionally, a non-mixed, non-aerated Fill period is used. Therefore the influent is evenly distributed into the bottom of the settled sludge blanket and closely contacted with the entire sludge content in the tank. This feature is a key element of this SBR concept and has been protected in many countries by patents in the name of the CRC for Waste Management and Pollution Control Ltd.

The objective of the feed distribution and sludge contacting is to achieve both a selector effect and to supply the incoming soluble COD to the phosphorus removing sludge with a minimal loss to denitrification reactions. Nitrate in the sludge blanket is typically removed during the settling and decant periods or the initial short time of Fill since the amount of nitrate in the sludge blanket volume is quite limited. The close contacting of the incoming wastewater with the sludge in the tank also improves settleability of the sludge similar to the effect of separate selectors used in continuously operated activated sludge plants. These selectors are small, mixed or aerated tanks where the return sludge from the clarifier is contacted with the incoming wastewater for a period of typically 15-30 minutes. The excellent settling performance observed in the operation of this pilot plant is a clear indication of the effectiveness of this approach.

Operation for Simultaneous Nitrification/Denitrification (SND)

As shown in Table 9-1, the optimal operating dissolved oxygen (DO) level was found to be 0.2-0.4 mg/l. This is very much lower than typically used for aerobic nitrification, but still higher than usual anoxic conditions for denitrification. The objective of this operation was to achieve Simultaneous Nitrification/Denitrification (SND) in one tank at the same time.

This has been success as shown in the low effluent nitrite and nitrate results (see Chapter 10). While this type of operation is still not well understood, it is clearly demonstrated that complete nitrification can be achieve at these low DO concentrations. Possibly influenced by the above mentioned feed distribution system, effective denitrification is also maintained at the same time, leading to direct nitrogen removal in a single tank/single stage operation.

Intermittent Fill Operation

These SBRs have been operated in a true sequencing batch mode with influent only being supplied for approximately 50% of the total cycle time. Therefore, during most of the aerated React period and the entire Settle and Decant times, no influent is supplied to the tank. This ensures that the effluent only consists of fully treated water and no short-circuiting or partially treated influent can be discharged. This allows to maintain a very high quality effluent even in smaller systems with short distances between influent and effluent discharge points.

9.4 SBR Capital and Operating Cost

9.4.1 Capital Cost

As with any pilot plant, and similar to the experimental pond, the capital costs of the SBR unit cannot be directly translated into full-scale cost estimates. Some items are even more expensive in the pilot scale than the full scale installation. One such example is the control systems since it is more sophisticated for this research project than is required for the full-scale operation. Additionally, much of the equipment was duplicated since two independently operating SBR tanks are included in this unit. On the other hand, thanks to the use of internal resources at UQ for a large part of the design and construction period, the overall costs on the project have been kept at a lower level than would have been possible otherwise.

The project related capital costs of the SBR system have amounted to approximately $80,000 which also included some additional expenses due to modifications and repairs during the operation of the pilot plant.

An estimation of the likely capital cost for a full-scale installation is not possible from this project. They will depend largely on the construction method chosen (concrete tank vs earthen pond), specific site conditions (power supply, wastewater lines etc), availability and suitability of existing structures and numerous other factors. However, for initial estimates, the hydraulic retention time (HRT) of 24 hours applied in this project can be used to determine the likely minimal volume required. The aeration capacity required can be estimated from the oxygen requirement given in Table 9-1. but will depend heavily on the oxygen transfer efficiency in the specific situation.

9.4.2 Operating Cost

Aeration costs, sludge disposal costs and operation/maintenance will be the main cost items in such an SBR process. Again, many of these depend heavily on local or design specific factors and can not be determined from this project with any certainty. To get an initial estimate, some of these factors have to be known which can only be done on a case-by-case basis.

To determine an initial guess for the aeration costs, the oxygen requirement given in Table 9-1 might be useful. For a 60:40% Pond1:Pond2 mixture of wastewater in this case and an aeration efficiency of 1 kg oxygen/kWh aeration power (typically somewhat higher in activated sludge systems), the estimated power consumption is in the order of 1 kWh/kL treated. At a nominal power cost of 10c/kWh, this is an operating cost of $0.1/kL

Chapter 10

SBR Pilot Plant Performance

This chapter describes the performance of the SBR pilot plant for the entire test duration of the project. The unit was operated in various modes to initially optimise the nitrogen removal, and to achieve biological phosphorus removal in the later stages of the operation.

10.1 Summary of SBR Commissioning and Operation

The SBR pilot plant underwent the following major stages in its development and testing:

• Design and Construction:	November 1994 – May 1995
• SBR testing and commissioning	June 1995 – February 1996
• SBR operation and optimisation	February 1996 – December 1996

10.1.1 Design and Construction

The pilot plant was designed on the results achieved in the small scale experiments at The University of Queensland and on standard BNR design calculations. Detailed design was also performed by the project team at UQ with additional input from equipment suppliers and technical staff at UQ's Department of Physics.

Construction of the fibreglass tanks, the base frame and control room was contracted to external manufacturers. Installation of all equipment and piping took place at The University of Queensland whereas all electrical services were installed by the control systems supplier.

Given the significant complexity of this pilot plant, the technical tasks proofed quite demanding. In particular, the selection and installation of all equipment provided a range of challenges due to the relative small size of the plant. These could only be overcome by direct supervision of all aspects of the construction by the CRC WMPC project team at The University of Queensland.

10.1.2 SBR Testing and Commissioning

Following construction and preliminary testing at UQ, the pilot plant was delivered to the AMH Dinmore abattoir site on 17 June 1995. Loading and transportation was done by a tilt-tray truck while for the unloading and positioning on site a crane was used. This was necessary since the site was only levelled roughly and no specific base (concrete slab or gravel bed) was provided for the pilot plant.

The extensive period required for testing and commissioning was largely caused by a four month delay in the replacement of the air blowers. This became necessary since the initially installed blowers did not perform to their specifications and could not deliver any significant amount of air to the tanks. This lack of performance was finally acknowledged by the supplier and higher capacity blowers were ordered, delivered and installed at the suppliers costs. Nevertheless, this caused a major delay in this stage of the project since no further progress could be made prior to the replacement of the blowers.

Following extensive water tests, the SBRs were finally started with sludge from Pond 4 (an SBR-like activated sludge pond) and feed from Ponds 1 and 2 at design loading.

10.1.3 Summary of Operations

The SBRs were operated over the period from 19 February to 4 December 1996 according to the operating parameters listed in Table 9-1. A detailed description of the operation is given in Appendix 10.1

The operation was affected by two major interruptions in wastewater supply from AMH Dinmore (due to plant shutdown and record rainfall) as explained in Section 8.1.2.

10.1.4 Operational Difficulties

Operation of the SBR unit was hampered by a number of equipment failures particularly during the early period of operation (prior to April 1996). Further details of are outlined in Appendix 10-6, but in summary these problems included:

- The original blowers supplied were unable to provide the specified capacity. These were replaced free of charge by the suppliers.

- The effluent discharge valves were found to be undersized and were replaced with larger capacity, full bore valves.

- A split occurred in one of the fibreglass tanks, requiring repairs and the removal of internal tank baffling.

- An intermittent communication problem between the SBR's processor and the monitoring desktop computer caused significant disruptions to operations. This was largely overcome by upgrading the communications cable, it was eventually eliminated in mid-1996 by software changes.

- With the larger capacity blowers installed, the originally used PVC discharge pipework deformed due to excessive heat. It was replaced by polypropylene irrigation pipe and fittings in April 1996.

- The sludge wastage valve blocked repeatedly and the sludge wastage duty was eventually taken over by the full-bore effluent discharge valve.

- The SBR feed pumps were found to have significantly reduced capacity on the anaerobic influent streams. This is caused by the high concentration of dissolved gases, particularly carbon dioxide, in these streams. Operation at higher speed to overcome this problem has lead to excessive wear and ultimately premature failure of the pumps. The only method to overcome this problem is by supplying the feed at neutral or positive pressure to the suction side of the feed pumps.

10.2 Overall SBR Performance

Table 10-1 below shows the mean values of the last month (6 November to 4 December 1996) of the experimental period. At this stage, the SBR operation had been optimised to a large degree and showed a stable performance.

Table 10-1: Summary of optimised SBR effluent results

(all mg/l)	COD s	COD t	NO_2-N	NO_3-N	NH_4-N	PO_4-P	TKN	Total N	TSS
SBR 1 effluent	142	182	1	12	2	27	12	25	36
SBR 2 effluent	125	169	1	14	1	26	10	24	29

The following key conclusions can be drawn from these results:

- COD is removed to over 90% with the remaining soluble COD of 120-150 mg/l largely undegradable as has been found in previous studies on the same wastewater.
- Total nitrogen removal achieved in this period 85-90% with the remaining nitrogen compounds mainly as nitrate or organic nitrogen. The organic nitrogen fraction seems to be consistent at around 10 mg/l.
- Little if any phosphorus removal has been achieved, largely due to the low levels of soluble COD in the influent streams (see section 10.4)
- Total suspended solids (TSS) are somewhat higher than the required level for discharge to waterways. However, this is likely a consequence of the relative rudimentary decanting system used in this pilot plant. Therefore, the effluent TSS should improve in a full scale installation with a well-designed decanting mechanism.

Figures 10-1 to 10-4 summarise the important effluent quality characteristics from both reactors over the test period. The major observations from these figures are:

- Figure 10-1 shows that the quantity of nitrogen present in the effluent of both SBRs generally *decreased* over the study period, with a total nitrogen content as low as 20 mg/L being achieved towards the end of the study period in both systems.
- The variation in COD concentration in the effluents of both SBRs *reduced* with time leading to a relatively consistent effluent COD concentration of between 100 and 200 mg/L (Figure 10-2)
- There is no obvious trend in the effluent suspended solids concentration over the study period. The levels of TSS in the effluent were consistently below 100 mg/L for both reactors and most the time below 50 mg/l (Figure 10-3).
- Figure 10-4 shows that the phosphorus content in the effluent of both reactors remained high over the entire test period as there is very little phosphorus removal achieved in these experiments.

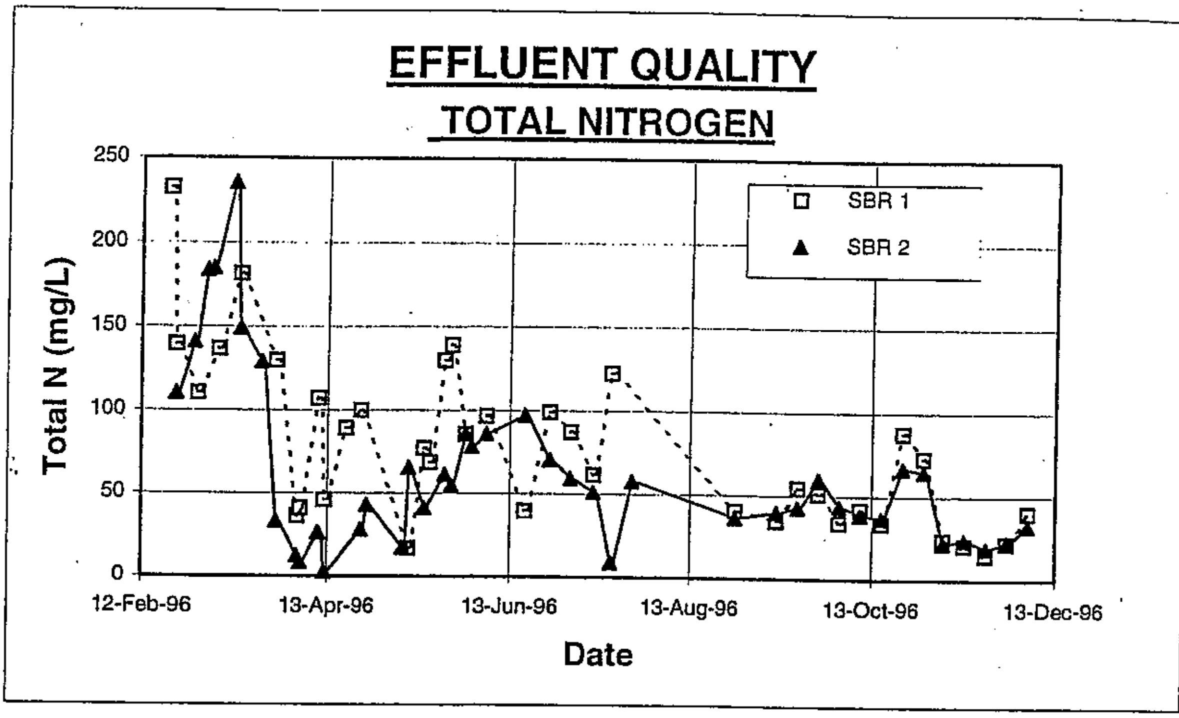


Figure 10-1: Effluent Total Nitrogen concentration

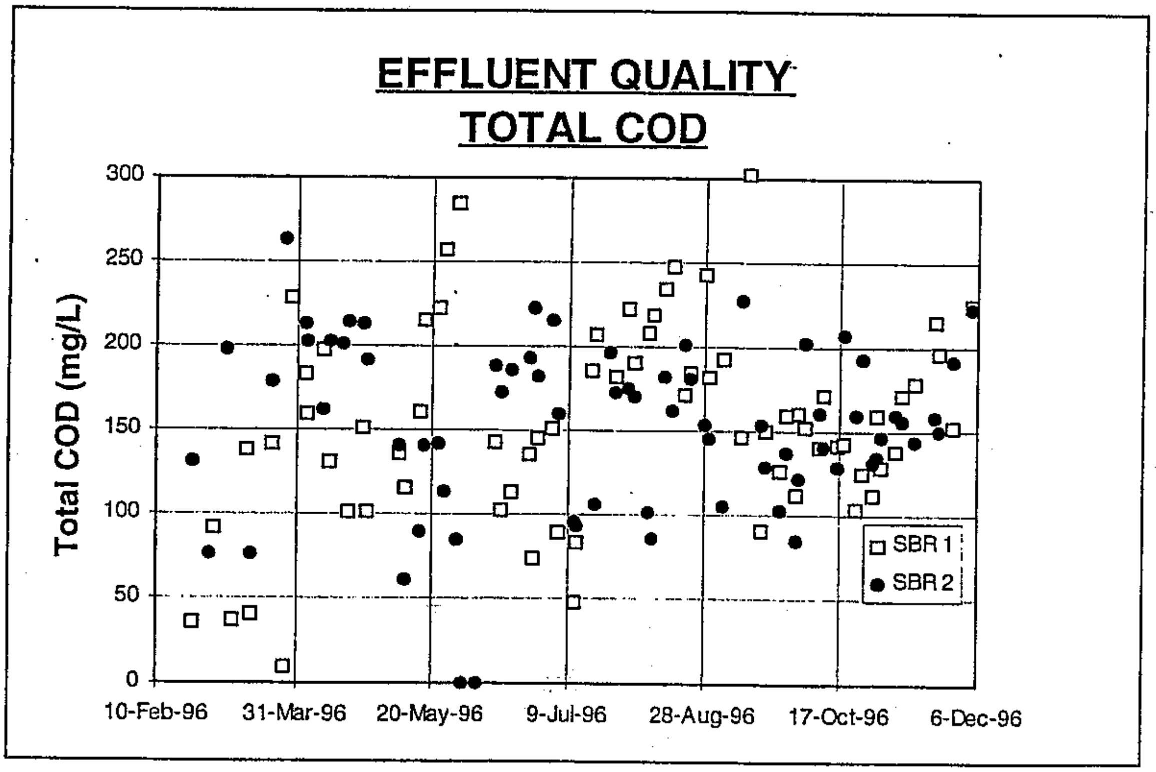


Figure 10-2: Effluent COD concentrations

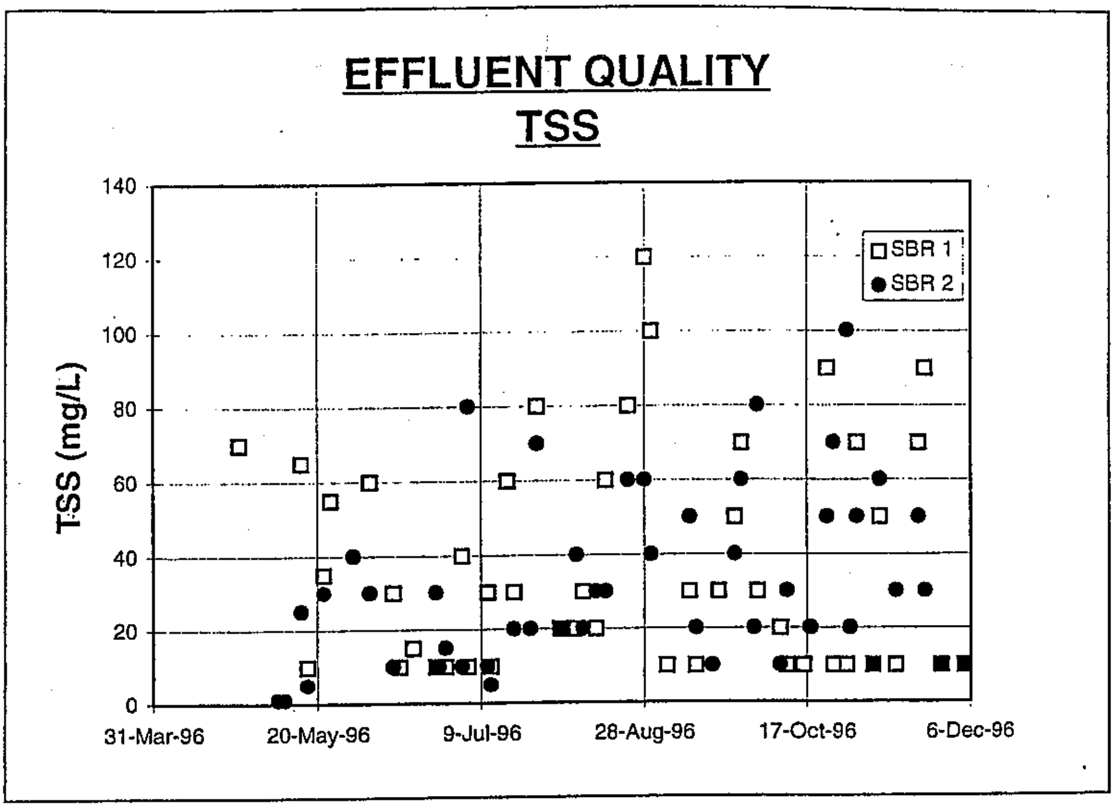


Figure 10-3: Effluent TSS concentration

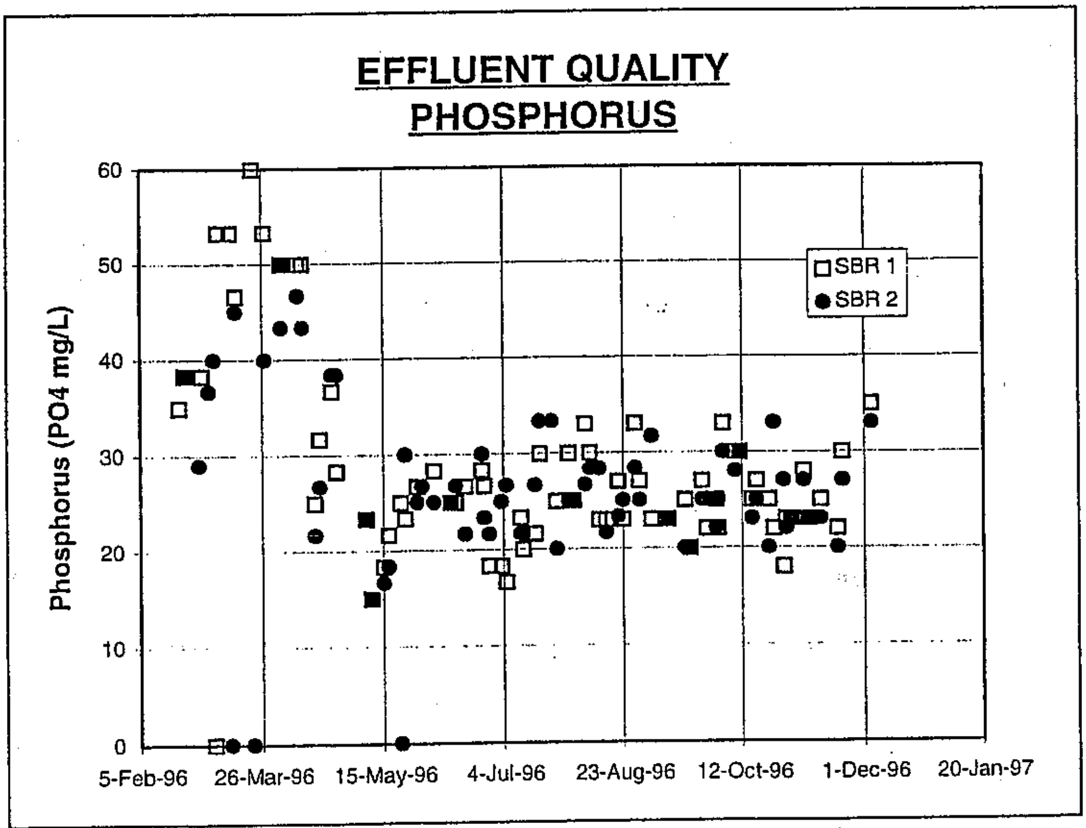


Figure 10-4: Effluent Phosphorus concentrations

10.3 Nitrogen Removal Performance

Figures 10-5 and 10-6 show a summary of the nitrification and denitrification efficiency and the resulting nitrogen removal of both reactors over the test period.

In both SBRs, three distinct periods are evident in the removal of nitrogen over the entire study period - these are:

February - May 1996	Good levels of nitrification with wide fluctuations in the degree of denitrification
May - July 1996	Poor overall performance due to some long term effects of the extensive rain in early May and operational problems
August - December 1996	Increasing levels of both nitrification and denitrification based on a more stable operation and successful optimisation of the operating conditions

However, additionally to these general trends, there are a number of fluctuations obvious in both reactors. On close examination of the results it became evident that the nitrogen removal, which consisted of denitrification and nitrification steps, was affected by the following parameters

- Mixed liquor suspended solids (MLSS) concentration
- Influent COD concentration
- DO control limits
- Effects of weekend shut-down of abattoir operation
- Variability in feed quality

The specific influence of these parameters is further investigated in the following section.

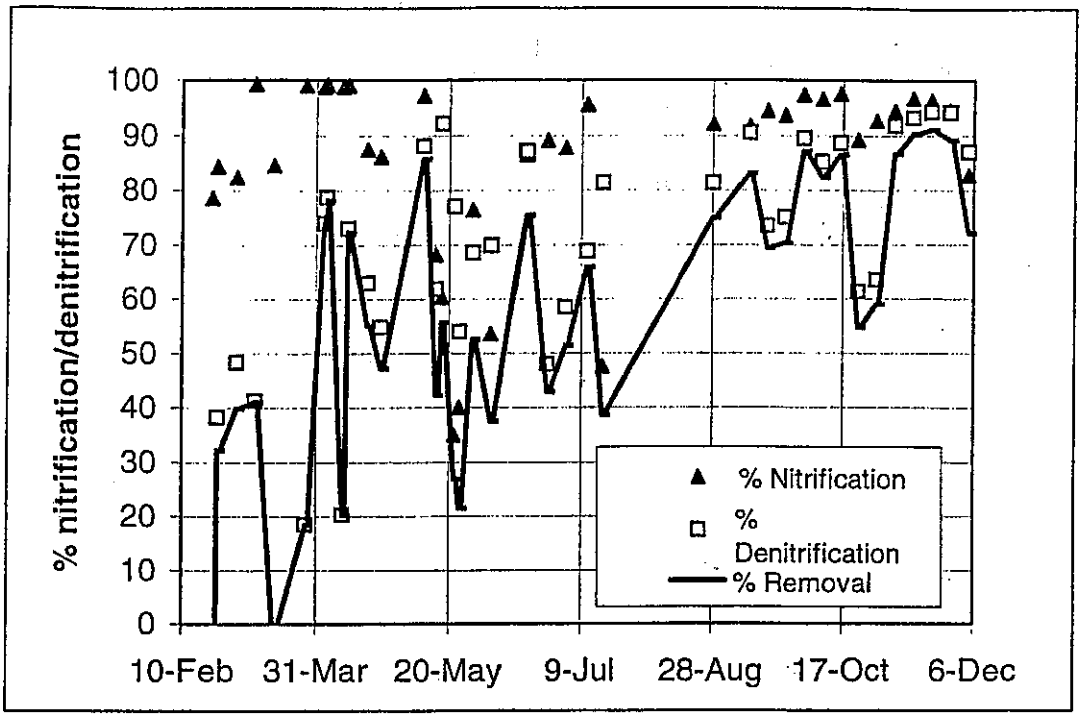


Figure 10-5: SBR 1 Nitrification, Denitrification and Nitrogen Removal Efficiency

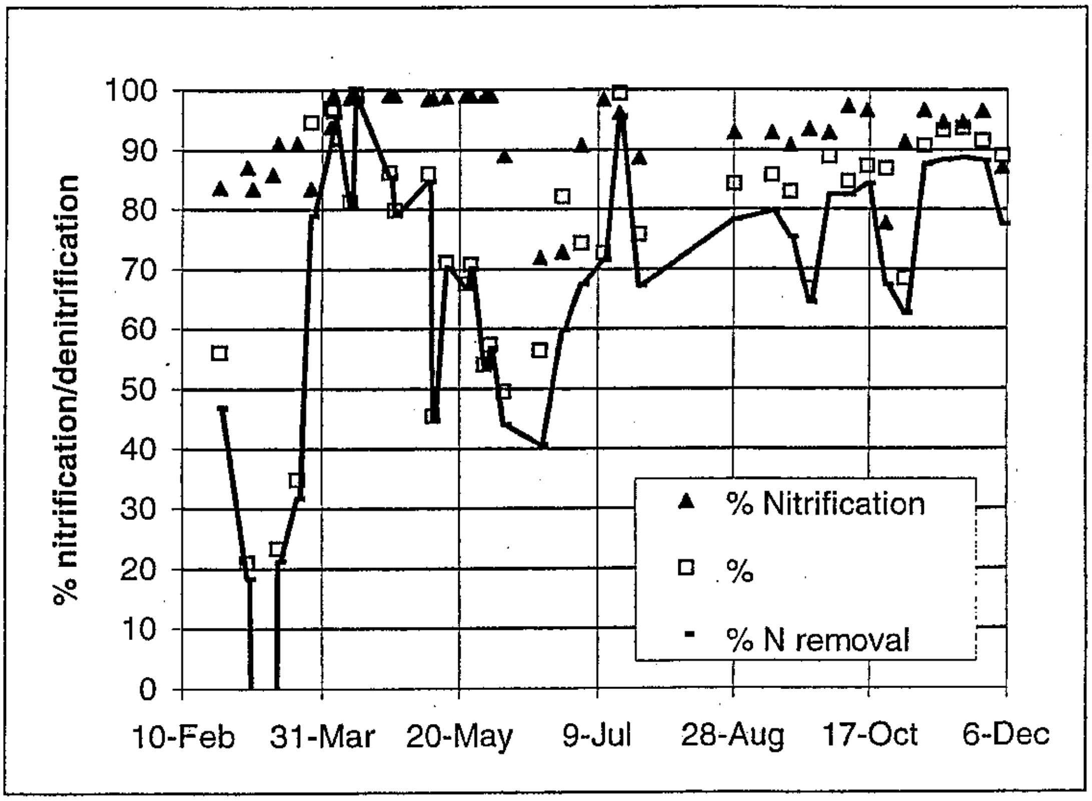


Figure 10-6: SBR 2 Nitrification, Denitrification and Nitrogen Removal Efficiency

10.3.1 Effect of Level of Mixed Liquor Suspended Solids

An interesting observation made was on the effect of the Mixed Liquor Suspended Solids (MLSS) concentration on nitrification. As shown in Figures 10-7 and 10-8, for those periods where the MLSS was below 5-6000 mg/L, nitrification was clearly negatively affected.

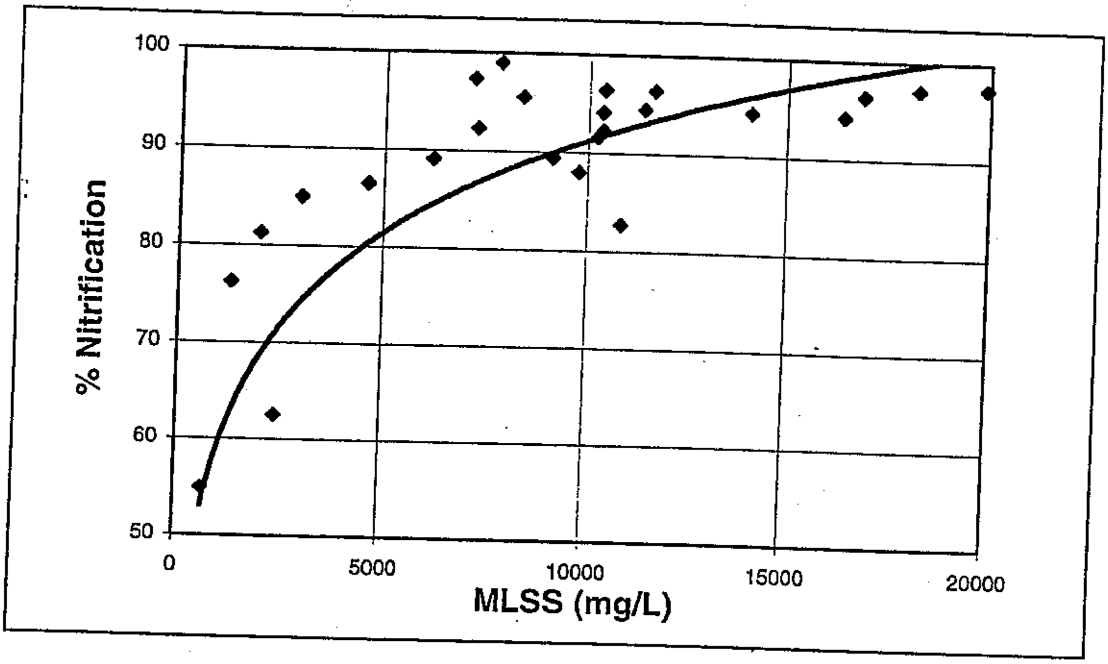


Figure 10-9: SBR 1 Effect of MLSS on Nitrification

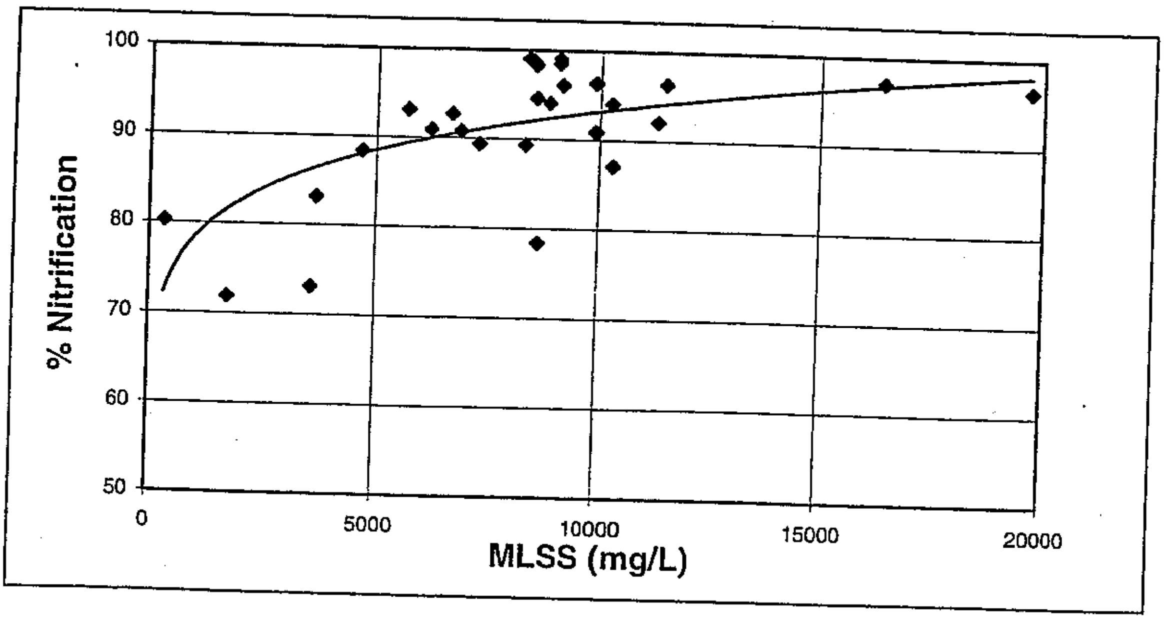


Figure 10-8: SBR 2 Effect of MLSS on Nitrification

This behaviour is not surprising and reflects a similar observation made in the pond, although the critical level was significantly lower in accordance with the lower loading rate on the pond. This effect is likely caused by the reduction of the nitrifying organisms at lower MLSS concentrations and shows that the SBR operation should be maintained in the range above this critical MLSS level. While this level was around 6000 mg/l in this case, lower loading conditions will certainly change that critical level to lower MLSS values.

The extreme quantity of rain in early May (800 mm in 8 days) severely disrupted operation of the SBRs (and also the pond). It caused a significant dilution of the feed concentrations, including the suspended solids, and had consequently an adverse effect on the MLSS levels and the overall performance (see Figures 10-5 and 10-6). For SBR1, the effect was so pronounced that in early June it was partially re-seeded to build up the MLSS concentration.

To maintain MLSS levels above the critical level, the rate of sludge wastage was closely controlled during the second half of the experimental period. This resulted in high consistently nitrification levels with only few occasions where did nitrification drop below 90%.

10.3.2 Effect of Feed Ratio

As previously stated, the most pronounced difference between the operation of the two SBRs was that SBR1 was fed with 60% Pond 1 effluent (for most of the time), and SBR2 with 80%. Based on the average COD concentrations from these ponds over the experimental period, this results in an mean influent COD concentrations of approximately 1150 mg/l and 1410 mg/l for SBR1 and SBR2, respectively.

The effect of this difference can be seen in Figure 10-9 as the level of denitrification from SBR1 was mostly below that of SBR2. Late in the test programme, problems developed with one of SBR1's feed pumps and SBR1 was operated with 100% Pond 1 feed from 10 October. During the subsequent period (October/November), the performance of SBR1 rose to the same level as SBR2.

As denitrification requires sufficient COD in the influent, the higher concentration supplied to SBR2 has resulted in the improved performance compared to that of SBR1. This confirms previous findings from the small scale experiments and emphasises the importance of optimising the process in respect to the anaerobic COD removal prior to the BNR stage. While the optimal ratio in this study was somewhere around 70-80% of Pond 1 feed (ie primary anaerobic treatment only), this will most likely vary in other situations depending on the abattoir effluent COD concentration and the degree of COD removal in the anaerobic ponds.

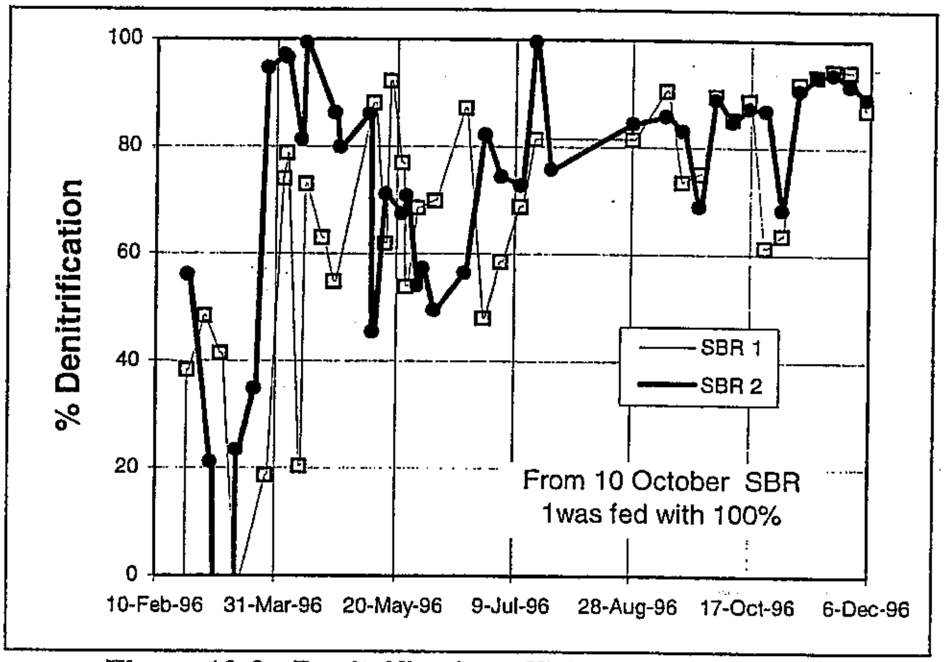


Figure 10-9: Denitrification efficiency in both SBRs

10.3.3 Effect of Dissolved Oxygen Control Limits

One of the key findings of the SBR operation was that is was possible to operate the reactors at relatively low levels of dissolved oxygen during the aeration phase. The optimal performance was found to be in the range of 0.2 - 0.4 mg/L DO.

During the initial part of the experimental period, the SBRs were operated with a DO control range of 0.5 - 2.0 mg/L O_2. As shown in Figures 10-5 and 10-6, this stage was characterised by very good nitrification but widely varying denitrification levels of between 20 and 80%. This was probably due to two reasons:

- the higher average level of DO inhibited the denitrification reaction; and
- the higher DO levels would also encourage the aerobic oxidation of the COD in the feed, thereby reducing the amount of COD available for denitrification.

As of early June 1996, the upper DO level was progressively reduced from 2.0 to 1.0 mg/L DO (Figure 10-10). Through July and August further refinements were made, including the introduction of an idle period (2 - 5 minutes) of no aeration, from the time the DO reached the lower level of the control range. These changes clearly helped to improve the level of denitrification while not having any major effect on the nitrification performance. Therefore, the overall level of nitrogen removal removal continuously improved in both reactors.

Over September and October the DO control limits were reduced to 0.2 - 0.4 mg/L. This further improved denitrification, and consequently total nitrogen removal, to around 90%, achieving 20-30 mg/L total N in the effluent.

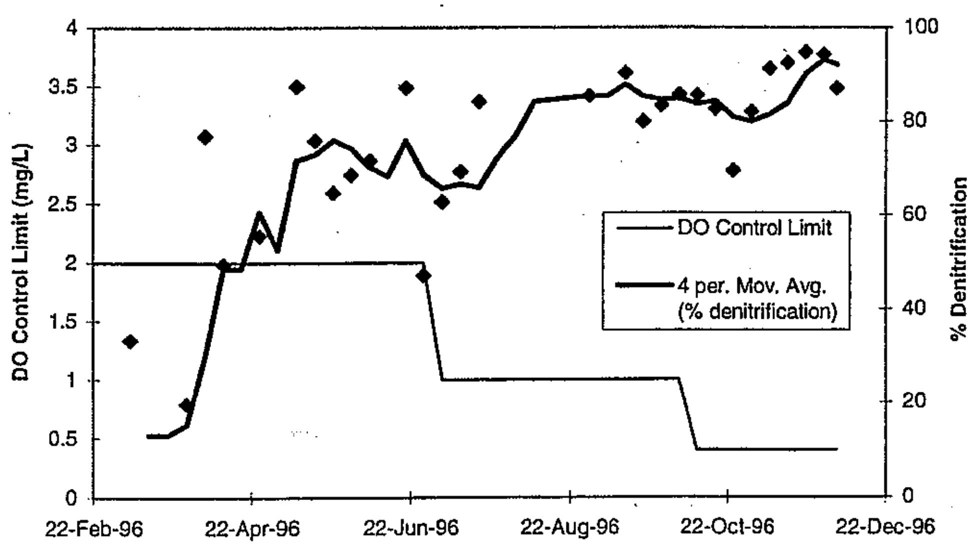


Figure 10-10: Effect of DO Control on Denitrification

10.3.4 Effect of variations in feed concentrations

A significant influence on the steady performance of both SBRs was caused by the variation in the feed composition - in particular the COD concentration.

This was most noticeable every Monday morning, following the weekend shutdown of the abattoir. From each Friday to the following Monday, the total COD in the feed from Pond 1, which comprised the bulk of feed to both SBRs, usually fell by 50-60%. The resultant drop in overall COD to both SBRs was greater than 30%. At the same time there was little change in the total nitrogen content of the feed streams.

The net result of this was a sharp increase in nitrate in the effluent over the weekend, indicating a limitation in denitrification. However, this rise in effluent nitrate level was only temporary as by Wednesday the nitrate levels again dropped to the normal low concentrations.

The partial failure of denitrification was caused by the imbalance of the feed COD and total nitrogen concentrations. While nitrification of the incoming nitrogen could proceed without problems, the insufficient COD in the influent limited the extent of denitrification. This lead to the rise in nitrate levels in the effluent over the weekend.

This effect is likely a specific problem of the pilot plant operation only. The influent flow rate remained constant throughout the week and therefore on the weekend a higher flow was supplied to the SBRs than would be expected in the full-scale operation. Therefore, the nitrogen load remained the same while he COD load was drastically reduced. In actual treatment plant operation, both loads would be reduced over the weekend since the flow rate would be significantly lower in that period.

Consequently, a method to overcome these problems is the reduction of feed rates to the SBRs over the weekend - a practice which occurs in reality anyway. The effect of this is to reduce the amount of ammonia (and total nitrogen) available for nitrification to nitrate and to increase the hydraulic retention time in the reactor, thereby allowing greater time for the denitrification of the produced nitrate.

This operating strategy, in which the feed rate is reduced to 20% over the weekend, was implemented in the final weeks of the experimental operating period of the SBRs - the results of which were encouraging. It is recommended this aspect of the operation of the SBRs be further investigated in any future research work.

10.4 Phosphorus Removal

One of the objectives of the SBR operation was to demonstrate its ability to biologically remove phosphorus from the waste stream. Extensive bench scale testing had clearly shown the technical feasibility of using this technology for the removal of phosphorus from abattoir effluent.

However, despite using suitable operating conditions for biological phosphorus removal, the SBR showed no sign of removing phosphorus at all. Even the addition of sludge from a phosphorus removing domestic treatment plant did not stimulate biological P removal. This is evident in Figure 10-11.

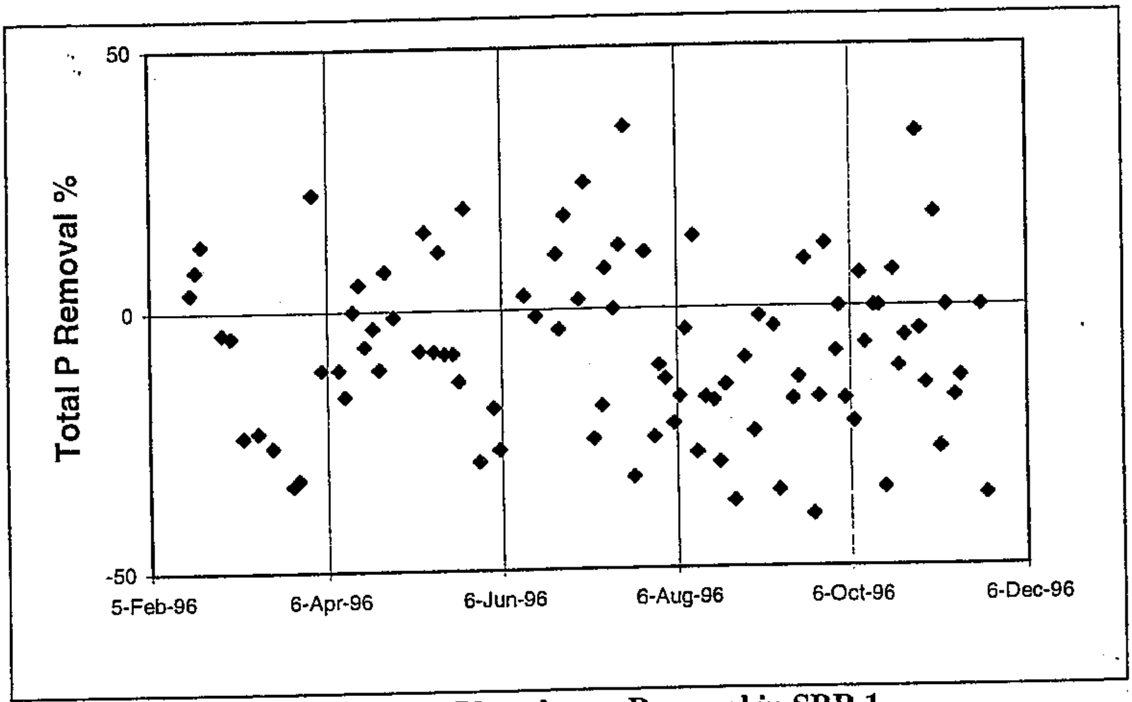


Figure 10-11: Phosphorus Removal in SBR 1

Two main reasons for this failure are given below:

- The major reason was the lack of soluble COD in the feed. While there was plenty of total COD, the feed contained relatively little COD in the soluble form. Figure 10-12 shows the levels of COD in the feed to SBR 2. The relationship for SBR1 is very similar. As discussed previously, a sufficient supply of soluble COD is critical for the biological phosphorus removal to occur. Given that in SBR1 (with only 60% Pond 1 feed) limitations of denitrification due to insufficient COD was observed, it is not surprising that little or no phosphorus removal was achieved.

- The phosphorus release, which occurs during the anaerobic phase, can be inhibited by the presence of nitrate. Until late in the SBR testing program there was often insufficient denitrification efficiency, which would have left nitrate present during the (anaerobic) feed phase of the cycle. This likely used up some of the incoming soluble COD, leaving little if anything remaining for the biological P removal.

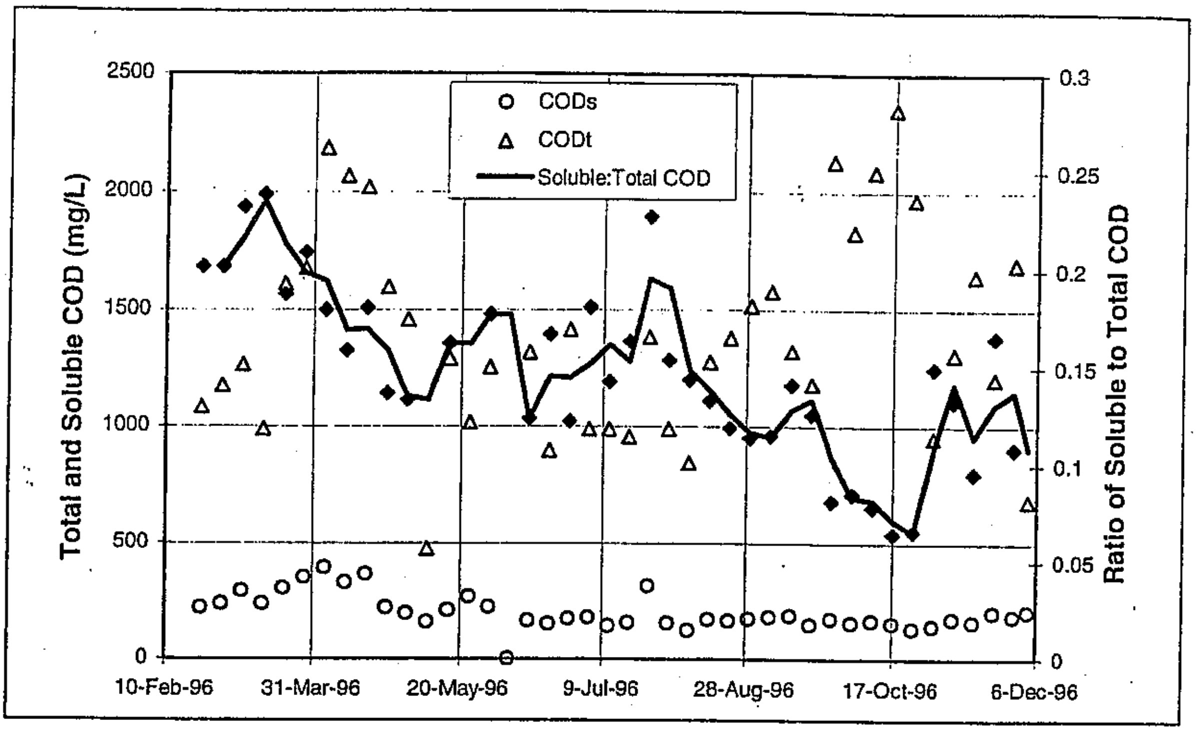


Figure 10-12: Soluble and total COD in SBR2 feed

As shown in Figure 10-12, the soluble COD was only 10-20% of the total COD present and declined further during the experimental period. In previous studies on this wastewater, the soluble COD in Pond 1 effluent usually was in the range of 500-1000 mg/l, significantly higher than the range found during these studies (typically 150 – 400 mg/l).

The generally accepted minimal ratio of soluble COD : total P is in the order of 20. During this study, even Pond 1 effluent had on average only a ratio of 8 whereas Pond 2 effluent only reached a ratio of 5 (see Sections 6.1 and 6.2). This clearly indicates that the lack of soluble COD is the major limiting factor for the biological phosphorus removal in the SBRs.

To try to overcome this potential problem, it is recommended to undertake some further studies to determine suitable sources of soluble COD in the abattoir operation. One possible approach is the use of prefermentation of a highly concentrated COD stream to generate suitable soluble COD that can be supplied specifically for biological P removal.

10.5 Removal of Suspended Solids

During the effluent withdrawal phase (which was preceded by a 30 minute settle phase), the effluent was decanted from the liquid surface using a floating decanter. Given the short settling period and the high loading on the reactors, successful solids/liquid separation was strongly dependent on good settling characteristics of the sludge.

Figures 10-13 and 10-14 summarise the total suspended solids in the effluents from both SBRs.

The resultant effluent was found to be clear of suspended solids, with TSS typically in the range 10 - 30 mg/L. Even when the mixed liquor suspended solids concentration rose to 20,000 mg/L, the sludge settled sufficiently to produce a very clear effluent. The corresponding Sludge Volume Index (SVI) measurements were in the order of 25-40 ml/g. These are extremely low values as well settling sludge is usually expected to have a SVI value of less than 100 ml/g.

It is usually impossible to identify any particular reason for achieving such extremely well settling sludge. However, similar observations have been made during the bench scale experiments and possibly the bottom feeding strategy into the settled sludge blanket contributes significantly to this extraordinary result.

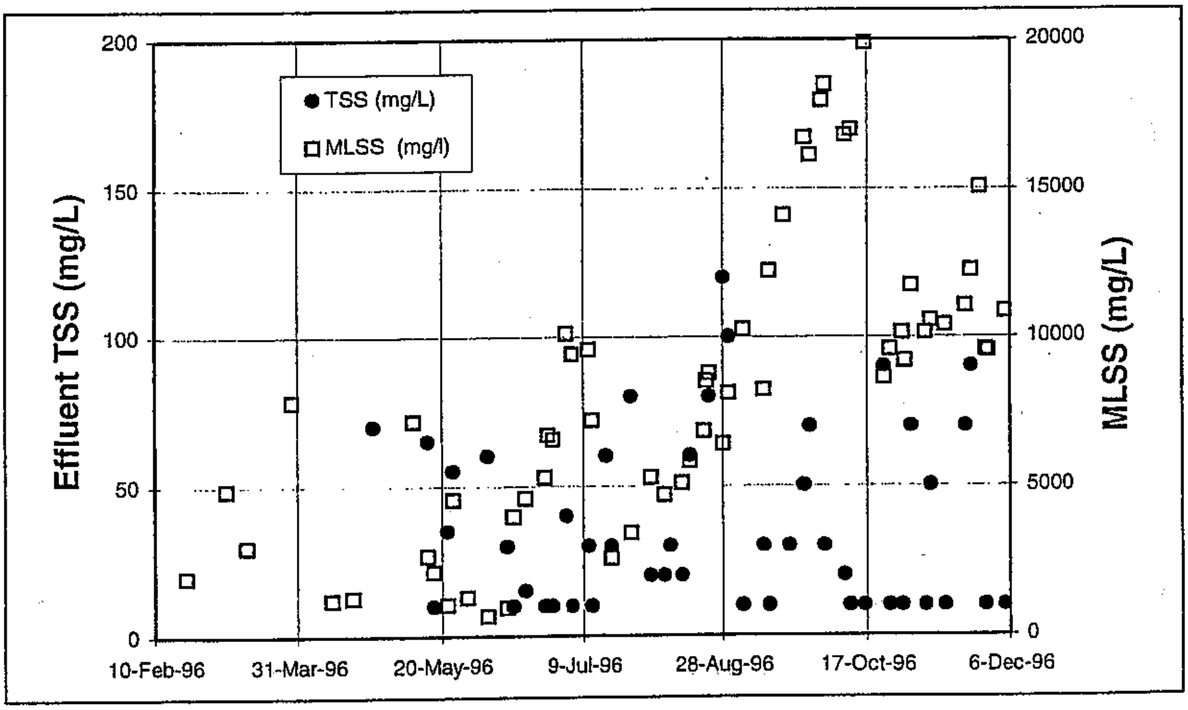


Figure 10-13: SBR 1 MLSS and effluent TSS

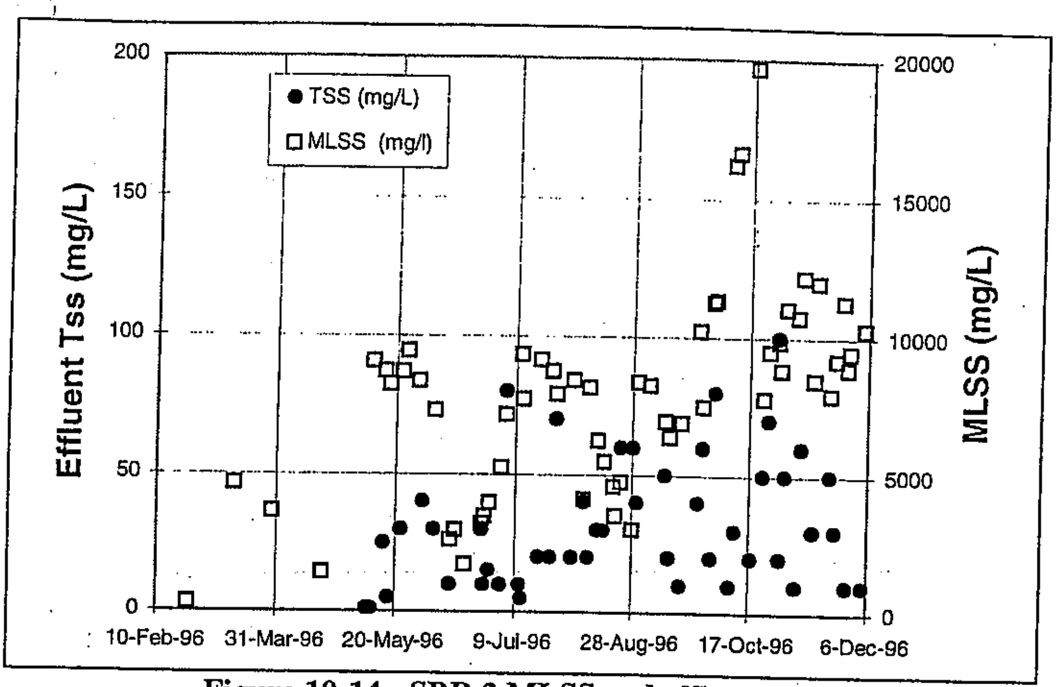


Figure 10-14: SBR 2 MLSS and effluent TSS

10.6 Removal of COD

As expected, the removal of COD in the SBRs was good, with both reactors consistently achieving 80 - 95% removal. Total COD in the effluent was generally 120-200 mg/l. Figures 10-15 and 10-16 show the COD removal efficiency of both SBRs.

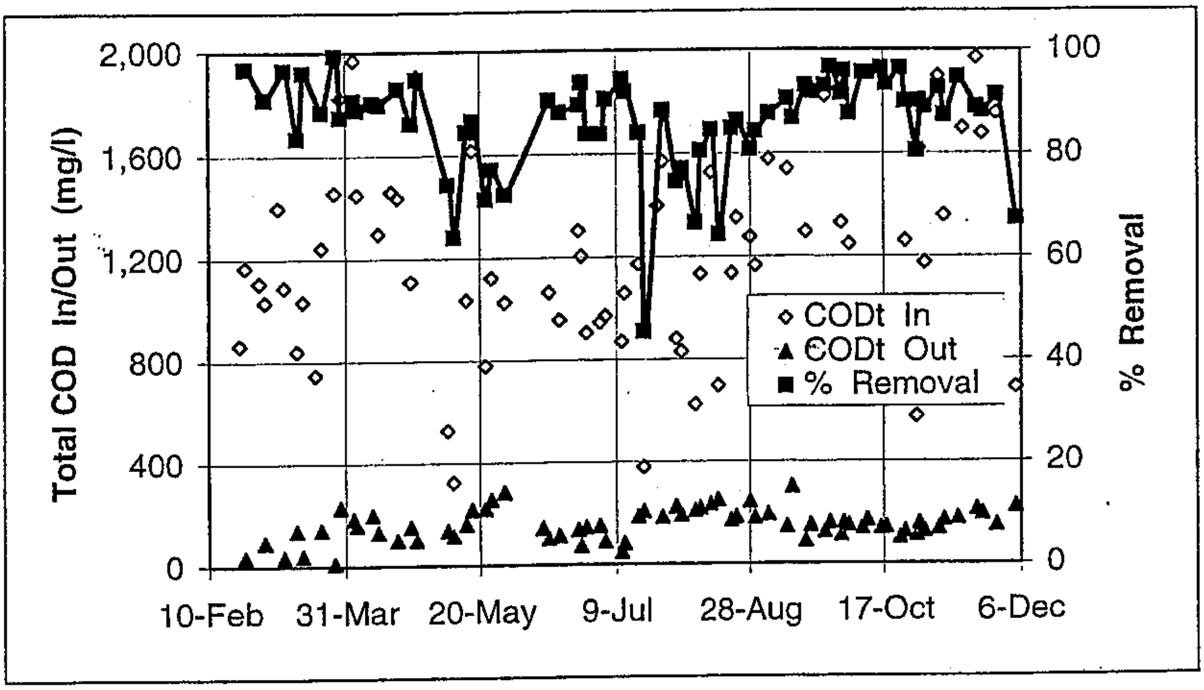


Figure 10-15: COD Removal in SBR 1

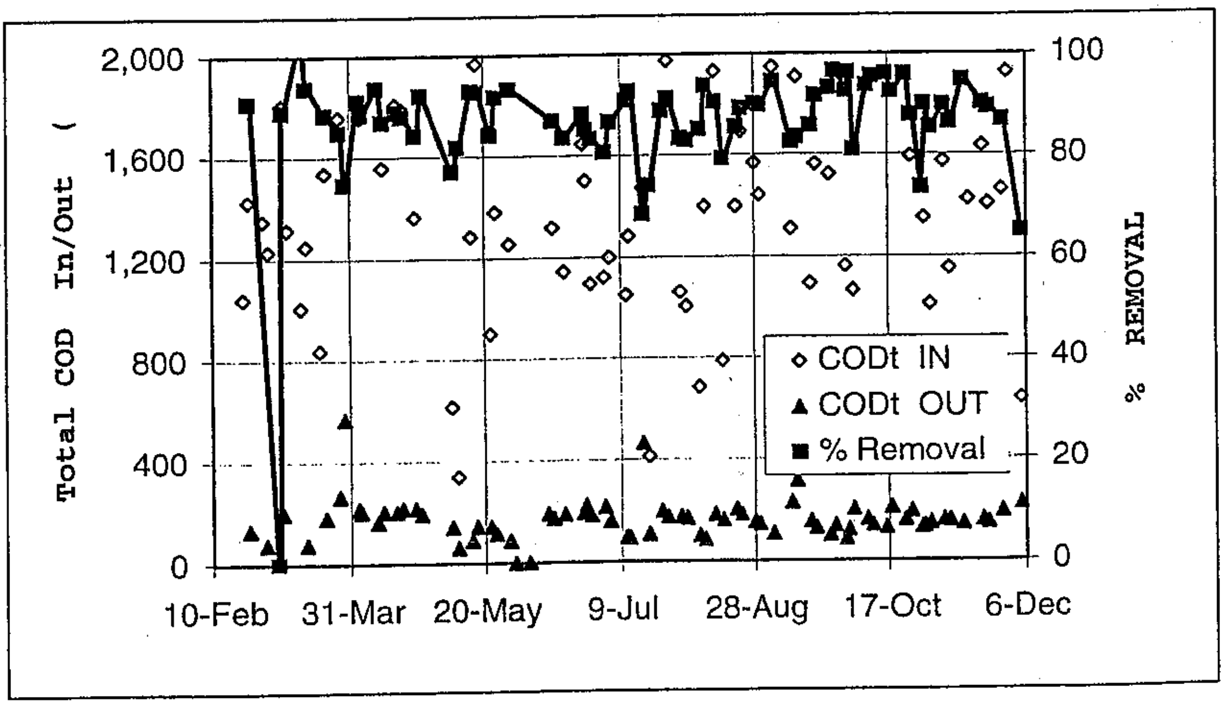


Figure 10-16: COD Removal in SBR 2

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APPENDICES

Appendix 5.1 Difficulties experienced with Analysis of Nutrients in Meat Processing Wastewater

The team responsible for the M.445 Nutrient Audit project identified a number of problems with the measurement of pollutants in raw meat processing wastewater. In this project, repeated problems were experienced achieving reliable and accurate values of nitrogen chemical species in particular.

5.1 Ammonium Nitrogen

The measurement of ammonium-N concentrations in MPI wastewater proved difficult. Altogether three methods were trialled. These were:

- Using the Merck SQ118 method
- Using the Merck RQFlex portable instrument
- Using ditillation and titration (performed by PEAC, Univeristy of Queensland).

The SQ118 and RQFlex values did not agree with those determined by distillation and titration. The later method was found to be most accurate and was retained for the work.

RQFlex: The agreement of RQFlex ammonium N values with those from distillation and titration (PEAC NH_4-N) are contrasted for anaerobic pond 1 effluent in Fig. 6.1. The RQFlex values underestimated ammonium-N concentrations significantly in this wastewater, although both methods showed good agreement in trend. There was a consistent offset described by the relationship:

$$\text{PEAC } NH_4\text{-N} = 1.4 \text{ RQFlex } NH_4\text{-N}$$

for N above 30 mg/l. The relationship also held for pond 2-treated (Fig 6.3), SBR-treated and pond-treated wastewater. For ammonia N concentrations of 50 mg/l, or less, the error between the two methods become relatively small.

Merck SQ118: This instrument consistently overestimated ammonium-N values relative to distillation and titration in all types of meat process wastewater by up to 50%. It is not recommended for ammonia-N determination for meat process wastewater.

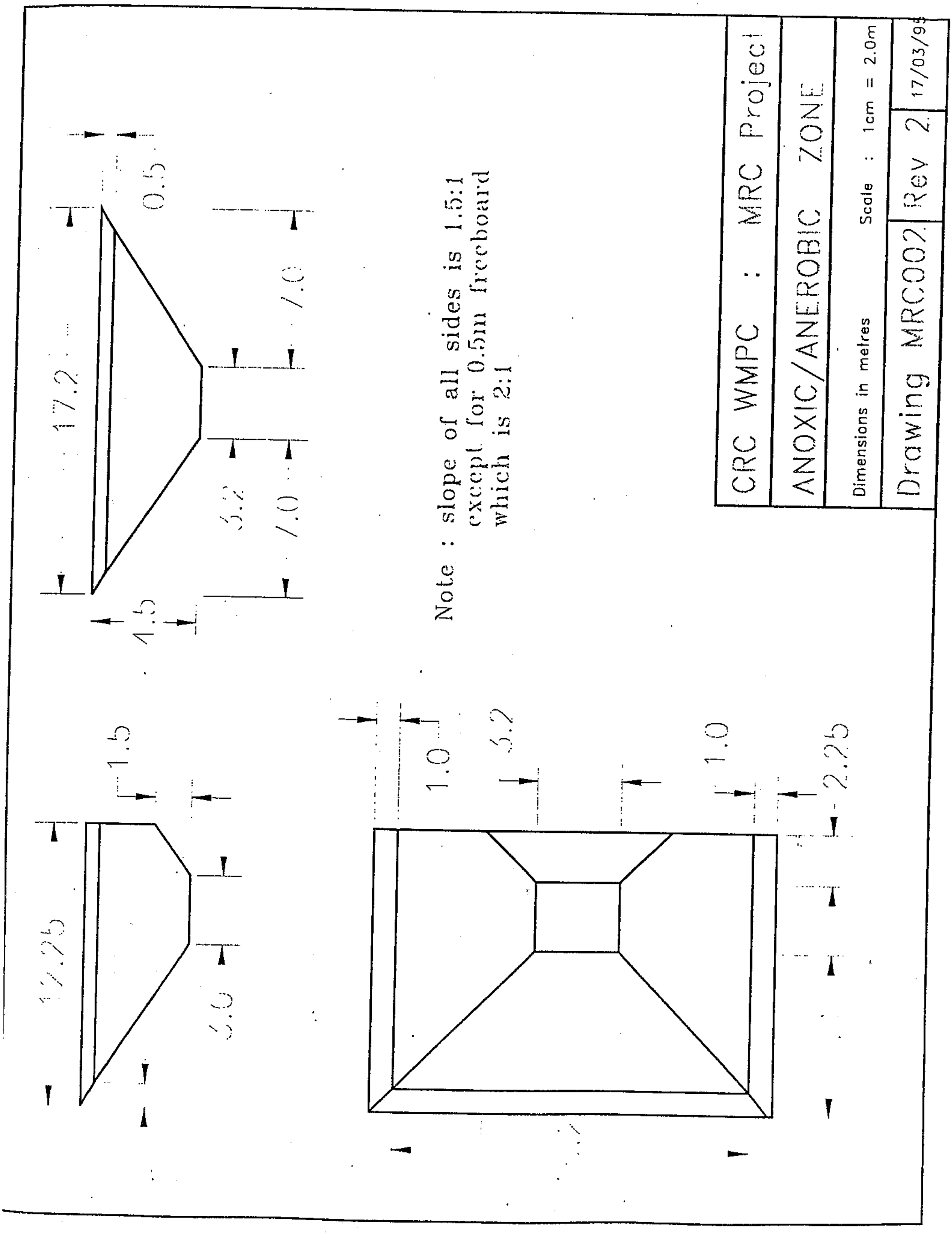
5.2 Nitrogen by Distillation

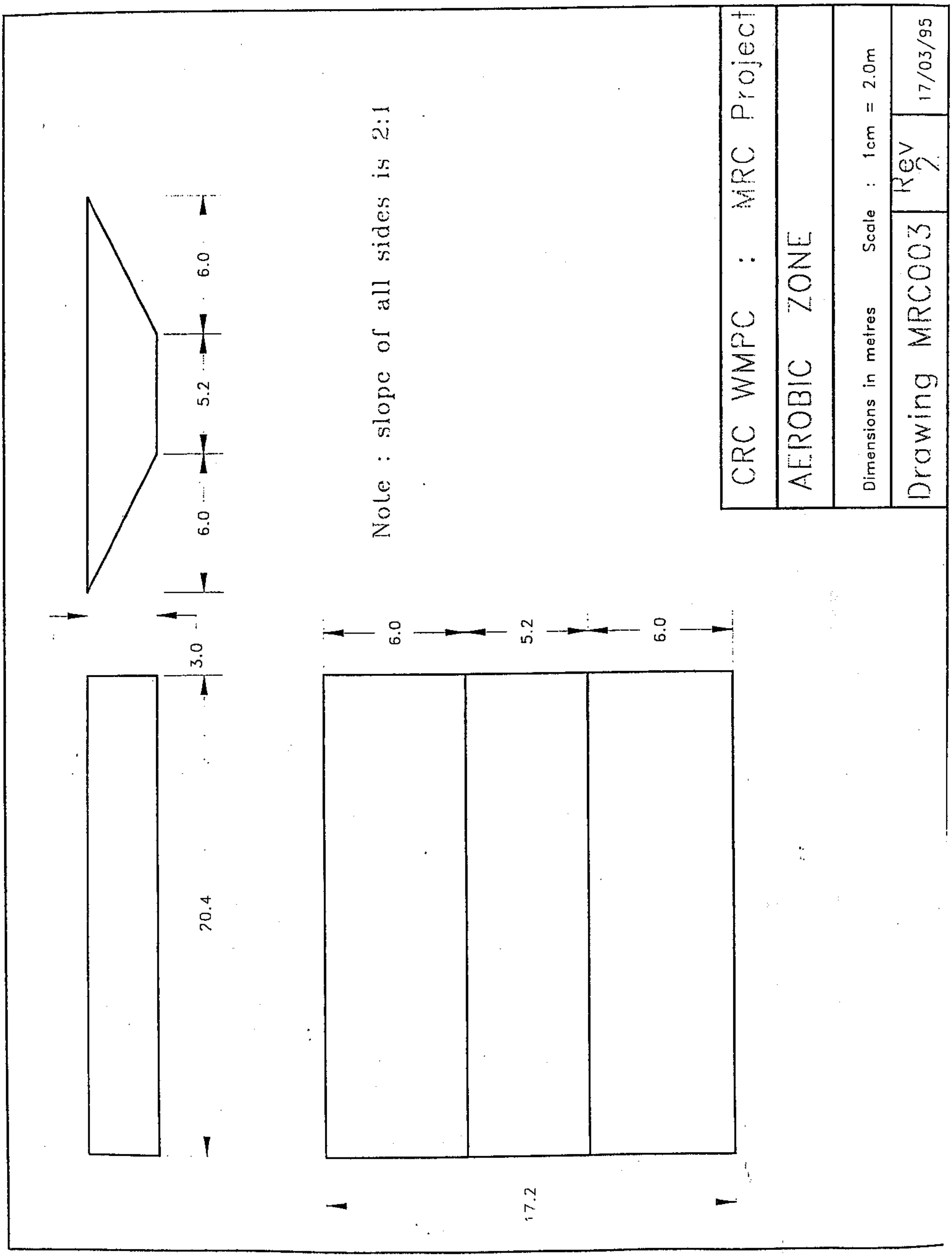
The presence of nitrate concentrations at 10 mg/l or higher is known to interfere with the distillation method of total kjeldahl nitrogen determination. This is not a problem with raw, or anaerobically treated meat process wastewater in which nitrate concentrations are zero, but it is a major problem in nitrified meat process wastewater. Nitrate interference can be commonly observed as a result in which ammonia nitrogen concentrations exceed the TKN values for the same sample. The problem is difficult to circumvent, other than by careful temperature control of the analytical process.

5.3 Nitrate Nitrogen

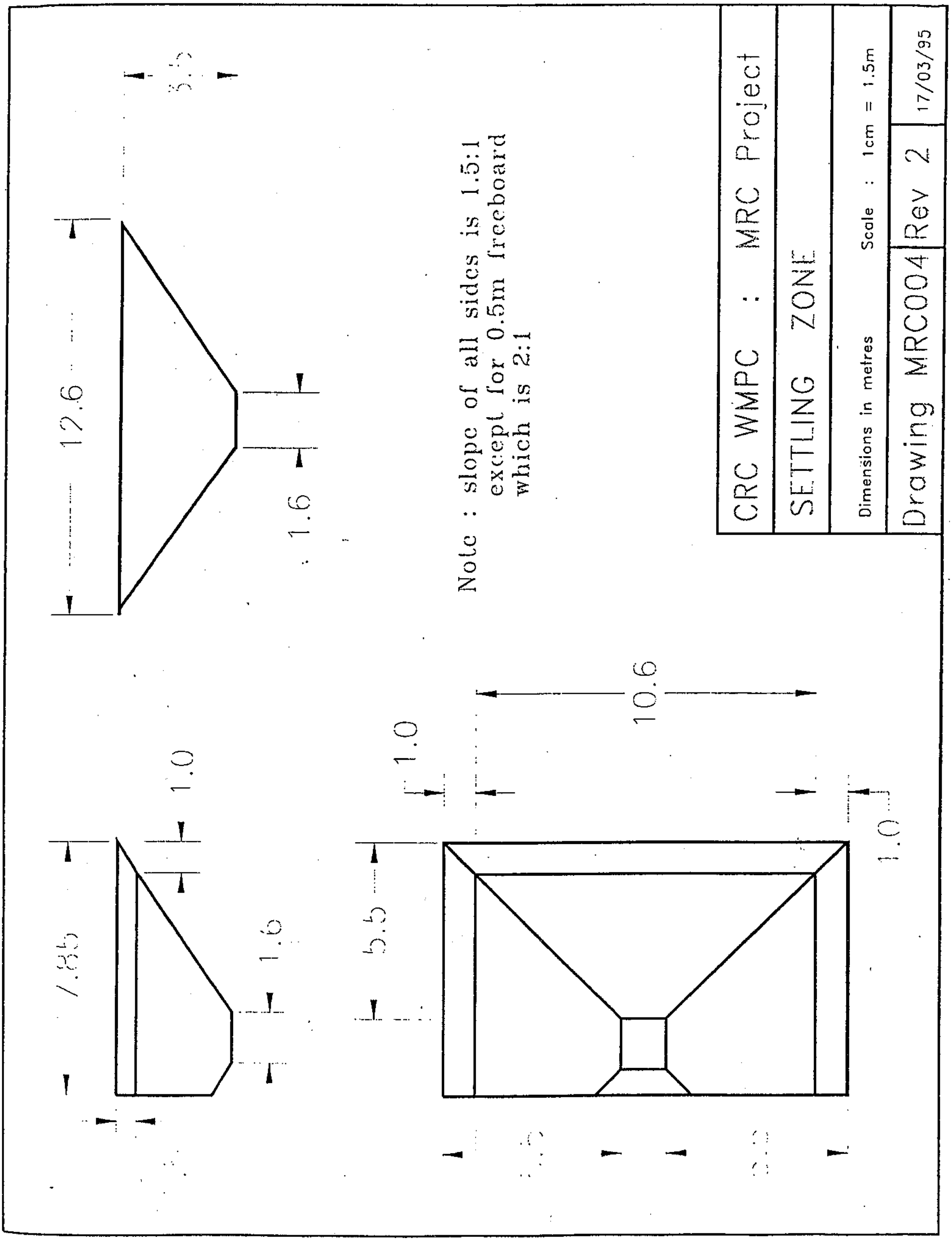
The measurement of nitrate-N concentrations in MPI wastewater using the Merck SQ118 needs to be performed carefully to ensure that nitrite nitrogen does not interfere with the result. The nitrite can be chemcially removed to permit accurate results to be obtained..

Appendix 7.1 Diagrams (MRC 002-004) of the Pond


CRC WMPC : MRC Project
ANOXIC/ANEROBIC ZONE
Dimensions in metres
Scale : 1cm = 2.0m
Drawing MRC002
Rev 2
17/03/95
Note : slope of all sides is 1.5:1
except for 0.5m freeboard
which is 2:1
17.2
0.5
7.0
7.0
4.5
1.5
1.0
1.0
2.25



Note : slope of all sides is 2:1
6.0
5.2
6.0
3.0
20.4
17.2
CRC WMPC : MRC Project
AEROBIC ZONE
Dimensions in metres
Scale : 1cm = 2.0m
Drawing MRC003
Rev 2
17/03/95


CRC WMPC : MRC Project
SETTLING ZONE
Dimensions in metres
Scale : 1cm = 1.5m
Drawing MRC004
Rev 2
17/03/95
Note : slope of all sides is 1.5:1
except for 0.5m freeboard
which is 2:1
12.6
1.6
10.6
1.0
1.0
5.5
7.85
1.0
1.6
1.0

Appendix 7.2 Equipment Schedule for MRC Pond

The equipment schedule is listed on the following pages.

EQUIPMENT SCHEDULE

ITEM	SPECIFICATION	MAKE	SUPPLIER
Feed Pumps	two (2) pumps 60-200 m^3/day variable capacity (can be derated by 30-40% on anaerobic wastewaters) helical-rotor positive displacement	MONO	Mono Pumps Aust.
Effluent Return Pump	400 m^3/day capacity helical-rotor positive displacement	MONO	Mono Pumps Aust.
Aerators	Aspirating aerators with stainless steel marine propeller, shaft and draft tube	AIRE-O2	Patrick Charles Pty Ltd
Feed Flowmeters	two (2) flowmeters 25mm & 40mm pipe size magnetic flowmeters	TechFluid	Measurement Engineering
Baffle material	650 gm/m^2 vinyl		Copelands

ITEM	SPECIFICATION	MAKE	SUPPLIER
Baffle posts	Partial baffle : 100mm x 100mm x 4mm RHS - galvanised mild steel Over/Under Baffle : 75mm x 50mm x 2mm RHS - galvanised mild steel		Posts : Scotts Metal Galvan. : Sunstate Coatings
Poly pipe, valves & fittings	Rural B (except with mains pressure city water where you must use Metric Class 12)		R.J McCracken or Pump & Pipes
PVC pipe & fittings	Class 12 minimum (ie not stormwater rating)		R.J. McCracken or Pumps & Pipes
Wire rope & fittings	6mm stainless steel wire rope Stainless steel fittings		Any marine or boating store

Appendix 7.3 Baffle Design for MRC Pond

There are basically three baffles:-

- the partial baffle between the anoxic and aeration zone - for which there may be two or three different designs requiring this baffle to be replaced without the need to empty the pond.
- the over baffle, and
- the under baffle, both of which will be fixed non-changeable designs.

The basic idea of support was to have pockets shown in all edges of the baffle. Through these pockets was run stainless wire rope inside plastic electrical conduit (to avoid friction and wear-and-tear between the wire rope and the poly baffles). At each corner of where the baffle will be, was a concrete anchor point with a U-bold imbedded in it. The wire rope passed through the U-bolt at each corner of the baffle.

Additionally, 2" galvanised steel posts were strung out at 1m distances across the pond supporting the wire rope and providing some horizontal support to the baffle from the wash from the aerators. These 2" posts were not tied to the baffles in any way and only support the top wire rope.

Over Baffle

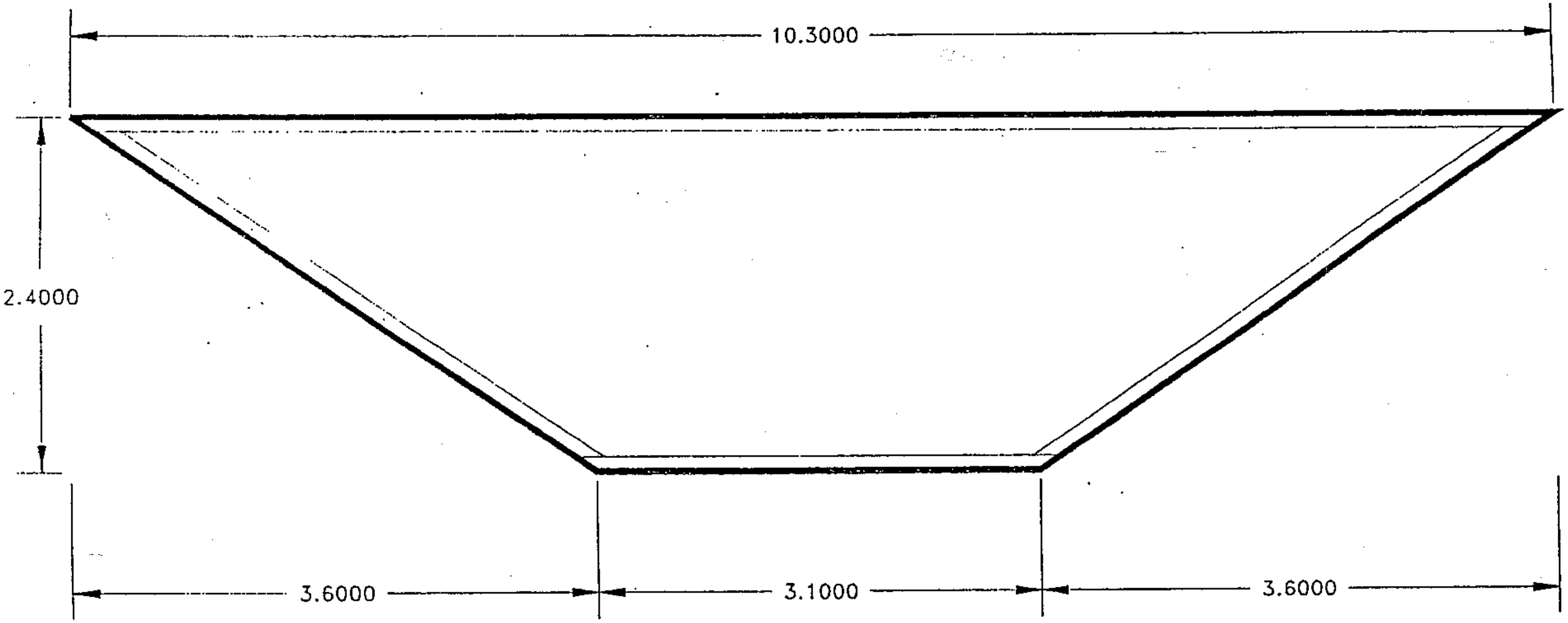
As per Drawing MRC009. Design Basis : top edge 100mm below top water level supported either by floats or 2" galvanised steel posts at 1-2m intervals.

Under Baffle

As per Drawing MRC010. Design Basis:
- Top edge 200-300mm above top water level, supported by 2" galvanised steel posts at 1 m intervals.
- Bottom edge 600mm above pond bottom.
- 150mm gap between over and under baffles.

The Partial Baffle

The sides have large pockets to actually fit over the 2" support posts. The baffles can be slid up and down these support posts. The bottom was anchored to the pond base.



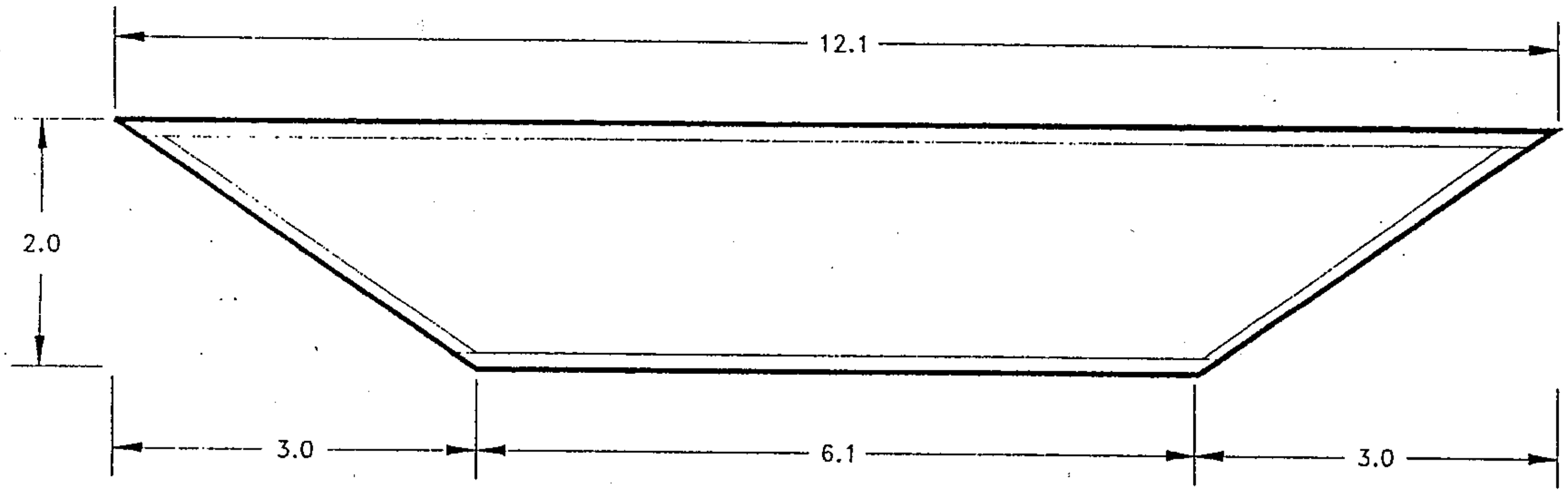
NOTE : Dimensions given are for the overall finished product – allow for 75mm (3") sown pocket around all four edges

Material : Baffle – either Nylex camlon 650 , or
Reem canvacon 7000SS
(final material selection to be confirmed)

Thread – poly-cotton thread

Design Basis : top edge 100mm below water level
bottom edge on pond botto

CRC WMPC : MRC Project		
BAFFLE 2 – Over baffle		
Dimension in metres		
Drawing MRC009	Rev 1	18/04/95

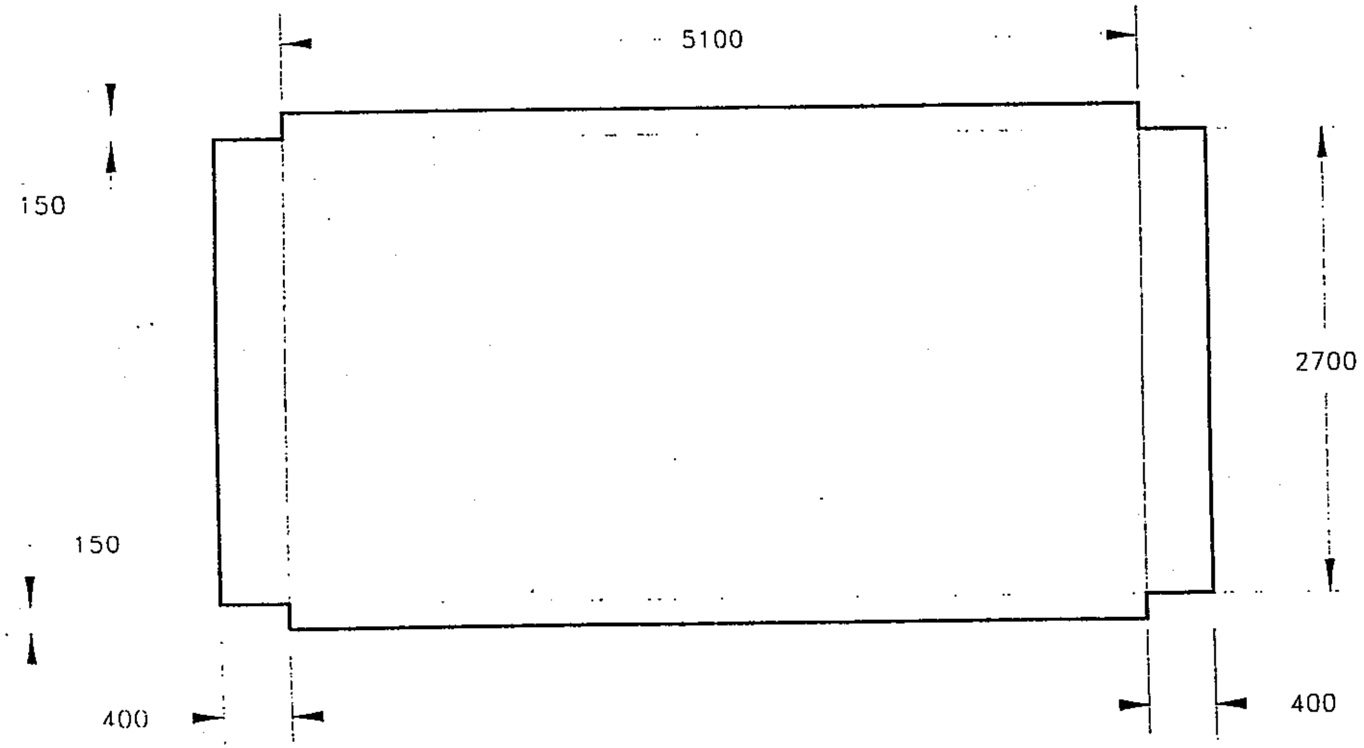


NOTE : Dimensions given are for the overall finished product – allow for 75mm (3") sown pocket around all four edges

Material : Baffle – either Nylex camlon 650 , or
Reem canvacon 7000SS
(final material selection to be confirmed)
Thread – poly-cotton thread

Design Basis : top edge 500mm above water level
bottom edge 600mm above pond bottom
150mm gap between over/under baffles

CRC WMPC : MRC Project		
BAFFLE 3 – Under baffle		
Dimension in metres		
Drawing MRC010	Rev 1	18/04/95



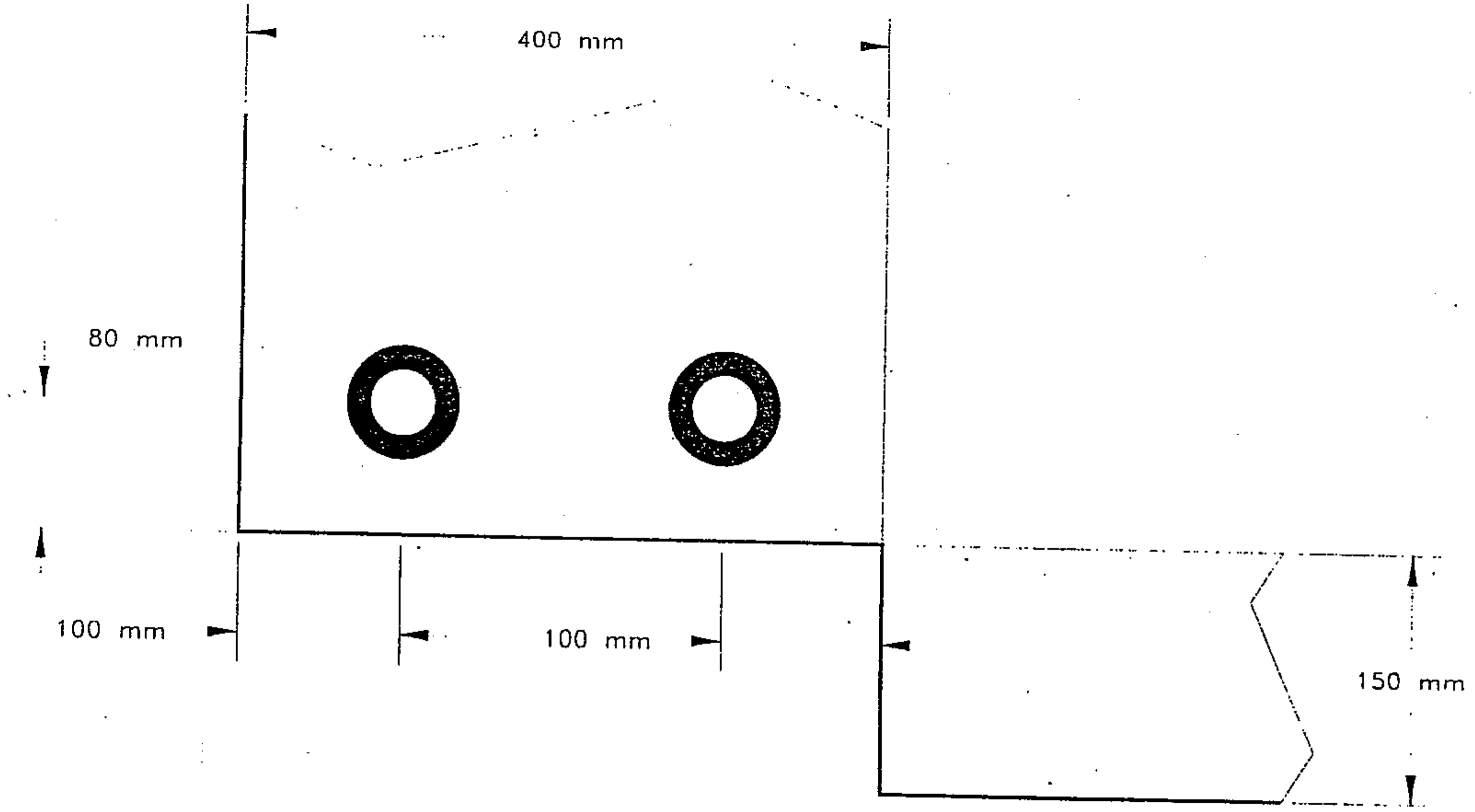
Note 1 : the pockets are open at each of the four courners of the baffle

Note 2 : refer to Drawing MRC-027 for details of eyelets to be sown into the bottom of the 400mm pockets on each side of the baffle

Material : 650 gm/sqm vinyl

Colour : a dark shade of green is preferred

CRC WMPC : MRC Project		
Partial Baffle – redesigned		
Dimension in millimetres		
DRAWING MRC–026	Rev 0	05/12/96



Note 2 : for details of the baffle, refer to Drawing MRC-026

CRC WMPC : MRC Project		
Part. Baff. – details of eyelets		
Dimension in millimetres		
DRAWING MRC-027	Rev 0	05/12/96

Appendix 8.1 Commissioning Procedure

The timetable for the original commissioning of the pond was as follows :-

14/09/95 Pond mechanically complete. Started to fill pond with water from AMH Dinmore Pond 5 (maturation pond) using effluent return pump (with suction and discharge suitably re-arranged).

21/09/95 Pond 75% full (estimated volume-wise) with Pond 5 water.

22/09/95 - 31/10/95 Interruption due to AMH Dinmore shutdown (5 week shutdown due to industrial disputes). A further 2 weeks was lost awaiting the recovery of the AMH pond system. Aerator testing completed.

13/11/95 Aerators on-line and commenced filling the pond with mixed liquor from AMH Pond 4 (SBR). As the water level was below the top of the over baffle, care was needed to prevent baffle bursting (eg. alternate feed point between aerated and settling zones).

17/11/95 Pond 90-95% full (estimated) - at level of over baffle. Pond 4 feed stopped and commissioned Pond 2 feed line. Filling with Pond 2 water.

29/11/95 Pond 1 feed on. Nominal total feed rate at 100m^3/day with 2:1 Pond 2 :Pond 1 feed ratio. Sampling of feed and effluent started around this time and generally showed good levels of nitrification but with little denitrification.

13/12/95 With commissioning of level float switches in effluent sump, the effluent return system (to AMH system) under automatic control.

05/02/96 - 12/02/96 Feed pumps installed on lines from Ponds 1 and 2 and commissioned to overcome consistent problem of loss of prime due to gassing in the pipes. At this point it was considered the pond was fully operational with reliable feed, good nitrification and improving levels of denitrification.

Appendix 8.2 Pond Operation - Summary of Major Operational Changes/Events

DATE	EVENT
21/12/95 - 27/12/95	Feeds to pond shutoff over Christmas period - aerators left on (worried about loosing Pond 2 feed and only having Pond 1 feed to pond)
30/12/95 - 02/01/96	Loss of power to project site with AMH feeder problems
10/01/96 - 11/01/96	Loss of power to project site because of damaged feed cable - AMH electricians repairing
05/02/96 - 12/02/96	AMH Dinmore shutdown - feed to pond shut-off
05/02/96 - 12/02/96	Feed pumps installed & commissioned - improved connection to Pond 2 installed
13/02/96	Total feed rates raised to 200 m^3/day - feed ratio unchanged @ 2:1
20/03/96	Total feed rates reduced to 150 m^3/day - feed ratio unchanged @ 2:1
17/04/96	Total feed rates reduced to 100 m^3/day - feed ratio unchanged @ 2:1
late April/early May 1996	Continuous heavy rain for over a week - 800mm recieved in two weeks. Considerable dilation of feed streams and pond/SBR. Most solids washed out of pond
06/05/96 - 13/05/96	AMH Dinmore shutdown due to lack of cattle brought about by flooding
09/06/96 - 13/06/96	Problems with Pond 1 feed line gassing up. No Pond 1 feed to either pond or SBR
13/06/96	Pond partially reseeded with 27m^3 of Pond 4 ML. No 2 aerator turned off
01/07/96	Pond feed ratio changed to 1:1. Total feed still 100 m^3/day
04/07/96	No 2 aerator turned back on due to falling DOs in the pond and settling zone.
08/07/96	Problems with getting consistent Pond 1 feed - total feed found to be 140 m^3/day at Pond 1:Pond 2 ratio of 1.5:1. Total feed reduced back to 100 m^3/day at 1:1 feed ratio.

09/07/96	Started regular (usually 1 hr for twice a week) sludge recycle from settling zone to aerobic zone.
19/07/96	Started to waste sludge ex settling zone to AMH Pond 4 as solids in pond was very high. Sludge recycle suspended. This has continued on a 1-2 weekly basis for around 1 hour each time.
02/08/96	No 1 Aerator (one closest to partial baffle) turned off.
09/08/96	Feed ratio changed back to 2:1 Pond 2:Pond 1 - still at 100m^3/day total feed rate.
10/09/96	Feed ratio changed to 2:1 Pond 1:Pond 2 (ie 67% Pond 1). Total feed rate remains at 100 m^3/day.
02/10/96	Both feed streams directed to anoxic zone. Total feed rate and ratio unchanged.
16/10/96	Wasted sludge ex anoxic zone for 2 hours in order to get solids content down.
18/10/96	Pond feed points back to normal - Pond 1 to anoxic zone with Pond 2 to aerobic zone.
21/10/96	Further sludge wasting (45 min) from anoxic zone.
22/10/96	Aerators on timed operation. No 1 & 3 on 3 hr ON, 1 hr OFF. No 2 on continuously.
25/10/96	Aerators 1 & 3 changed to 2 hrs ON ; 1 hr OFF
30/10/96	Aerators 1 & 3 changed to 2 hrs ON ; 2 hrs OFF
04/11/96	Problems getting timers coordinated - No 1 aerator left off with No 3 set up to 2 hrs ON ; 1 hr OFF. Aerator 2 still on continously.
13/11/96	Aerator No 3 timer changed to 1 hr ON ; 1 hr OFF. No 1 is off and No 2 on continuously
29/11/96	Partial baffle removed. Aerators 2 & 3 on continuously. Aerator 1 still off.
16/12/96	Feed to pond stopped as pond prepared for shutdown. All three aerators on.
20/12/96	Aerators turned off and remaining solids allowed to settle.
23/12/96	Settled sludge removed from both settling basin and anoxic zone - sent back to AMH Pond 4. Pond shutdown with all aerators and pumps stopped and isolated at switchboard.

Appendix 9.1 SBR Design Values

Design for Pilot Scale Abattoir SBR (Influent COD = 3000 mg/L)

Reactor Length =		3.95	3.95	3.95	3.95	m
Reactor Width =		0.95	0.95	0.95	0.95	m
Reactor Depth =		2	2	2	2	m
Reactor Working Volume =		7505	7505	7505	7505	L

Assumptions:	typ. values					
REACT:FILL =		6	6	5	4	
Cycle Time =		8	6	6	6	Hours
Aeration fraction of cycle =		0.45	0.45	0.45	0.45	
HRT =		48	36	30	24	Hours
Daily Flow =		3753	5003	6004	7505	L/Day
Feed flow @ 50% of time		313	417	500	625	L/h
Influent COD		3000	3000	3000	3000	mg/L
TKN		200	200	200	200	mg/L
Unbiodegradable soluble COD fraction for raw sewage	0.05	5%	5%	5%	5%	
Unbiodegradable particulate COD fraction for raw sewage	0.13	8%	8%	8%	8%	
Unbiodegradable soluble TKN fraction	0.025	2.5%	2.5%	2.5%	2.5%	
Yield coefficent for heterotrophs	0.45	0.35	0.35	0.35	0.35	mgVSS/mg COD
Endogenous respiration rate	0.24	0.24	0.24	0.24	0.24	/day
Endogenous residue fraction	0.2	0.2	0.2	0.2	0.2	mg VSS/mg VSS
COD to VSS ratio of the volatile sludge mass	1.48	1.48	1.48	1.48	1.48	mg COD/mg VSS
MLVSS/MLSS	0.8	0.92	0.92	0.92	0.92	
Sludge age		20	20	20	20	days

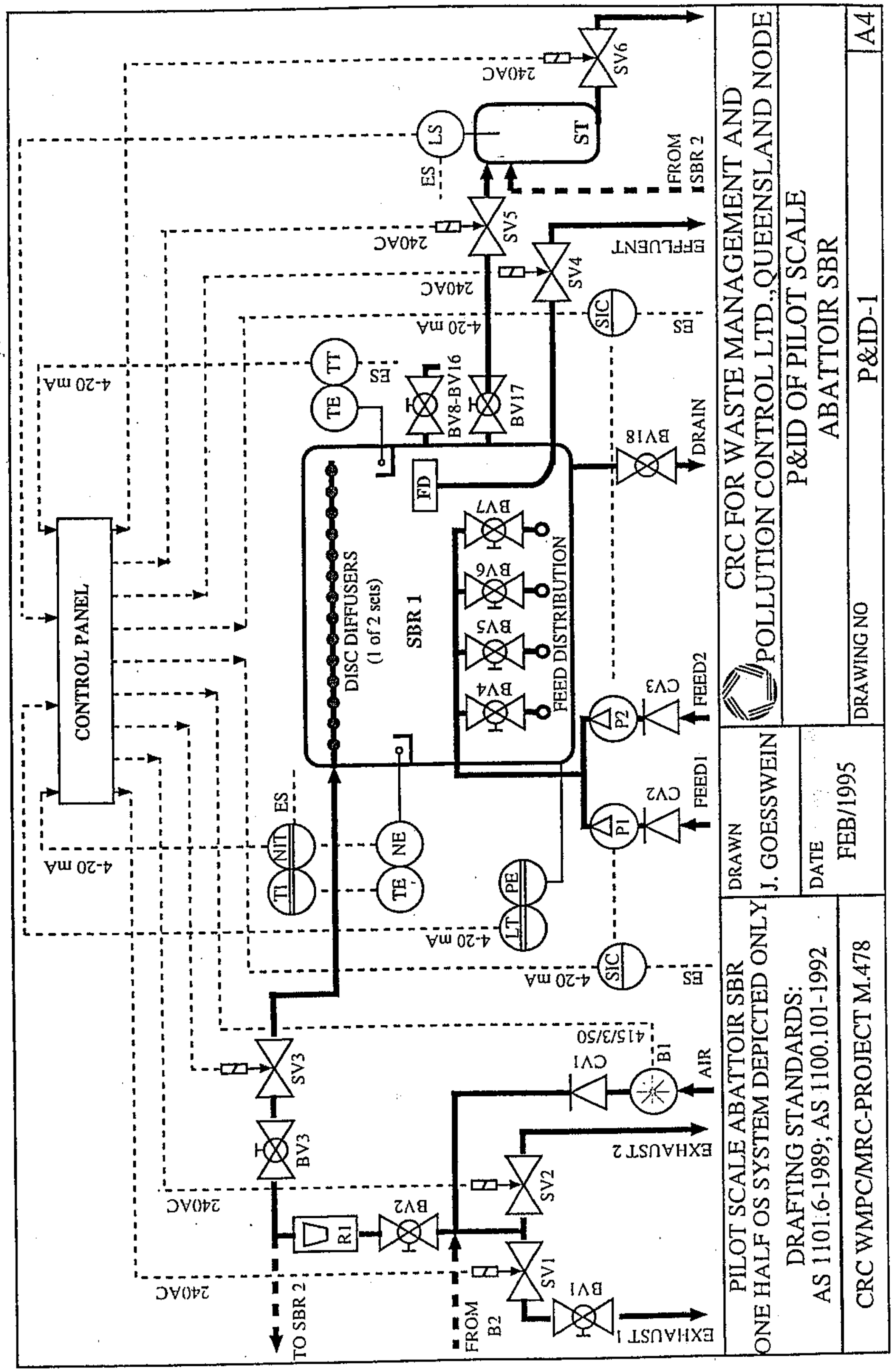
Design Calculations: Carbonaceous oxygen demand						
Mass of COD treated per day		11.26	15.01	18.01	22.52	kg COD/day
Mass of biodegradable COD		9.79	13.06	15.67	19.59	kg COD/day
Mass of unbiodegrable particulate solids		0.61	0.81	0.97	1.22	kg VSS/day
Total Mass of MLVSS		35.34	47.12	56.54	70.68	kg VSS
Total Mass of MLSS		38.41	51.21	61.46	76.82	kg SS
Process MLSS concentration		5118	6824	8189	10236	mg/L
Process MLVSS concentration		4709	6278	7534	9417	mg/L
Maximum SVI allowed (50% safety)		244	183	147	110	ml/g
The average daily carbonaceous oxygen demand		8.08	10.77	12.93	16.16	kgO2/day

Design Calculations: Nitrogen removal oxygen demand						
Influent TKN concentration		200	200	200	200	mg/L
Ammonia fraction of the influent TKN	0.75	0.85	0.85	0.85	0.85	
Unbiodegradable soluble organic N fraction of influent TKN		0.03	0.03	0.03	0.03	
Nitrogen content of the VSS		0.1	0.1	0.1	0.1	
Influent ammonia concentration		170	170	170	170	mg/L
Unbiodegradable soluble organic nitrogen concentration	6	5	5	5	5	mg/L
N conc associated with unbiodegradable particulate COD		24	24	24	24	mg/L
Biodegradable organic N in influent(==> ammonia)		0.0	0.0	0.0	0.0	mg/L
Nitrogen required for sludge production		47.09	47.09	47.09	47.09	mgN/L
Process nitrification capacity		147.91	147.91	147.91	147.91	mgN/L
Nitrification oxygen demand		2.54	3.38	4.06	5.07	kgO2/day
Nitrification oxygen demand with denitrification		0.95	1.27	1.52	1.90	kgO2/day
Process maximum total oxygen demand		10.62	14.15	16.99	21.23	kgO2/day
		0.442	0.590	0.708	0.885	kgO2/h
Peak maximum oxygen demand during aeration period		0.983	1.311	1.573	1.966	kgO2/h

Aeration Design Calculations (Circular, fine bubble membrane diffusers)						
DO required in tank		2.0	2.0	2.0	2.0	mg/l
Operating temperature		30.0	30.0	30.0	30.0	°C
Standard Oxygen Transfer Efficiency (SOTE)		11%	11%	11%	11%	
Correction factor for O2 transfer: alpha=Kla(WW)/Kla(Tap)		0.4	0.4	0.4	0.4	-
Correction factor for O2 solubility: beta=Cs(WW)/Cs(Tap)		0.95	0.95	0.95	0.95	-
Actual oxygen rating / standard oxygen rating (AOR/SOR)		0.33	0.33	0.33	0.33	
OTR		3.7%	3.7%	3.7%	3.7%	
Maximum air flow needed (during aeration period)		98.74	131.65	157.98	197.48	m3/h
Air flow rate/diffuser (diam 178 mm)		5	5	5	5	m3/h
Number of diffusers needed (per tank)		20	27	32	40	
Power estimate for blower (70% mech, 90% elec eff, ≈270 mbar)		0.84	1.12	1.34	1.68	kW

Appendix 9.2 SBR Equipment Schedule

P&ID symbols are according to AS 1101.6 - 1989.


CRC FOR WASTE MANAGEMENT AND
POLLUTION CONTROL LTD., QUEENSLAND NODE
P&ID OF PILOT SCALE
ABATTOIR SBR
DRAWING NO
P&ID-1
A4
PILOT SCALE ABATTOIR SBR
ONE HALF OS SYSTEM DEPICTED ONLY
DRAFTING STANDARDS:
AS 1101.6-1989; AS 1100.101-1992
CRC WMPC/MRC-PROJECT M.478
DRAWN
J. GOESSWEIN
DATE
FEB/1995
CONTROL PANEL
SBR 1
DISC DIFFUSERS
(1 of 2 sets)
FEED DISTRIBUTION
BV4
BV5
BV6
BV7
FD
BV8-BV16
BV17
BV18
DRAIN
EFFLUENT
SV1
SV2
SV3
SV4
SV5
SV6
ST
LS
FROM SBR 2
TO SBR 2
FROM B2
EXHAUST 1
EXHAUST 2
BV1
BV2
BV3
R1
CV1
CV2
CV3
B1
AIR
P1
P2
FEED1
FEED2
SIC
LT
PE
TE
NE
TI
NIT
TT
ES
4-20 mA
240AC
415/3/50

Equipment List for Pilot Scale Abattoir SBR

QTY	Item	Supplier
1	plant base, chassis, control room	James Hardie Building Systems Graham Lambert, ph: 271 22 88
1	fibreglass tank	Don Burge PTY LTD ph: 812 22 83
1	installation of equipment	Physics Workshop, Roger ph: 52334
1	rotameter, max 616 N m3/h	Measurement Engineering
6	2-way solenoid valves, 1 inch	Kevin Hamilton, ph: 262 86 11
3	2-way solenoid valves, 1/2 inch	
2	25 mm ball valves	
2	temp. probes	
2	temp. transmitters	
1	floating level switch	
2	level sensors (diff. pressure)	
1	signal/power wiring, control system	
1	486/DX 66	
2	DO probes and transmitters	Danfoss
4	variable speed drives	Bradley Pound, ph: 356 79 11
4	radio frequency int. filters	
2	pumps, 330 l/h	Mono Pumps
2	pumps, 750 l/h	Michael Morrow, ph: 350 45 82
2	air blowers	Dynavac Eng.
		Adam Cole, ph: 857 53 21
56	disc diffusers, incl. pipework	ITT Flygt Limited
		Gabe Vigna, ph: 02-647 18 55
2	floating decants	Total Water Treatment
		ph: 888 07 71
2	50 mm check valves	Pumps & Pipes
1	50 mm PVC tee cat	ph: 277 78 66
4	50 mm PVC pipe, price/m	674 Beaudesert Rd., Salisbury
1	50 mm PVC elbow	
4	40 mm PVC elbow	
2	40 mm PVC union cat	
2	40 mm ball valves	
1	40 mm PVC pipe, price/m	
2	40 mm x 25 mm tee cat	
5	25 mm poly elbows	
2	25 mm Tee cat	
1	25 mm PVC union cat	
2	25 mm PVC valve socket	
4	25 mm tank flange	
8	25 mm ball valves	
2	25 mm check valves	
14	25 mm PVC pipe, price/m	
10	25 mm PVC pipewor price /m	
22	20 mm tank flange	
22	15 mm ball valve	
10	15 mm PVC pipe, price/m	
20	Elbow 19 mm x 15 mm	
20	Poly Nipple 20 mm x 15 mm	
8	25 mm x 15 mm PVC tee cat	
6	thread seal tape 12 mm x 10 m	
2	PVC glue, price/125 ml	
1	copper tube, price/m	
1	copper union, 15 mm x 20 mm	
1	copper elbow	

Code	Description	Function	Power Requirements
		The following equipment is listed for one reactor only, i.e. needs to be dublicated	
B1	air blower	Aeration for SBR	415/3/50
BV3	Ball Valve, 25 mm	regulation of air flow to SBR 1	
BV4-BV7	Ball Valve, 15 mm	regulation and shut off for feed	
BV8-BV16	Ball Valve, 15 mm	sample valves	
BV17	Ball Valve, 15 mm	regulation of sludge flow	
BV18	Ball Valve, 25 mm	SBR drain	
CV1	Check valve, 50 mm	protection of B1 in case B2 is on	
CV2	Check valve, 25 mm	protection for P1 of running dry	
CV3	Check valve, 25 mm	protection for P2 of running dry	
FD	floating decant	decants effluent at surface	
LS	floating level switch	indicating fill of sludge tank	?
P1	pump, flow rate: 330 l/h	Feed pump for SBR	240 V 3/50, 0.55 KW
P2	pump, flow rate: 750 l/h	Feed pump for SBR	240 V 3/50, 0.55 KW
PS/LT	level sensors (diff. pressure)	filling level of SBR	11 V to 45 V DC

Equipment List - continued

Code	Description	Function	Power Requirements
The following equipment is listed for one reactor only, i.e. needs to be dublicated			
SBR 1	1 of 2 reactors	reactor for sewage and biomass	
SIC	pump speed controllers	control of pump flowrate	240 50 5 A
SV2	2-way solenoid valve, 25 mm	on/off for aeration	240/50 16 W
SV3	2-way solenoid valve, 25 mm	on/off for effluent	240/50 16 W
SV4	2-way solenoid valve, 12 mm	on/off for sludge wastage	240/50 8 W
TE/NE	Dissolved Oxygen and temp. sensor	DO in SBR	24V/DC from TI/TNT
TI/NIT	Display for DO and temp.	DO transmission to control panel	240 50/60 Hz, 7 VA
TE/TT	Temp. sensor and transmitter	Temp. transmission to control panel	12-45/DC
The following equipment is used for both reactors			
BV1	Ball valve, 25 mm	Flow regulation for exhaust 1	
BV2	Ball valve, 25 mm	Flow regulation to reactors	
R1	Rotameter, max air flow: 560 m^3/h	Air flow meter for both reactors	
ST	200 L Sludge tank	used for sludge wastage/storage	
SV1	2-way solenoid valve, 25 mm	valve for exhaust 1	240/50 16 W
SV2	2-way solenoid valve, 25 mm	valve for exhaust 2	240/50 16 W
SV6	2-way solenoid valve, 12 mm	sludge tank drain	240/50 8 W

Appendix 10.1 SBR Operational Events

CRC for Waste Management & Pollution Control Limited
(Department of Chemical Engineering , The University of Queensland)

SBR Operation - Summary of Major Operational Changes/Events

DATE	EVENT
17 June 1995	SBR delivered to site
mid-July 1995	SBR blowers confirmed as being undersized in both air capacity and discharge pressure. Suppliers asked to rectify the situation
22/09/95 - 31/10/95	AMH Dinmore shutdown
10/10/95	Replacement blowers finally delivered. Extensive modification of suction/discharge pipework and mounting frame required before blowers could be installed.
Nov/Dec 1995	Continuing delays with split in side wall of one tank, the replacement of the effluent withdrawal valves with larger capacity units.
late Dec 1995	First signs of the communication problem between the processor and the PC
30/12/95 - 02/01/96	Loss of power to project site with AMH feeder problems
10/01/96 - 11/01/96	Loss of power to project site because of damaged feed cable - AMH electricians repairing
January/February 1996	Numerous attempts to resolve communications problems - finally isolated to earthing differences.
05/02/96 - 12/02/96	AMH Dinmore shutdown - feed to SBR shut-off
March 1996	Numerous failures of blower air PVC pipework due to excessive temperature from the larger blowers
late March 1996	SBR obtaining fairly consistent operation - although there are still random problems with communications
09/04/96	PVC blower air pipework replaced with black PP pipe and fittings - appears to have solved problem

late April/early May 1996	Continuous heavy rain for over a week - over 500 mm received in two weeks. Considerable dilation of feed streams and pond/SBR. Most solids washed out of pond
03/05/96	Due to sludge wasteage valve continually blocking up, sludge wasteage made manual as an interim measure.
06/05/96 - 13/05/96	AMH Dinmore shutdown due to lack of cattle brought about by flooding
03/06/96	Sludge wasteage made automatic using effluent withdrawal valve
04/06/96	Checked SBR feed ratios : SBR1 57% Pond 1 (60%) SBR2 83% Pond 1 (80%)
05/06/96	SBR 2 maximum DO reduced from 2.0 to 1.0 mg/l
09/06/96 - 13/06/96	Problems with Pond 1 feed line gassing up. No Pond 1 feed to either pond or SBR
14/06/96	Reseeded SBR1 with 3300l of AMH Pond 4 mixed liquor
17/06/96	18 minute non-aerate mixed react added to the start of each React cycle
28/06/96	SBR 1 maximum DO reduced from 2.0 to 1.0 mg/l
03/07/96	During reset of SBR operations accidentally lost 2,000 l from SBR1. Little or no solids appear to have been lost.
17/07/96	Both DO sensors failed within 48 hrs of each other. Diagnosis indicates punctured membranes. Aeration control switched to timed aerate/idle while sensors are replaced.
22/07/96	DO sensors replaced. Aeration back on DO control but with a 5 min idle period after the DO falls to the min DO level.
02/08/96	Changed DO idle period from 5 min to 3 minutes.
02/08/96	SBR1 sludge wasteage back on, but sludge age raised from 20 to 30 days.

09/08/96	Problems with SBR1 DO probe (won't go below 0.4 mg/l). SBR1 DO control back on timed aerate/idle (3min/5min). SBR2 max DO raised from 1.0 to 2.0 mg/l.
12/08/96	SBR1 timed aerate/idle changed to 2min/5min.
19/08/96	SBR1 DO probe fixed up. Both SBR's on DO control - 0.3/2.0 mg/l with 5 min idle.
22/08/96	Changed SBR DO control - min 0.3/max 2.5 mg/l with 2 min idle.
22/08/96	New programme loaded into SBR to allow it to recover from communication problems - stable operation.
02/09/96-06/09/96	Intermittent problems with SBR cycles - severe disruption to both SBR due to problem with new programme - sorted out OK.
06/09/96	Problems first noticed with SBR1 taking longer to fill up (one of the feed pumps must be falling off).
17/09/96	DO idle period changed from 2 min to 3 minutes with 5sec bursts of air every minute during idle.
20/09/96	Removed 5sec burts of air during idle period - was having no effect. Idle remains at 3 minutes.
23/09/96	SBR1 sludge age reduced from 30 to 20 days due to high solids content. SBR2 sludge age remains at 30 days.
25/09/96	SBR2 DO control changed ; 2.2 hr React B @ 0.3/0.5 mg/l followed by 0.5 hr React D @ 0.3/2.5 mg/l. No idle period. Total react and cycle time unchanged. SBR1 DO control remains at 0.3/2.5 mg/l with 3 min idle.
27/09/96	SBR2 React B changed to 0.2/0.4 mg/l with React D at 2.0/2.5 mg/l.
01/10/96	Capacity check of SBR1 feed pumps has confirmed that pump 1A (Pond 2 feed) is not pumping anything. ie since early September SBR1 has been operating on 100% Pond 1 feed.
02/10/96	SBR1 sludge age reduced from 20 to 15 days. (SBR2 still at 30 days)

07/10/96	SBR1 DO control set up the same as SBR2 - ie 2.2 hrs @ 0.2/0.4 mg/l ; 0.5 hr @ 2.0/2.5 mg/l
09/10/96	SBR2 DO control moved to 2.7 hrs 0.2/0.4 mg/l
11/10/96	SBR1 sludge age reduced from 15 to 10 days ; SBR2 sludge age reduced from 30 to 20 days - high MLSSs
16/10/96	SBR1 Pond 2 feed pump (1A) repaired and back in service - ie SBR1 back on 60% Pond 1/40% Pond 2.
16/10/96	2 min idle period added to SBR2 DO control
18/10/96	SBR2 sludge age reduced from 20 to 15 days. Manually wasted 1500 l (25% volume) of mixed liquor in order to get solids content down.
18/10/96	SBR2 DO control - idle period reduced from 2 minutes to 30 seconds - incomplete nitrification.
21/10/96	SBR1 feed pumps sped up in order to complete filling before end of aeration cycle.
21/10/96	Another 1500 l of mixed liquor wasted from SBR2.
22/10/96	SBR2 feed pumps sped up in order to minimise overrun into aeration cycle. 30second idle on DO control removed.
23/10/96	SBR2's feed pumps sped up even more by raising frequency limit.
25/10/96	SBR1 sludge age raised from 10 to 15 days. SBR2 at 15 days. SBR2 feed time reduced from 1.8 to 1.6 hrs with non-aerated mixed react increased from 0.3 to 0.5 hrs. SBR1 put back on 100% Pond 1 feed.
07/11/96	Replaced worn stator on SBR1 Pond 1 feed pump - increase in performance allows feed to be complete before React starts.
11/11/96	SBR2 HRT increased from 24 to 30 hrs in order to allow feed pumps to fill before React starts.
15/11/96 - 18/11/96	All feed pumps to both SBRs tripping out due to high temperature in the VSDs - very high ambient temperatures. Cycles continued - there was just no feed.

02/12/96	Power dip. Pond feed pumps stopped which allowed Pond 1 feed line to gas up. This in turn created problems for SBR feed pumps - could not prime. Appears all four feed pumps are damaged. Replaced stators on Pond 1 feed pumps to both SBRs - now appears OK.
05/12/96	Prime lost again to SBR for some unkown reason - pumps again not pumping. SBRs left on idle while new pump stators were ordered.
09/12/96	Replaced stators on Pond 1 feed pumps - did not solve the problem - obviously the rotors are damaged as well. SBRs left cycling but without any feed.
16/12/96	SBR cycle stopped and both SBRs drained to the pond. SBR isolated at switchboard.