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AUSTRALIAN Pork™

Improved Piggery Effluent Management Systems Incorporating Highly Loaded Primary Ponds

Final Report
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Executive Summary

This project has demonstrated the technical feasibility and benefits to the Australian pig industry of utilising highly loaded (and significantly smaller) primary effluent ponds for the treatment of effluent from piggery sheds. In comparison to conventional effluent ponds, the project results indicate that highly loaded ponds offer comparable levels of treatment (solids reduction) along with a range of practical and financial benefits including easier desludging, lower overall odour emissions, reduced construction costs, reduced lining and covering costs, and improved potential to establish or expand piggeries at sites limited by separation distance to sensitive receptors.

The alternative pond design standards developed based on the results of this project have already received limited acceptance by regulatory authorities. Over recent months, officers of the DPI&F (Queensland) Intensive Livestock Environmental Regulation Unit (ILERU) have suggested to some producers that highly loaded pond systems may be the best option for meeting specific environmental outcomes in relation to proposed piggery developments.

At the request of APL, the draft recommendations for the design and management of highly loaded ponds provided in Appendix 3 of this report, have been forwarded to the consultants preparing the revised National Environmental Guidelines for Piggeries (Tucker *et al*, 2006), for incorporation in the revised edition.

Over recent decades, the design methods used throughout Australia for sizing anaerobic treatment ponds have generally been based on the Rational Design Standard (RDS) developed by Barth (1985) in the United States. This standard appears to have been developed primarily to limit odour emission from anaerobic ponds, based on the principle that higher effluent loading rates result in higher odour emissions. In Australia, application of the RDS results in relatively large anaerobic pond volumes, ranging from 6.0 to 7.7 m^3/SPU for hot to cool climates, respectively, based on a 10 year desludging interval (Tucker *et al.*, 2004).

Towards the end of the design lifespan of the pond, sludge accumulation may encroach on the pond treatment volume, adversely affecting pond function. At this point in time, the pond effluent may become unsuitable for flushing sheds and irrigation onto agricultural land, due to higher total solids concentrations, while the large surface area may emit high levels of offensive odours as pond biological function becomes impeded. Producers are then faced with the major practical and financial problem of determining how to desludge a relatively large pond without interfering with the ongoing operation of the piggery.

Prior to the commencement of this project, limited anecdotal and scientific evidence (Skerman & Collman, 2006) suggested that piggeries with anaerobic ponds that were undersized according to the RDS operated satisfactorily in terms of biological function, odour emission and sludge accumulation. These observations were supported by the findings of Payne *et al.* (1995) who demonstrated relatively high levels of solids removal at loading rates ranging from four to ten times the rates determined using the RDS.

In the light of this evidence, this project was developed to more comprehensively evaluate the performance of highly loaded ponds in relation to treatment of effluent (removal of solids), sludge accumulation and odour emission.

Trials were carried out on a newly constructed, highly loaded pond at a privately-owned, commercial piggery located north of Dalby, on the Darling Downs in southern Queensland. This piggery was operated as a farrow to bacon facility, with an average capacity of 530 sows (5025 SPU) throughout the duration of the project. The trials at this piggery were carried out in two stages, from April 2007 until June 2008; with average loading rates ranging from 0.54 to 0.88 kg VS/m^3/day (approximately six to ten times the loading rate suggested using the RDS).

Further trials were carried out from April 2007 until January 2008 at the 1300 SPU commercial grower unit located at DPI&F Wacol piggery. A 10 000 L polythene tank was used to simulate a highly loaded primary pond at this facility. The tank loading rate varied from 0.35 to 1.89 kg VS/m^3/day with an average loading rate of 0.78 kg VS/m^3/day.

The solids reduction performance of the highly loaded primary pond at the Dalby piggery was within the range normally expected for anaerobic lagoons used to treat intensive livestock effluent. Similar results were obtained for the settling tank at the DPI&F Wacol piggery. Based on these results and previous findings of Payne *et al.* (1995) and Skerman and Collman (2006), it is anticipated that volatile solids removal rates in excess of 70% will be achievable in most piggery effluent systems employing suitably designed and managed highly loaded pond systems. In this regard, highly loaded primary ponds appear to perform similarly to much larger ponds designed to operate at lower loading rates, in accordance with the RDS (Barth, 1985).

New methods were successfully trialled for measuring sludge depths in anaerobic treatment ponds. Based on the results of the sludge measurements for the Dalby and Wacol trials, the rate of sludge accumulation in highly loaded ponds appears to be less than the rate suggested by Barth (1985); however, heavy crusting is likely to occur on ponds loaded at rates exceed approximately 0.6 kg VS/m^3/day.

A solids mass balance successfully accounted for 96% of the total solids in the inflow to the highly loaded pond at the Dalby piggery over the 22 month trial period.

The odour emission rates recorded from the highly loaded primary pond at the Dalby piggery were within the range measured previously by Hudson *et al.* (2004). Following the establishment of a thick crust during the second stage of the project, however, the emissions from the highly loaded primary pond were generally less than the minimum rates recorded by Hudson *et al.* (2004). These emission rates were also significantly less than the those suggested by the APL VEF Maker software (Pacific Air and Environment, 2004), commonly used for odour dispersion modelling carried out to support applications for new and expanding piggery developments.

The trial results suggest that total odour emissions from highly loaded ponds where thick crusts have been established are likely to be significantly less than for conventional ponds designed according to the RDS, based on the anticipated lower odour emission rates per unit area, and the significantly smaller surface area emitting odour. Even on highly loaded ponds without thick crusts, overall odour emissions are expected to be lower than for conventional ponds, due to the effect of the reduced surface area.

Based on a limited number of samples, the non-specific gas sensor array system successfully discriminated between piggery effluent pond and poultry odour; and crusted and non-crusted pond surface odour samples.

While the results of PIGBAL and DPI&F Piggery assessment spreadsheet modelling suggest that both tools gave reasonable predictions of piggery waste output, accurate recording of pig feed intakes, dietary ingredients, pig numbers and pig weights would be required to enable more comprehensive assessments of their performance. Feed wastage remains a difficult issue to address, even in a more controlled environment.

In general, highly loaded primary ponds appear to provide a viable alternative piggery effluent management option. In comparison to conventional effluent ponds, they have a wide range of practical and financial benefits.

Subject to acceptance by state regulatory authorities, the draft recommendations for the design and management of highly loaded primary ponds included in Appendix 3 of this report provide a sound basis for extending this new technology throughout the Australian pig industry.

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1. Background

1.1 Introduction

Over recent decades, Australian piggeries have commonly employed anaerobic ponds to treat effluent discharged from conventional pig production sheds. These ponds have several advantages over higher technology treatment options including relatively low construction costs and moderate ongoing management requirements. The treated effluent is generally considered suitable for recycling for shed flushing purposes and for irrigation onto crop or pasture. Most piggeries are located in rural areas where agricultural crops are grown either on the piggery property or on nearby properties. Consequently, it makes sense to use the valuable water and nutrient resources in the treated effluent for incorporation into the soil as an organic fertiliser and soil amendment to promote crop growth, rather than treating the effluent to a higher standard (for example, by removing nutrients) for discharge/disposal into more sensitive parts of the environment. In this way, the nutrients in the effluent can be effectively recycled into crops that are harvested for use as pig feed or for other purposes. This practice also reduces synthetic fertiliser requirements.

1.2 Rational Design Standard

Throughout Australia, the current design standards used for sizing anaerobic treatment ponds are generally based on the Rational Design Standard (RDS) developed by Barth (1985) in the United States. This standard appears to have been developed primarily to limit odour emission from anaerobic ponds, based on the principle that higher organic loading rates result in higher odour emissions. Anaerobic pond loading rates are generally expressed in terms of the mass of volatile solids (VS) discharged into the pond on a daily basis, per cubic metre of pond volume provided for effluent treatment. In Australia, the RDS (baseline loading rate of 0.1 kg VS/m^3/day) generally results in relatively large anaerobic treatment pond volumes (Table 1), ranging from 7.7 m^3 per standard pig unit (SPU) for cool climates down to 6.0 m^3/SPU for hot localities (National Environmental Guidelines for Piggeries, Tucker *et al*., 2004).

It is acknowledged that anaerobic ponds designed in accordance with the RDS generally function effectively, with relatively low to moderate ongoing odour emissions, over their design lifetime, which generally ranges from 2 to 10 years. However, once the sludge build-up starts to encroach on the design pond treatment volume, pond function may be adversely affected. This may increase odour emission over the entire surface area of the pond and the effluent may become unsuitable for use in flushing sheds and for irrigation onto agricultural land, due to higher total solids concentrations. At this time, producers are faced with the major problem of determining how to desludge a relatively large pond while minimising disruption of the ongoing piggery operation.

Table 1: Anaerobic pond volumes and dimensions for a medium sized (5000 SPU) piggery determined using the RDS, for a range of Australian climates and desludging intervals.

Climate	**Desludging interval** (years)	**Pond storage volume** [1] (m^3)	**Pond side length at top** [2] (m)	**Pond side length at base** [2] (m)	**Pond volume per SPU** [1] (m^3/SPU)
Cool (k = 0.60)	1	22,306	78.9	53.9	4.5
	2	24,079	81.5	56.5	4.8
	5	29,397	88.8	63.8	5.9
	10	38,259	99.7	74.7	7.7
Warm (k = 0.80)	1	17,173	70.7	45.7	3.4
	2	18,946	73.6	48.6	3.8
	5	24,263	81.8	56.8	4.9
	10	33,126	93.6	68.6	6.6
Hot (k = 1.00)	1	14,093	65.1	40.1	2.8
	2	15,865	68.4	43.4	3.2
	5	21,183	77.2	52.2	4.2
	10	30,046	89.7	64.7	6.0

[1] Pond volumes based on 5000 SPU piggery (equivalent to 500 sow farrow to finish operation).
[2] Pond dimensions based on square shape with storage depth of 5 m and 1 : 2.5 (vertical to horizontal) batters on all four sides.

1.3 Highly Loaded Primary Ponds

Prior to the commencement of this project, limited anecdotal and scientific evidence (Skerman & Collman, 2006) suggested that piggeries with anaerobic ponds that are undersized according to the RDS, do not emit excessive odour or exhibit impaired pond biological function compared to ponds designed based on the RDS. Furthermore, higher rates of solids (sludge) accumulation were not observed and the treated effluent from undersized ponds appeared to be suitable for shed flushing or irrigation onto agricultural land, in terms of solids content and chemical characteristics. These observations were supported by the findings of Payne *et al.* (1995) who constructed 20 L capacity "mini ponds" that demonstrated relatively high levels of total solids (TS) and volatile solids (VS) removal (minimum 70% and 80%, respectively) at loading rates ranging from 0.4 to 1.0 kg VS/m^3/day. As a consequence of these observations, this project was developed to provide further scientific evidence regarding the performance of highly loaded ponds in relation to treatment of effluent (removal of TS and VS), sludge accumulation rates and odour emission. Subject to approval by state regulatory authorities, the outcomes of this project can potentially provide scientific justification for the development and widespread adoption of a new, alternative design standard for anaerobic effluent ponds used by the Australian pig industry. It is intended that this new standard will be acknowledged as a viable alternative to rigidly applying the principles of the RDS in all situations.

In comparison to conventional effluent ponds, highly loaded ponds have the following potential benefits:

- Reduced earthworks costs due to smaller storage volume.
- Easier and less expensive to line to minimise the risk of seepage of contaminants into underlying groundwater resources.
- Easier and less expensive to cover to reduce odour and greenhouse gas emissions or to capture methane for productive use, e.g. shed heating or power generation.
- Greater ease and reduced cost of effluent solids removal (desludging).

- More regular and effective utilisation of the valuable nutrient and soil amendment values of piggery solids, resulting in reduced fertiliser costs and healthier soils, respectively.
- Lower odour emissions due to reduced pond surface area and the development of a crust on the pond surface.
- Potential to establish or expand piggeries at sites limited by separation distances to sensitive receptors.

1.4 Highly Loaded Pond Crust Formation and Odour Emission

Odour emissions from piggery effluent treatment ponds have been identified as a major contributor to odour nuisance experienced by neighbouring residents. The odour emissions from an effluent pond vary according to changes in the physical, chemical, and biological conditions of the pond. In general, the development of a crust at the surface of the pond indicates that the effluent (*i.e.* volatile solids and total solids) loading has exceeded the treatment capacity of the anaerobic effluent pond (SA EPA, 1998). However, this crust helps to maintain anaerobic conditions, keep the pond temperature constant, and minimise offensive odour emissions. Odours may be released when the crust is broken during pump-down (Funk *et al.*, 1993).

Misselbrook *et al.* (2005) hypothesized that crust development occurs as a result of solids in suspension in the stored slurry being carried to the surface of the pond by bubbles of gas (carbon dioxide and methane) generated by microbial degradation of the organic matter. Evaporation at the surface promotes drying and binding of the particles at the slurry surface, forming a crust. The concentration and nature of the solids present in the slurry, which in turn may be dependent on the livestock diet and degree of feed wastage, are therefore likely to be important in influencing crust formation together with environmental factors such as temperature, wind speed and rainfall that affect surface drying.

The hypotheses in the odour-minimising mechanism of a crust are that it acts as: (1) a physical barrier to the odour emissions from the liquor of an effluent pond; and (2) a bio-filtration medium which can reduce the strength of odours by changing their characteristics during the dispersion process of odours through the crust. These hypotheses are supported by the findings of Hudson *et al.* (2006) [APL 1829] who found that a range of permeable piggery effluent pond covers reduced odour emission by 41% to 50% when compared to an uncovered pond. It is postulated that the odour reducing mechanism of a permeable pond cover is similar to that of a naturally formed crust. Misselbrook *et al.* (2005) also reported that the formation of a natural crust on a dairy slurry storage in the UK reduced ammonia emissions by approximately 50%.

These findings suggest that the formation of a natural crust on a highly loaded pond may have significant benefits in terms of odour emission reduction.

1.5 Trial Piggery Details

1.5.1 Dalby Piggery

1.5.1.1 Climate Details

Figure 1 shows historical average monthly rainfall, pan evaporation, and maximum and minimum temperatures recorded at the Dalby Airport composite meteorological station, as reported by the Rainman software (DPI&F, 2008).

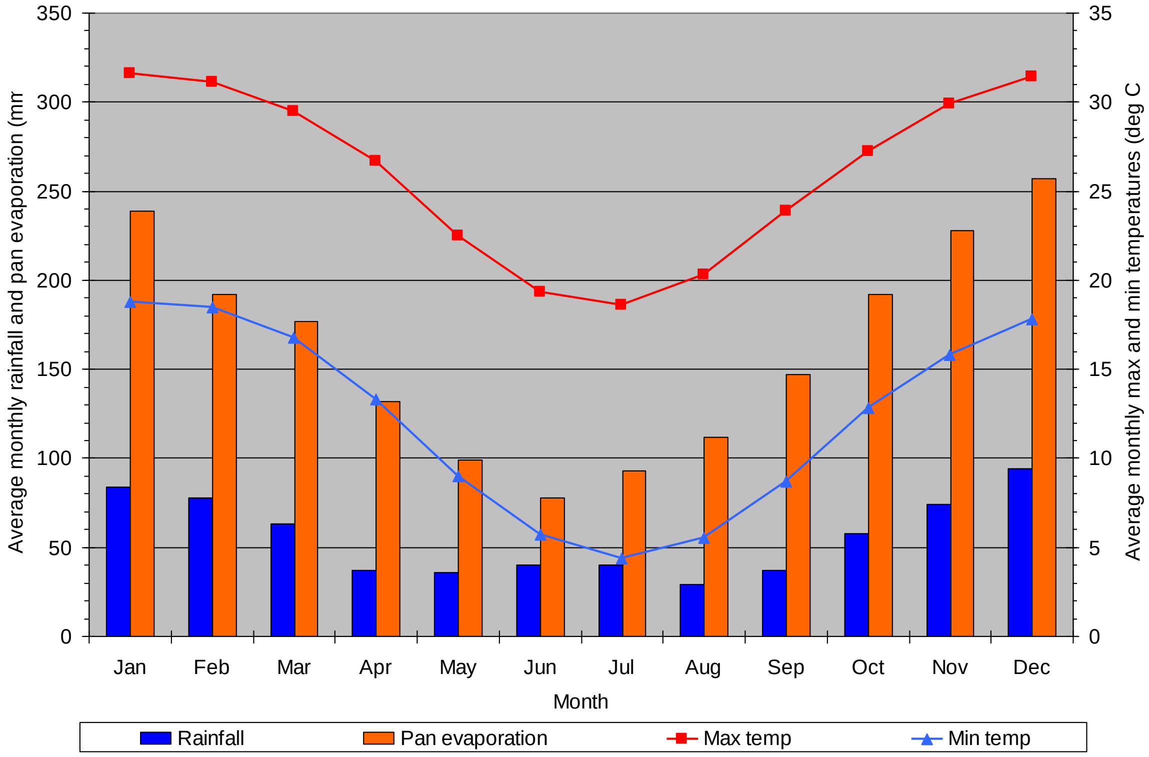


Figure 1: Average monthly rainfall, pan evaporation, and maximum and minimum temperatures at Dalby.

1.5.1.2 Description of Operation

For the purpose of this project, trials were carried out on a newly constructed, highly loaded pond at a privately owned commercial piggery located north of Dalby, on the Darling Downs in southern Queensland. This piggery was operated as a farrow to bacon facility, with an average capacity of 530 sows (5025 SPU) throughout the duration of the project.

All piggery sheds had fully slatted floors with the exception of the farrowing section of Shed 2 which was partially slatted. The shed floors were constructed using slatted, pre-cast concrete and plastic tiles. Piggery shed flushing details are outlined in Table 2.

Figure 2: Aerial photograph of Dalby piggery showing approximate location of highly loaded primary pond.

All sheds are flushed using recycled effluent pumped from wet weather storage pond 4, as shown in Appendices 1 and 2. Each 0.3 m wide flushing channel is individually flushed at a flowrate of approximately 6.5 L/s. The piggery manager advised that the flushing pump is turned on and off at approximately 7 AM and 5 PM respectively, on a daily basis. Consequently, recycled effluent flushing medium is running through the piggery flushing channels for approximately 10 hours per day. After the required flushing is completed in the scheduled sheds, recycled effluent is generally directed through one of the flushing channels in shed 1 for the remainder of the 10 hour daily pumping time.

The number of flushing channels and flushing times per shed vary. Because the flushing channels under sheds 1, 2 & 3 were built without any fall (on a level gradient), they require longer flushing times, to adequately remove the deposited manure, than the flushing channels under sheds 4 and 5, which were constructed more recently on a gradient of 1%. Details of the shed flushing times and volumes are provided in Table 2.

Table 2: Dalby piggery shed flushing times and volumes.

Shed No:	**1**	**2**		**3**		**4**	**5**	(Note 2)	**Total**
Shed description	Grower	Farrow	Weaner	Dry sow	DMA	Grower	Finisher		
Average pig population (SPU)	1,084	358	347	662	97	1,026	1,448		5,022
No of flushing channels	18	16	22	14	20	20	20		
Channel flushing time (min)	18 x 10 min	8 x 10 min + 8 x 5 min	22 x 2 min	14 x 5 min	20 x 2 min	20 x 5 min	20 x 5 min		
Section flushing time (min)	180	120	44	70	40	100	100		
Flushing volume (L) [1]	70,200	46,800	17,160	27,300	15,600	39,000	39,000		
Section flushes per week	4	7	3	7	3	4	4		
Shed flushing time (hr/week)	12.00	14.00	2.20	8.17	2.00	6.67	6.67	18.30	70.00
Weekly flushing volume (L/week)	280,800	327,600	51,480	191,100	46,800	156,000	156,000	428,220	1,638,000

Notes:

[1] Flushing volumes are based on the measured shed flushing flowrate of 6.5 L/s.

[2] The flushing pump is generally operated for 10 hours per day. After all of the scheduled sheds have been flushed for their allocated times, the flushing flow is directed through one of the shed 1 flushing channels for the remainder of the 10 hour period.

1.5.2 DPI&F Wacol Piggery

1.5.2.1 Climate Details

Figure 1 is a graph showing historical average monthly rainfall at the Goodna Post Office metrological station which is situated approximately 3.8 km south of the piggery. The pan evaporation, maximum and minimum temperature data presented in this figure are based on records from Archerfield Aerodrome metrological station which is situated approximately 10.5 km east of the piggery. All of the climatic data presented in this figure was obtained from the Rainman software (DPI&F, 2008).

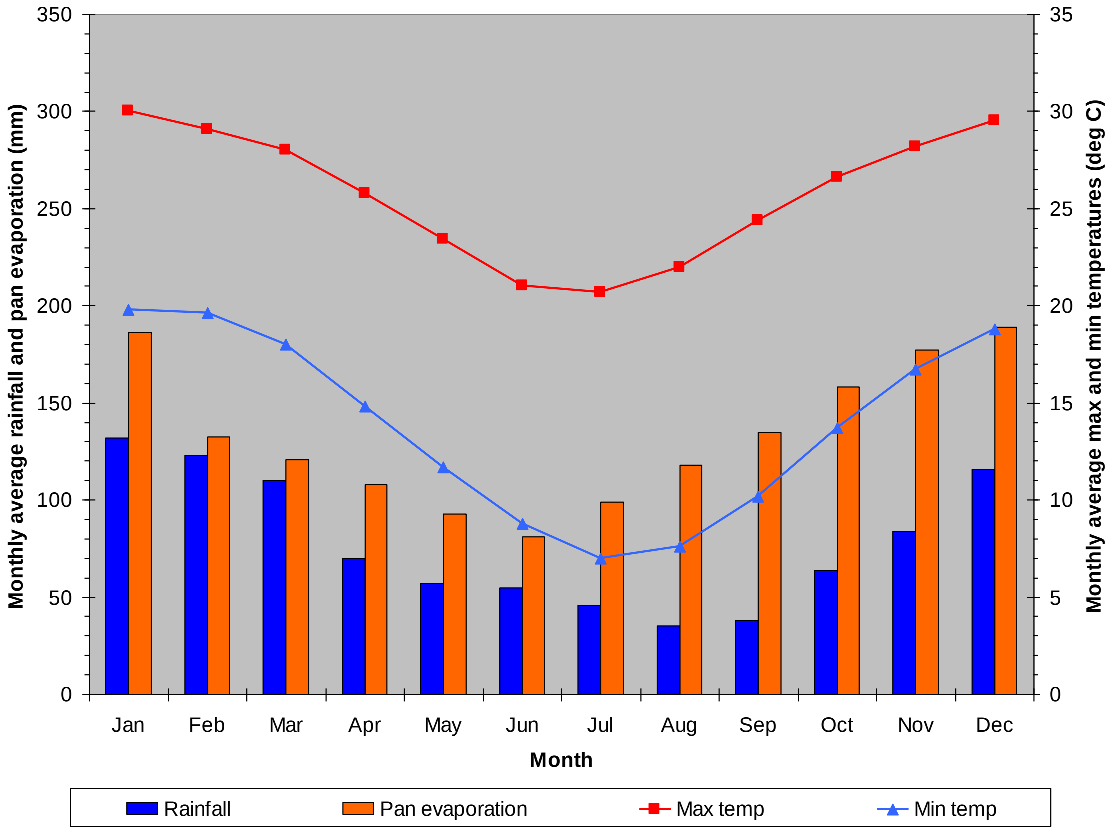


Figure 3: Average monthly rainfall at Goodna meteorological station; and pan evaporation, and maximum and minimum temperatures at Archerfield aerodrome. Both meteorological stations are within approximately 10 km from the DPI&F Wacol piggery.

1.5.2.2 Description of Operation

The DPI&F Wacol piggery is operated as a commercial grower unit with additional specialised facilities for carrying out a range of research trials. There are two commercial grower/finisher sheds at the piggery, accommodating a total of 1000 pigs. Grower pigs enter the facility at 10 weeks of age and an average weight of 25 kg. The majority of pigs are grown out to bacon weight (approximately 100 kg) at an age of 19 to 20 weeks; however, some pigs are sold as 90 kg porkers at approximately 17 weeks of age. The piggery was running at a capacity of approximately 1300 SPU throughout the trial period.

Trials were carried out at the DPI&F Wacol piggery using a 10 000 L polythene tank to simulate a highly loaded primary pond. The grower and finisher sheds at this piggery are flushed simultaneously every second day using effluent recycled from a single effluent treatment/storage pond. The recycled effluent is pumped from the pond to the three separate flushing tanks used to flush the sheds. Open concrete drains convey the flushed effluent from the sheds by gravity flow into a concrete sump having a capacity of 52 000 L, situated near the western end of the grower and finisher sheds. This sump is large enough to store a full flush from these sheds. The sump is fitted with an electric motor driven agitator which commences operation 10 minutes before a Grundfos submersible effluent pump (model AP100.100.61.3) starts pumping the effluent from the sump to the anaerobic treatment/storage pond situated on the south-eastern side of the piggery complex. It generally takes approximately 35 minutes for the pump to transfer the effluent to the single treatment/storage pond. The pump and agitator are controlled electronically by float switches installed in the sump.

An aerial photograph of the grower and finisher sheds, sump and tank is provided in Figure 4.

Figure 4: Grower and finisher sheds at the DPI&F Wacol piggery, showing the effluent sump and settling tank on the western end.

2. Research Methodology

2.1 Dalby Piggery

2.1.1 Variation in Shed Effluent Quality

The quality of the effluent discharged from each shed varies significantly from channel to channel across the shed, as some flushing channels collect more manure than others. For example, the grower / finisher sheds (1, 4 and 5) have laneways along the exterior sides of the sheds, with two rows of 3 m wide, back to back pens, between the laneways. Manure and spilt feed is generally deposited more heavily towards the centres of rows of pens.

Figure 5: Interior of shed 4 showing back to back 3 m x 3 m grower pens extending across the shed, with walkways along the exterior sides of the shed.

To examine the variation in effluent quality discharged from the channels across one of the sheds, individual effluent samples were collected and analysed for channels 1 to 10, underlying half of shed 5.

2.1.2 Shed Effluent Sampling Program

To enable the performance of the highly loaded primary pond to be evaluated, it was important to collect and analyse representative effluent samples discharged from each of the piggery sheds into the highly loaded primary pond. This data could then be used for comparison with samples of effluent discharged from the highly loaded pond to determine the pond performance in terms of the solids reduction. The shed effluent data could also be used for comparison and verification of estimates determined using the DPI&F *Piggery assessment spreadsheet* (v 10C, Skerman, 2004) and the PIGBAL model (v 3.1, Casey *et al*., 2003).

The trials at the Dalby piggery were carried out in two stages. During the first stage (stage), only the effluent from grower and finisher sheds 4 and 5 was directed into the highly loaded pond. In the second stage (stage 2), effluent from all five piggery sheds was directed into the trial pond.

Over the course of the project, samples that were representative of the entire flushing flow from each shed were collected on several occasions. Due to of the significant time required to collect these samples and to fit in with the piggery shed flushing schedule outlined in Table 2, only one shed was sampled per day. Because the composition of the pig herd, the herd genetics and the feed rations fed to the pigs remained relatively constant throughout the 14 month sampling period, it has been assumed that the quality of the effluent discharged from each shed also remained relatively constant. Table 3 outlines the 14 month shed effluent sampling program, commencing in April 2007.

Table 3: Shed effluent sampling program.

Stage	Sampling date	Shed 1	Shed 2	Shed 3	Shed 4	Shed 5
1	19/04/2007					✓
1	3/05/2007					✓
1	15/05/2007					✓
1	31/05/2007					✓
1	14/06/2007					✓
1	26/06/2007				✓	
1	12/07/2007				✓	
1	24/07/2007				✓	
1	7/08/2007				✓	
1	21/08/2007				✓	
1	28/08/2007				✓	
2	30/01/2008		✓			
2	6/02/2008			✓		
2	13/02/2008			✓		
2	14/03/2008			✓		
2	19/03/2008		✓			
2	23/04/2008			✓		
2	2/05/2008		✓			
2	9/05/2008	✓				
2	4/06/2008	✓				
Total:	20 samplings	2	3	4	6	5

This project involved working at both the Dalby and Wacol piggeries, which both require a minimum 72 hour biosecurity quarantine period for all visitors. Consequently, it was not generally possible to collect samples from both piggeries during the same week and samples were often collected from each piggery at fortnightly intervals.

2.1.3 Shed Effluent Sampling Methods

Representative samples of the effluent discharged from the sheds were collected primarily by pumping almost continuously into a 200 L tipping drum, throughout the entire shed flushing period. As outlined in Table 2, shed flushing times ranged from 100 to 180 minutes. When the 200 L drum filled with effluent, the contents of the tipping drum were thoroughly agitated manually using a plastic bladed canoe paddle. While the drum contents were being agitated, a sub-sample, generally having a volume of approximately 1 L, was collected from the drum. During stage 1, subsamples were collected by manually plunging a 1 L wide-mouthed sampling bottle to a depth of approximately 600 mm into the tipping drum. A shoulder-length disposable glove was used to protect the arm of the sample collector. During stage 2, 1 L sub-samples were collected via a 38 mm valve fitted approximately half way up the side of the 200 L tipping drum.

The 200 L plastic drum was mounted in a steel tipping frame specially manufactured in the DPI&F Toowoomba workshop to enable the drum contents to be emptied quickly and easily, with minimal physical effort. Figure 6, 9 &10 shows the tipping drum in place at the end of shed 5.

Following collection of each 1 L sub-sample, the contents of the 200 L tipping drum were tipped into the effluent discharge channels at the rear of the sheds. After the tipping drum was locked into the upright position, pumping into the tipping drum was recommenced as soon as possible. This procedure minimised disruption of the almost continuous sampling process to produce a representative composite effluent sample with a manageable volume suitable for further sub-sampling and transport to the laboratory for analysis.

Figure 6: Effluent collection facilities on shed 5, showing the 200 L tipping drum, effluent stirring paddle, 225 mm x 225 mm PVC pipeline tee and polythene sampling sump.

The 1 L sub-samples collected from the 200 L tipping drum were tipped into a 25 L plastic drum fitted with a 20 mm outlet valve installed approximately halfway up the side of the drum, as shown in Figure 9. The threaded internal fitting on the valve protruded approximately 75 mm into the drum, ensuring that the sub-sample was taken from near the centre of the drum where the agitation should be uniform. The outlet valve was allowed to run for a few seconds before the sample was taken, to clear any unmixed effluent from the outlet pipe and valve.

Figure 7: 200 L tipping drum during pumped sampling from the shed 5 effluent sump.

Figure 8: 200 L tipping drum during manual bucket sampling from the shed 5 effluent drain.

Figure 9: 25 litre sampling drum used for temporary storage, transport and sub-sampling of composite effluent samples.

For most sheds, this 25 L drum was practically full by the end of the shed flushing cycle. (In some cases the sub-sample volume was varied to ensure that the drum was practically full by the end of the shed flushing.) The composite sample collected in the 25 L drum was then thoroughly agitated manually using the stirring paddle, prior to the collection of a 1 L sub-sample through the outlet valve. (To ensure that the sub-sample was representative of the effluent collected in the 25 L drum, the agitation was carried out in a manner that avoided a circular flow pattern around the centre of the drum.) This effectively produced a 1 L sub-sample that was representative of the effluent discharged from the shed being sampled over the entire shed flushing cycle.

During stage 1, the 25 L drum was transported back to the laboratory for further sub-sampling; whereas during stage 2 of the project, the 25 L drum was generally sub-sampled in the field, reducing the size of the sample to be transported by vehicle from the piggery back to the laboratory.

A Davey D15A submersible sump pump was used for sampling the raw shed effluent throughout the project. According to the manufacturer's specifications, this pump is suitable for pumping soft solids up to 20 mm in diameter. The pump outlet was fitted with a 32 mm delivery hose to convey the sampled effluent into the tipping bucket. A tee was installed on the pump delivery line to allow the recirculation of some of the pumped effluent back to the pump inlet. The resulting recirculation of effluent was intended to agitate and resuspend any solids that settled around the pump inlet, to reduce the risk of pump blockages. The recirculation line also reduced the sampling flowrate, thereby increasing the time taken to fill the 200 L tipping drum.

It was found that the sampling pump delivered a total flowrate of approximately 1.3 L/s. This flowrate was split approximately equally between the sampling and recirculation lines, resulting in a sampling flowrate of approximately 0.65 L/s (39 L/minute). At this sampling flowrate, the 200 L tipping drum took approximately 5 minutes to fill. This was convenient for sampling sheds 4 and 5 in which the channels are flushed for a duration of 5 minutes each. This meant that 1 x 1 L sub-sample was collected from each channel.

The Davey sampling pump operated satisfactorily throughout the majority of the sampling events; however, the pump inlet became blocked several times during our initial sampling attempt. The addition of a simple 25 mm square galvanised weldmesh cage around the pump inlet reduced the occurrence of pump blockages during subsequent sampling trials.

The sampling pump required a reasonable depth of submergence so that it didn't suck air and for cooling of the electric motor. At some of the sampling locations, there was barely sufficient depth of flow for satisfactory operation of the sampling pump without breaking suction. To address this problem, at some of the sampling locations, a narrow spade was placed across the effluent flow path, on the downstream side of the pump, to partially obstruct the flow, thereby increasing the submergence of the pump inlet. This arrangement worked reasonably effectively. The pump was able to sample almost continuously throughout the flushing cycle, with minimal instances of sucking air or blockages. The effluent recirculation line was also used at some sampling locations to cool the motor if it was not sufficiently submerged in the effluent stream.

To address the possibility that the sampling pump described above may not have been picking up all of the heavier solids discharged from the piggery sheds, it was decided to carry out some sampling trials by manually bucketing samples from the drains at the ends of sheds 4 and 5, into the 200 L sampling drum. Samples were collected manually at 10 second intervals, throughout the 100 minute flushing cycle, using a 3 L capacity plastic bucket attached to an extendable aluminium sampling pole. An audible countdown timer was used to control the bucketing frequency. It is estimated that approximately 2.5 L of sample was collected in each bucket load. This proved to be a rather laborious but effective sampling method enabling valid comparisons with data obtained by sampling using the submersible pump. Samples were collected using this method on 15 May and 26 June 2007.

2.1.4 Shed Effluent Sampling Locations

Each shed had a different effluent drain and apron arrangement to direct the effluent into the pipeline to the highly loaded pond. Sheds 4 and 5 had relatively narrow, square drainage channels running transversely across the ends of the sheds (refer to Figure 6), while some of the other sheds had wider, open aprons directing effluent towards small sumps at the upstream ends of the delivery pipelines. The apron on shed 3 is shown in Figure 10.

Figure 10: Tipping drum positioned for sampling from Shed 3.

In the case of shed 5, a 600 mm x 600 mm x 600 mm black polythene sump was installed on the 225 mm PVC pipeline conveying raw effluent to the primary pond. A 110 mm long section of pipe was removed from the 225 mm PVC pipe passing through the sump. A 200 mm long, rubber backed, metallic coupling was purchased to slide over the gap in the pipeline after the completion of sampling. During sampling, a stainless steel baffle was fitted across the gap in the pipeline, being held in position by a bolt through the top of the PVC pipe. This baffle directed effluent coming from the shed into the sump, ensuring that it didn't pass directly into the outlet pipeline, effectively short circuiting the sump. This arrangement is shown in Figure 11.

The submersible sampling pump described in section 2.1.3 was used to pump effluent from the sump into the tipping drum. The recirculating line was used to agitate and resuspend solids that settled out on the base of the sump. This sampling method had the advantage that the sampling pump remained totally submerged in effluent throughout the flushing process. Several times during the 100 minute shed flushing cycle, a paddle was used to manually agitate heavier solids including undigested feed that tended to settle on the base of the sump.

This sampling method proved to be quite successful, with minimal pump blockages, resulting in almost continuous effluent sampling throughout the shed flushing cycle.

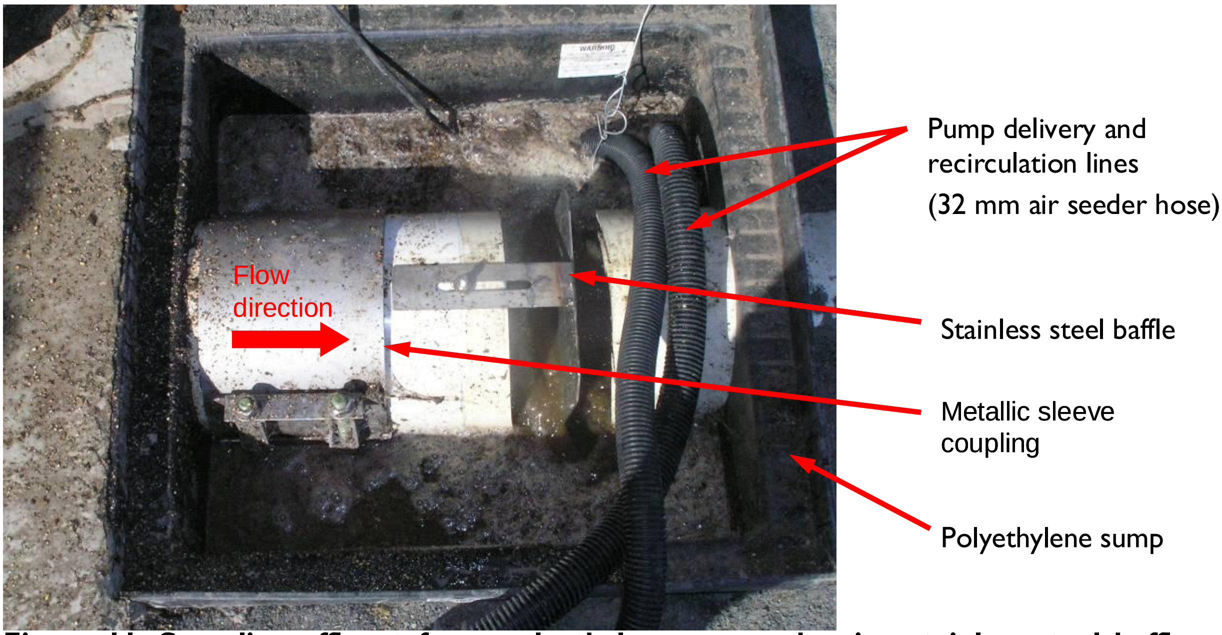


Figure 11: Sampling effluent from polyethylene sump, showing stainless steel baffle and 32 mm diameter air-seeder hose sampling and recirculation lines.

Effluent was also sampled from tees installed in the 225 mm diameter pipelines conveying flushing flows from the sheds to the highly loaded pond, as shown in Figure 12. As previously noted in section 2.1.3, at some of these sampling locations where there was insufficient depth of flow to allow the pump to operate satisfactorily, a narrow spade was placed across the effluent flow path, on the downstream side of the pump, to partially obstruct the flow, thereby increasing the submergence of the pump inlet.

The pipeline from shed 4 to the primary pond is fitted with a 225 mm x 225 mm PVC tee, however, because this pipeline is laid at a steeper gradient than the shed 5 pipeline, the flow depth was insufficient to allow pumped sampling from the tee. Consequently, shed 4 effluent was sampled by placing the submersible pump at the end of the open effluent drain, near the 225 mm pipe inlet, on the end of shed 4, as shown in Figure 12. By using the recirculation line to cool the top of the pump motor which was not continuously submerged in effluent, the pump operated satisfactorily, with minimal blockages.

Figure 12: Submersible pump sampling effluent from 225 mm x 225 mm PVC pipeline tee.

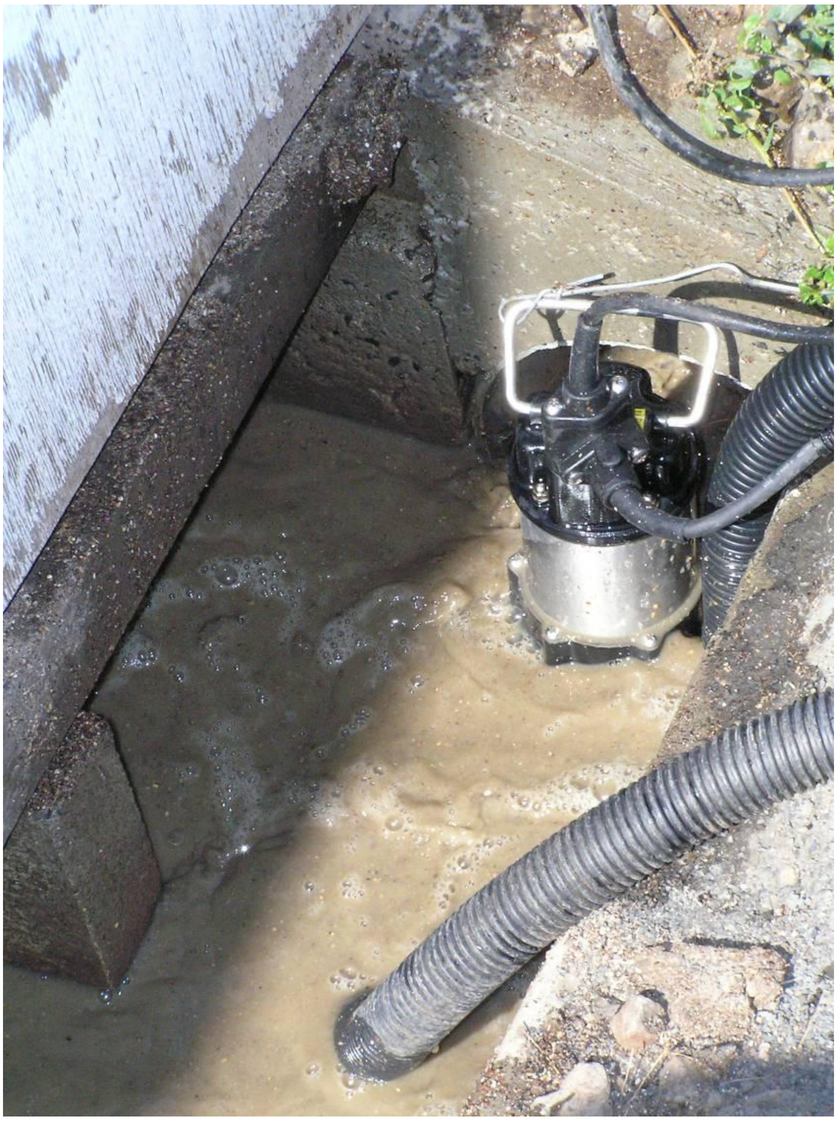


Figure 13: Pumped effluent sampling from the drain on the end of shed 4.

2.1.5 *Primary Pond Pump*

It was originally intended to use a gravity overflow pipeline to convey effluent from the highly loaded primary pond to secondary pond 3 (as shown in Appendix 1and Appendix 2). However, during stage 1, the pipeline from shed 4 regularly became blocked as the effluent level in the primary pond submerged the pipeline outlet before the effluent reached the higher gravity overflow level. As a result, the gravity overflow pipeline to the secondary pond 3 could not be used due to the need to maintain a lower operating level to prevent further blockages.

Consequently, a DPI&F owned Grundfos APG.50.09.3 submersible cutter pump was used to pump effluent from the highly loaded primary pond to secondary pond 3. This pump was suspended from a float, so that the pump inlet was situated approximately 500 mm below the pond surface. A float switch and automatic pump controller were installed to control the pump operation and hence the effluent level in the highly loaded pond, thereby preventing submergence and further blockages in the shed 4 inlet pipeline. The pump control facilities are shown in Figure 14.

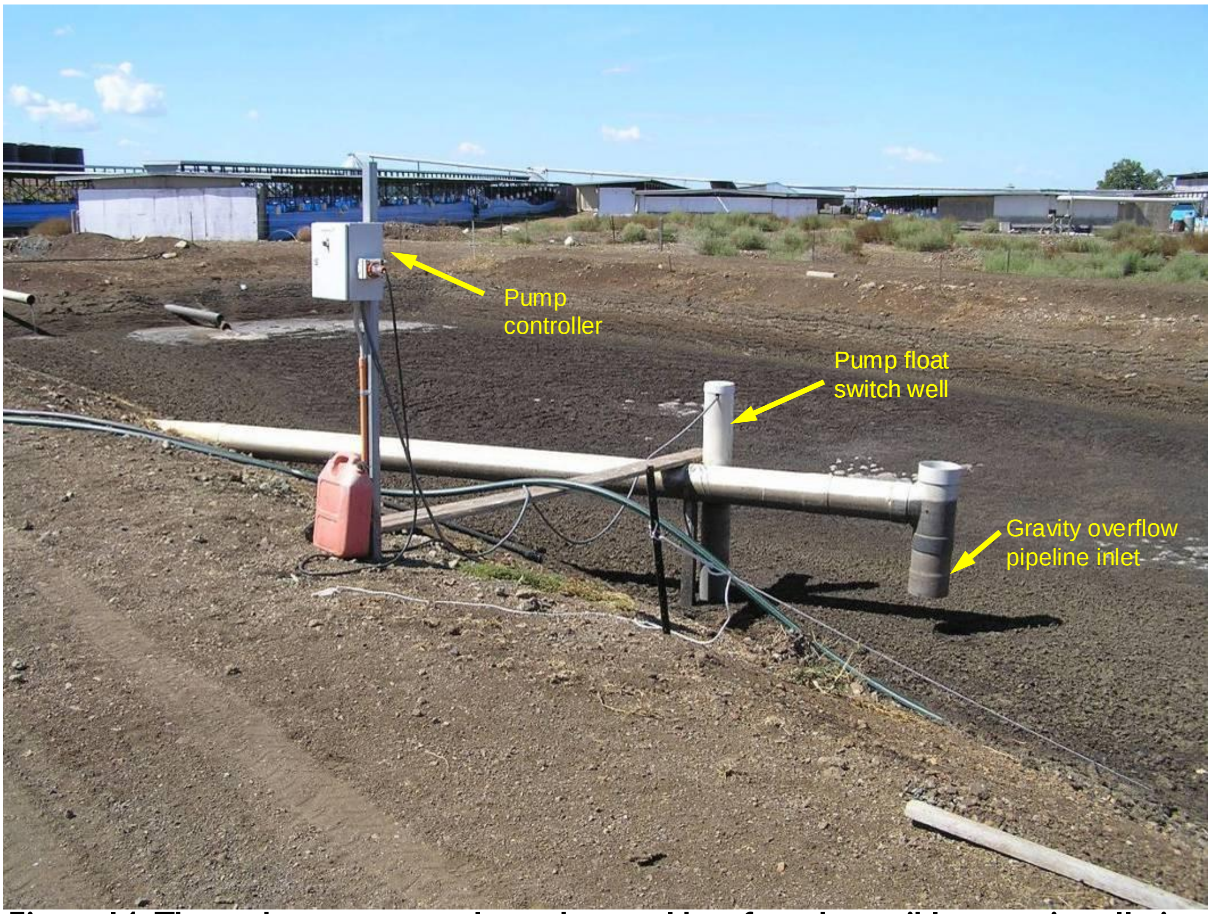


Figure 14: Three phase power outlet and control box for submersible pump installation in highly loaded primary pond. The float switch well is attached to the gravity overflow outlet.

2.1.6 *Primary Pond Outlet Sample Collection*

On each sampling visit to the Dalby piggery, primary pond outlet samples were collected by running the submersible effluent pump installed in the primary pond. If the pump was not operating at the time of the site visit, it was turned on manually and allowed to run for several minutes before collecting a sample from the 2" rural polythene pipeline used to convey effluent into secondary pond 3. The sample was collected in a 25 L sampling drum which was manually agitated and sub-sampled to produce a 1 L sample representing the effluent discharged from the highly loaded pond.

During stage 1, a further sample was taken from directly below the highly loaded pond surface by manually bucketing effluent into another 25 L sampling drum. This sample was collected using a 3 L plastic bucket mounted on an extendable aluminium sampling pole, from a location near the primary pond gravity overflow pipeline. Before commencing sampling, the floating surface crust was manually pushed away from the sample collection point to prevent contamination of the sample with floating crust material.

During stage 2, the surface crust became too thick to allow collection of representative samples from just below the pond surface by bucketing. Attempts to do so resulted in the samples being contaminated by floating crust material.

In a gravity overflow situation, the surface crust can easily be prevented from entering the gravity overflow pipeline by installing a tee on the upstream end of the pipeline, as shown in Figure 14.

2.1.7 *Highly Loaded Pond Loading Rates*

During stage 1, the pump float switch was set to maintain the effluent level in the highly loaded pond in the range from 0.7 m to 1.2 m below the gravity overflow level. This reduced the effective storage capacity of the primary pond from 2.1 ML to an average of approximately 1.3 ML.

Following the relaying of the pipeline from shed 4 into the highly loaded pond, prior to the commencement of stage 2, it was found that the highly loaded pond could operate at a higher level without causing any inlet pipeline blockages. Consequently, the pump float switch was adjusted to maintain the effluent level in the range from 0.0 m to 0.5 m below the gravity overflow, resulting in an average operating capacity of approximately 1.9 ML.

As previously noted, throughout stage 1, effluent from sheds 4 and 5 only was directed into the highly loaded primary pond. During stage 2, effluent from all five piggery sheds was directed into the highly loaded primary pond. The resulting volatile solids (VS) generation rates for both stages of the trial are outlined in Table 4, while the pond VS loading rates are provided in Table 5.

Table 4: Estimated piggery shed volatile solids (VS) generation rates, based on standard DPI&F Piggery Assessment Spreadsheet (Skerman, 2004) values.

Shed	**Pig population** (SPU)	**VS generation rate**[1] (Skerman, 2004) (kg VS/day)	**Shed flushing volume** (L/week)	**Raw effluent VS concentration** (% wet basis)
4	1026	255	156,000	1.14
5	1448	360	156,000	1.62
Recycled flushing medium	—	89	312,000	0.20
Total (Stage 1)	**2474**	**704**	**312,000**	**1.58**
1	1084	270	280,800	0.67
2	705	175	379,080	0.32
3	759	189	237,900	0.56
Recycled flushing medium	—	421	1,638,000	0.18
Total (Stage 2)	**5022**	**1670**	**1,638,000**	**0.71**

[1] Standard DPI&F Piggery Assessment Spreadsheet (Skerman, 2004) VS generation rate based on 0.249 kg VS/SPU/day

Table 5: Estimated highly loaded pond volatile solids (VS) loading rates, based on DPI&F Piggery Assessment Spreadsheet (Skerman, 2004) VS generation values.

Trial stage	**VS generation rate** (from Table 4) (kg VS/day)	**Pond capacity** (ML)	**Pond VS loading rate** (kg VS/m^3/day)	**VS loading rate ratio** (actual/RDS[1])	**Hydraulic retention time** (days)
Stage 1	704	1.3	0.54	5.9	29
Stage 2	1670	1.9	0.88	9.7	8

[1] RDS loading rate based on anaerobic pond activity ratio (k) value of 0.91 for Dalby, and base VS loading rate of 100 g VS/m^3/day suggested by RDS (Barth, 1985).

2.1.8 Laboratory Sampling and Analysis

Representative samples from the following sources were transported from the Dalby piggery to the DPI&F laboratory in Toowoomba (approximately 1.25 hours drive):

- effluent discharged from the sheds during the flushing cycle,
- outflows from the highly loaded primary pond, obtained by pumping (stages 1 and 2) and bucketing from just below the pond surface (stage1),
- recycled effluent used for flushing the sheds.

Immediately after arrival at the laboratory, the electrical conductivity (EC) and pH of the samples were measured while the samples were being manually mixed in their original containers.

A minimum of 3 x 50 mL replicate sub-samples were then decanted into ceramic crucibles, from each of the above effluent samples. During stage 1, these samples were decanted directly from the 25 L plastic drums transported back to the laboratory. During stage 2, the 1 L subsamples transported back to the laboratory were tipped into the 2 L sampling jug shown in Figure 15 for decanting into the crucibles.

Figure 15: A 2 L capacity jug was used in the laboratory to decant effluent into the crucibles used for TS and VS analyses during stage 2.

These replicate samples were then analysed for TS and VS concentrations to enable the comparison of pond inlet and outlet values and calculation of the solids removal performance of the primary pond.

The laboratory analysis procedures used to determine TS and VS concentrations of the effluent samples were in accordance with the DPI&F standards (Shatte, 2000 a & b), based on the methods recommended by Greenberg *et al.* (eds.), 1992. These analyses were performed in the DPI&F Sustainable Intensive Systems (SIS) laboratory located at the Tor Street complex in Toowoomba. In summary, the three replicate sub samples of each effluent source were placed in pre-weighed crucibles and heated in an oven initially set at 80°C to evaporate the liquid, and later increased to 105°C to completely dry the remaining solid material. After further drying, desiccation and cooling, each sample was reweighed to determine the mass of TS remaining in the crucible.

To determine the VS content of the effluent, the crucibles containing the solids remaining after the TS tests, were placed in a muffle furnace/ash oven at a temperature of 550°C for a period of at least one hour, or until a constant weight was obtained. After desiccation and cooling, each sample was reweighed to determine the mass of ash (fixed solids) remaining. The mass of VS was then determined by subtracting the mass of ash from the mass of the TS.

2.1.9 Effluent Chemical Analysis

Additional one litre sub-samples were taken from the composite samples collected from the Dalby piggery on three separate dates. These samples were transported directly to the Toowoomba Regional Council Mt Kynoch Water Treatment Plant laboratory for chemical analysis. This laboratory is commercially accredited to carry out chemical analyses on effluent samples. The sampling dates and sample descriptions are provided below for these samples.

14 June 2007	Shed 5 Effluent Highly loaded pond effluent – pumped Highly loaded pond effluent – bucketed from just below surface
2 May 2008	Shed 2 Effluent Highly loaded pond effluent – pumped Recycled effluent flushing medium
4 June 2008	Shed 1 Effluent Highly loaded pond effluent – pumped Recycled effluent flushing medium

2.1.10 Solids Accumulation Monitoring

During the course of the research project, several measurements of the pond sludge depth were carried out. Measurements were recorded at 10 m intervals, from a boat pulled along the longitudinal axis of the pond. The measurements were taken using a graduated aluminium tee-bar, a nephelometer (turbidity meter) and a sonar depth gauging instrument (fish finder), as described in the following sections:

2.1.10.1 Manual Sensing Using Aluminium Tee-Bar

An aluminium tee-bar was fabricated in the DPI&F Toowoomba workshop, consisting of 3 x 2 m long x 38 mm diameter sections of aluminium tubing that screw together, for ease of transport. Graduated depth markings were etched into the tubing at 0.1 m intervals.

The tee-bar was used to manually detect any changes in resistance to the movement of the tee down through the effluent – sludge profile in the primary pond. Measurements were taken from a boat towed along the pond surface. The operator read the depth to the solids surface from the graduations on the tee-bar shaft.

The top of the solids was generally recorded as the depth where the tee bar encountered sufficient resistance to prevent further downward movement under gravity, without applying downward pressure. However, this method was not always sufficiently sensitive to accurately detect the top of the sludge layer. Furthermore, in most instances, the tee could be manually pushed through the sludge to the original earthen base of the pond.

Figure 16: Using the aluminium tee-bar to estimate the depth to the top of the sludge layer that had accumulated on the base of the highly loaded pond at the Dalby piggery.

2.1.10.2 Turbidity Sensor Attached to Tee Bar

Because of the difficulty in accurately and consistently detecting the top of the sludge layer in the primary pond using the tee-bar, it was decided to attach the sensor from an Analite™ portable nephelometer (Model 152) to the tee-bar. This instrument uses the optical principle involving retro-scattering to determine any sudden changes in turbidity down through the effluent – solids profile. The top of the sludge layer was recorded as the depth where a sudden increase in turbidity was observed. This depth was generally above the point where physical resistance to the tee-bar was first detected. This method is considered to be more objective and consistent than the tee-bar method.

2.1.10.3 Sonar Depth Sounder

Further trials were carried out using a Lowrance LCX-18C fish finding sonar device to detect the build-up of solids in the primary pond. The sensor for this device was mounted on a bracket attached to the stern of a boat, so that it just protruded through the surface crust on the pond, as the boat was being towed across the pond surface. This device provided a visual representation of the base of the pond.

2.1.10.4 Sludge Sampling

During the course of the project, two samples of the sludge accumulating on the base of the highly loaded pond were taken on 13 August 07 and 4 June 08. These samples were collected from a boat, using the DPI&F sludge sampler shown in Figure 17.

This sampler was constructed from a 3.3 m long length of 75 mm diameter PVC pipe. A nylon cap was fitted to one end of the pipe and a 40 mm wide x 150 mm long slot was cut into the end of the pipe, just above the cap. A 170 mm long sleeve and collar made from larger diameter PVC pipe was fitted around the slotted end of the pipe. Two springs restrain the sleeve over the slot in the inner pipe. A piece of nylon cord attached to the collar on the top of the sleeve extends up both sides of the sampling pipe through a series of stainless steel guides.

During sampling, the boat was manoeuvred into a suitable position and the slotted end of the sampler was immersed to the required depth. A sludge sample was collected by the operator pulling on the chord so that the spring loaded sleeve uncovered the slot in the pipe, allowing the entry of sludge. The slot in the pipe was generally only opened for a sufficient period of time (approximately 1 – 2 seconds) to enable the collection of a few litres of sample. When the operator released the tension on the nylon cord, the spring loaded sleeve closed off the slot in the pipe and the sample was transferred into a bucket.

Several sludge samples were collected by this method at regular intervals along the central axis of the pond. After the contents of the bucket were thoroughly mixed, a 1 L wide mouthed sampling bottle was used to collect a sub-sample suitable for transport back to the DPI&F laboratory for TS and VS analysis.

Figure 17: DPI&F pond sludge sampler with the sludge collection slot partly exposed.

2.1.10.5 Crust Sampling

Crust samples were collected from the highly loaded pond on 18 March, 26 March and 4 June 2008. All samples were collected from a boat using a sampler manufactured from a 27 L capacity plastic crate fitted with long handles, as shown in Figure 18.

Samples were collected by digging a hole through the crust. The sampling crate was pushed through the hole in the crust and the long handles were then used to position the crate under the adjoining undisturbed crust. The crust sample was then lifted vertically out of the pond, prior to mixing and sub-sampling for transport back to the DPI&F laboratory. This sampling method was intended to provide samples that were representative of the whole crust profile which generally exceeded 0.5 m in thickness.

Figure 18: Crust sample collection on the highly loaded pond at the Dalby piggery.

2.1.11 Piggery Solids Balance

To gain a better understanding of the fate of the solids entering the highly loaded pond at the Dalby piggery and the processes that drive the transformations within the pond system, a mass balance of the solids entering, leaving and being stored in the pond has been carried out. The basic equation used in deriving this mass balance is outlined below:

Solids in pond inflow	–	Solids in pond outflow	=	Solids stored in pond sludge	+	Solids stored in pond crust	+	Solids stored in pond effluent	+	Gaseous losses from the pond

2.1.12 Olfactometry Assessment of Odour Emission

Odour samples were collected from the highly loaded pond at the Dalby piggery on four occasions as outlined in Table 6. On each sampling day, three sets of duplicate samples were collected using the DPI&F wind tunnel (refer to 2.1.12.1). Two sets of samples were collected from the crusted pond surface at opposite ends of the pond, while a third set was collected from the liquor surface, which was exposed by manually moving the crust away. The duplicate samples were obtained by simultaneously collecting the sample across two sampling drums.

Table 6: Odour sampling dates and locations for the highly loaded pond at the Dalby piggery.

Odour sampling date	**Sampling site** distance from eastern end of pond (m)	**Description of the sampled surface**
16/05/2007	14	Crust
16/05/2007	32	Crust
16/05/2007	32	Exposed liquor
26/03/2008	44	Crust
26/03/2008	10	Crust
26/03/2008	3	Exposed liquor
29/04/2008	42	Crust
29/04/2008	8	Crust
29/04/2008	10	Exposed liquor
12/08/2008	7	Crust
12/08/2008	40	Crust
12/08/2008	40	Exposed liquor

2.1.12.1 Wind Tunnel

The DPI&F wind tunnel used for odour sampling was originally constructed based on a University of New South Wales (UNSW) design. Modifications were made to the wind tunnel to improve sampling efficiency as described by Wang *et al.* (2001). This involved the manufacture of a curved 90-degree manifold, along with the installation of a hollow, stainless steel cross with equidistant spacings in the discharge vent of the wind tunnel.

Carbon-filtered air was forced into the wind tunnel using a 240-volt fan assembly to generate an internal air velocity of between 0.3 and 0.5 m/s in the working section of the tunnel, as proposed by Jiang *et al.* (1995). The velocity in the tunnel was determined by measuring the velocity of air going into the fan. This air then passes through a carbon filter, via a length of V-Flex® ducting into the wind tunnel. Air flow velocities were measured using a Thermo Systems Incorporated (TSI) Model 80125 or 8324 rotating vane anemometer.

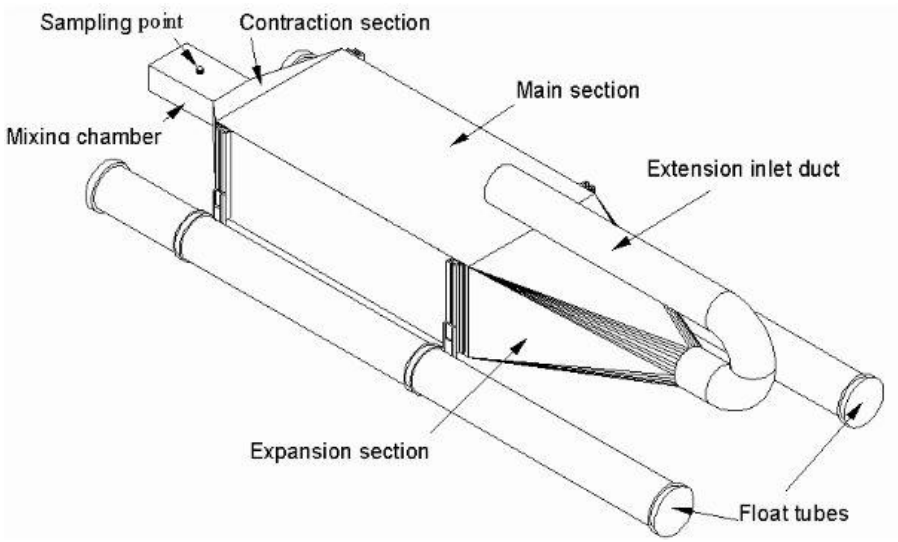


Figure 19: UNSW wind tunnel, without Wang *et al.* (2001) modification.

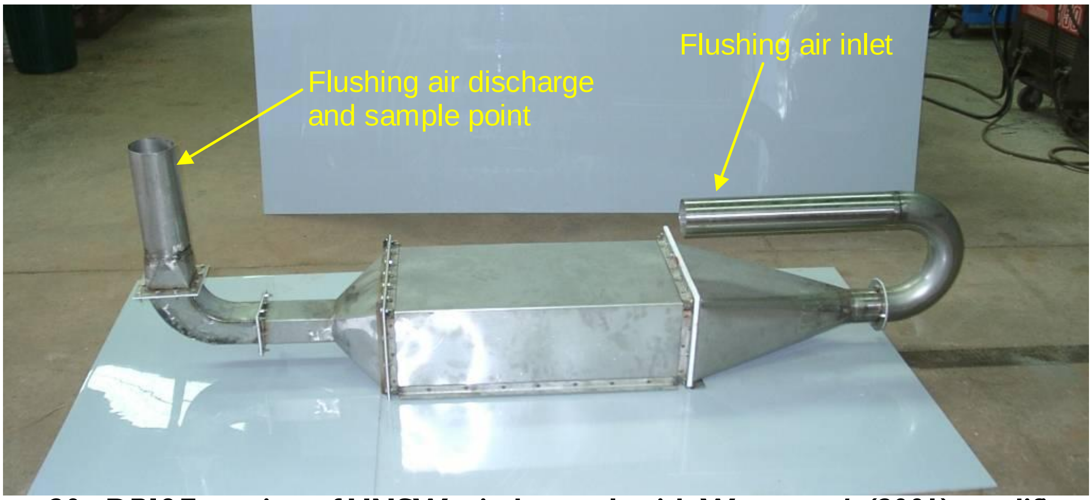


Figure 20: DPI&F version of UNSW wind tunnel, with Wang *et al.* (2001) modification.

Figure 21: DPI&F wind tunnel in use on highly loaded pond

2.1.12.2 On-Pond Odour Sample Collection

The wind tunnel was suspended on a cableway supported between two demountable steel frames erected at the eastern and western ends of the highly loaded pond. The cableway effectively allowed the wind tunnel to be positioned anywhere along the central longitudinal axis of the pond. The wind tunnel is fitted with two remotely controlled 12-volt electric servo motors that are used to position the wind tunnel onto the surface of the pond for sample collection.

Figure 22: Odour sampling from wind tunnel suspended above primary pond crust.

Figure 23: Wind tunnel suspended from cableway spanning the length of the pond, between supporting frames.

All odour samples were collected using standard DPI&F procedures. Odour samples were drawn into 120 L Melinex™ sample bags (Polyethylene Terephthalate) through polytetrafluoroethylene (PTFE) tubing, using the lung method. The sample bags were placed in rigid sample containers and the air inside the container was evacuated at a controlled rate using a diaphragm pump to fill the bags. All components used for sampling were manufactured from stainless steel or PTFE to minimise potential contamination of the odour samples. All bags were pre-conditioned by filling with odorous air from the probe then emptied prior to the sample being collected.

Each duplicate pair of samples was collected over a period of approximately ten to twelve minutes. The sampling drums were then sealed and transported to the DPI&F laboratory in Toowoomba for analysis by dynamic olfactometry and the sensor array system. All samples were analysed within two to six hours of collection in order to minimise the effect of sample storage. Each bag was used once and discarded after analysis.

2.1.12.3 Olfactometry

Odour concentrations were determined using an eight panellist, triangular, forced choice dynamic olfactometer developed by the DPI&F. This olfactometer was constructed to meet the requirements of the Australian/New Zealand Standard for Dynamic Olfactometry (AS4323.3). The development of the olfactometer has been described previously.

Panellists were first screened with the reference gas (*n*-butanol), according to the above Australian Standard, to ensure their detection thresholds for the reference gas were between 20 and 80 parts per billion.

For olfactometry analyses, diluted sample was presented to the panellists in one of three ports (see Figure 24), while the other two ports emitted clean, odour free air. The panellists were then asked to sniff from the ports and determine whether they could detect a difference between the three ports. Each panellist was allowed a maximum of 15 seconds to detect a difference. The panellists were then asked to indicate via an electronic keypad whether they were certain, uncertain or guessing and from which port the odour (if detected) was emitted, i.e. the active port.

This process was repeated, doubling the strength of the previous presentation and randomising the active port for each panellist, until each panellist responded with certainty and correctly for two consecutive presentations. Each panellist's individual threshold estimate (Z_{ITE}) was then determined by calculating the geometric mean of the dilution at which the panellist did not respond with certainty and correctly and the first of the two dilutions where the panellist responded with certainty and correctly. The complete dilution series is defined as a round. Three rounds were completed for each sample provided sufficient sample was available.

At the end of the three rounds, the results of the first round were discarded in accordance with the Australian Standard. The results from rounds two and three were then geometrically averaged ($\overline{Z}_{ITE}$). The ratio between Z_{ITE} and $\overline{Z}_{ITE}$ is defined as ΔZ. The calculation of ΔZ is presented in Equation 1 and Equation 2.

$$\textit{If } Z_{ITE} \geq \overline{Z}_{ITE}, \textit{ then } \Delta Z = \frac{Z_{ITE}}{\overline{Z}_{ITE}} \qquad \textbf{Equation 1}$$

$$\textit{If } Z_{ITE} \leq \overline{Z}_{ITE}, \textit{ then } \Delta Z = \frac{\overline{Z}_{ITE}}{Z_{ITE}} \qquad \textbf{Equation 2}$$

If ΔZ was greater than $\pm$ 5 then all Z_{ITE} values of the panel member with the largest ΔZ were excluded from the data set. The screening procedure is then repeated, after re-calculation of $\overline{Z}_{ITE}$ for that measurement. Again, if any panel member did not comply, the panel member with the largest ΔZ was omitted. This was repeated until all panel members in the dataset had an acceptable ΔZ value. The last value of $\overline{Z}_{ITE}$ was then defined as the odour concentration and expressed as odour units per cubic metre (OU/m^3).

Figure 24: The DPI&F olfactometer in operation showing panellists sniffing at ports.

2.1.12.4 Odour Emission Rate Calculations

The odour emission rate, commonly defined as OER or E was calculated using Equation 3.

$$E = CV_t \frac{A_t}{A_s}$$ **Equation 3**

Where:
C is the odour concentration in the bag;
V_t is the wind speed inside the tunnel;
A_t is the cross sectional area of the tunnel; and
A_s is the surface area covered by the tunnel.
Equation 3 assumes that all background odour is removed from the air introduced into the wind tunnel by the carbon filter, and there is complete mixing between the emissions and the airflow in the tunnel.

The calculated OER was then scaled to a standard tunnel wind speed of 1 m/s according to Smith and Watts (1994); who compared two different sized wind tunnels and concluded that the emission rate E_v at a particular tunnel wind speed V_t could be related to the emission rate E_1 at a tunnel wind speed of 1 m/s. This relationship is shown in Equation 4.

$$\frac{E_v}{E_1} = V_t^{0.63}$$ **Equation 4**

The exponent of 0.63 was derived as a factor for wind tunnels from research conducted on solid surfaces at feedlots. This exponent does not apply to liquid surfaces such as anaerobic ponds. However, Pollock (1997) recommended the use of an exponent of 0.5 for liquid surfaces (based on work of Bliss *et al.* [1995]). This value has been adopted for all calculations of odour emission rate for this project.

2.1.13 Gas Sensor Array Assessment of Odour Emission

A non-specific gas sensor array system was applied to examine the hypotheses regarding the effect of pond surface crusting on odour emissions. Recently, non-specific gas sensor array systems, also known as electronic noses, have been widely trialled in the field of environmental air quality monitoring. One of the characteristic features of a gas sensor array system is that it can objectively measure odour, and discriminate between odours from different sources. Thus, the sensor array system can also be used to identify the difference between odour samples based on the changes in their odour characteristics.

The air quality research group in Sustainable Intensive Systems (SIS) in the DPI&F has developed and evaluated a gas sensor array system. This system includes an array of 24 Metal Oxide Semiconductor (MOS) sensors, which are appropriate for the assessment of odour emissions from intensive livestock industries because of their sensitivity to volatile chemicals found in such odours. The gas sensor array is able to provide qualitative information (*i.e.* discriminate between odours from different sources), and predict odour concentrations using a model based on results from olfactometry.

This instrument and associated discrimination model were applied to odour samples collected from the highly loaded piggery effluent pond to investigate the effects of the crust on odour emissions from the effluent pond, which was being loaded 6 to 10 times the rate recommended by the Rational Design Standard (Barth, 1985).

2.1.13.1 Odour Sample Collection

To compare odour emissions between the crusted and un-crusted pond surface, 12 duplicate odour samples were collected from the highly loaded pond at the Dalby piggery using the UNSW wind tunnel (see the section 2.1.12.1).

Of the odour samples collected during this study, seven replicate samples collected on 26 March 2008 and 29 April 2008, were used for the odour discrimination assessment using the non-specific gas sensor array system. Three sets of replicate samples were collected on 26 March 2008: Two sets of samples were collected from the crusted pond surface at opposite ends of the pond, and a third set from the liquor surface, which was exposed by manually moving the crust away. On 29 April 2008, four sets of replicate samples were collected; two sets from the crusted pond surface and two sets from the liquor surface.

The odour sample collection was carried out as described for the olfactometry analysis in section 2.1.12. The details of odour samples used for sensor array assessment are summarised in Table 7.

Table 7: Details of the odour samples used for sensor array assessment.

Sample ID	PCA [1] ID	Sampling date	Odour source	Sampling site[2]	Odour concentration (OU)	Hedonic tone
260308003_B2531	95	26/03/2008	West end crust	44	93.50	-1.6
260308006_B2528	96	26/03/2008	East end crust	10	76.00	-2.0
260308009_B2530	97	26/03/2008	Exposed liquor	3	145.00	-2.0
290408001_B2624	98	29/04/2008	West end crust	42	215.00	-1.4
290408002_B2627	99	29/04/2008	West end crust	8	215.00	-1.5
290408005_B2621	100	29/04/2008	Exposed liquor	10	609.00	-2.8
290408006_B2623	101	29/04/2008	Exposed liquor	10	636.00	-2.1

1. PCA: principal component analysis
2. Distance from eastern end of pond (m)

2.1.13.2 Gas Sensor Array System

The sensor array system consists of 24 MOS sensors, one temperature and one humidity sensor. The sensors used are summarised in Table 8. The sensors were installed across three different stainless steel sensing chambers. The results from the three sensing chambers were integrated and analysed together. The details of these sensing chambers are presented in Table 9.

Signals from all sensors were collected at a sample rate of 60 Hz using a DT 800 data logger (Datataker Pty Ltd, Melbourne, Australia). The temperature, relative humidity and sensor responses were monitored and stored using a real-time data logging program developed in DPI&F, Queensland using Labview 7.1™. Odorous air samples were presented to the sensing chambers of the gas sensor array system at a flowrate of 500 ml/min. The data acquisition cycle for the gas sensor array system is outlined in Table 10.

A temperature and RH calibration model, developed using chemometric approaches (Sohn *et al.*, 2008), was applied to the raw sensor responses of the sensor array. The adjusted temperature and RH values of the sensor array outputs were 25°C and 25 %, respectively.

Table 8: Summary of the 24 MOS sensors and operating conditions used for the DPI&F gas sensor array system Mk 1.

DT 800 Channel	Type of chamber	Sensor ID	Sensor	Load Resister (R_L, Ω)	Signal voltage (V_C, Volt)	Heater voltage (V_H, Volt)
1	Prototype 1	G	TGS 2620	120K	5.00	5.00
	Prototype 1	A	TGS 832	27K	5.00	5.00
	Prototype 1	L	TGS 2610	119K	5.00	5.00
2	Prototype 1	H	TGS 2602	220K	5.00	5.00
	Prototype 1	B	TGS 813	330K	5.00	5.00
	Prototype 1	K	TGS 826	220K	5.00	5.00
3	Prototype 1	J	TGS 2611	140K	5.00	5.00
	Prototype 1	C	TGS 813A	330K	5.00	5.00
	Prototype 1	F	TGS 880	330K	5.00	5.00
4	Prototype 1	I	TGS 2600	180K	5.00	5.00
	Prototype 1	E	TGS 821	56K	5.00	5.00
	Prototype 1	D	TGS 822	27K	5.00	5.00
5	Univ. of Pisa	Blue	TGS 2611	4.7K	5.00	5.00
	Univ. of Pisa	Grey	TGS 2620	4.7K	5.00	5.00
	Univ. of Pisa	Yellow	TGS 2620	4.7K	5.00	5.00
6	Univ. of Pisa	Pink	TGS 2600	4.7K	5.00	5.00
	Univ. of Pisa	Grey	TGS 2610	4.7K	5.00	5.00
	Univ. of Pisa	Black	TGS 2602	4.7K	5.00	5.00
7	Prototype 2	A	TGS 2611	4.7K	5.00	2.00
	Prototype 2	B	TGS 2611	4.7K	5.00	2.93
	Prototype 2	C	TGS 2611	4.7K	5.00	3.72
8	Prototype 2	D	TGS 2611	4.7K	5.00	4.97
	Prototype 2	E	TGS 2611	4.7K	5.00	5.67
	Prototype 2	F	TGS 2611	4.7K	5.00	6.62
9	In-line	Temp	Thermocouple K	n/a	n/a	5.00
	In-line	RH	Honeywell	n/a	5.00	5.00

Table 9: Summary of sensing chambers used for the DPI&F gas sensor array system

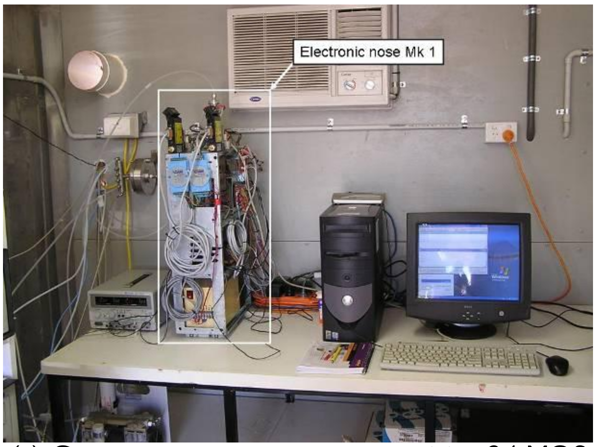
Sensing chamber	Sensor type	Number of sensors	Shape	Internal volume (mL)	Material	Features
Prototype 1	MOS	12	Hexahedron	575.0	Stainless steel	n/a
University of Pisa	MOS	6	Circular cylinder	35.2	Stainless steel	Internal flow distributor
Prototype 2	MOS	6	Circular cylinder	23.5	Stainless steel	Temperature modulation

Table 10: Data acquisition cycle used for the DPI&F gas sensor array system

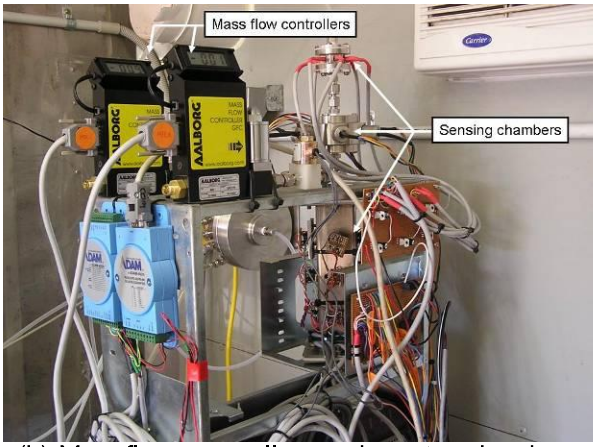
Operating stage [1]	Time (seconds)
Stabilisation	30
Sample	600
Purge [2] & Reference	600

1. Repetition: three times per sample
2. Purging gas: instrument grade clean air from a cylinder

Details of DPI&F's gas sensor array system are depicted in Figure 25.



(a) Gas sensor array system comprising 24 MOS sensors



(b) Mass flow controllers and sensing chambers


(c) Prototype 2 sensing chamber (external view)


(d) Prototype 2 sensing chamber showing the six MOS sensors and minimal internal volume of 23.5 mL (internal view)

Figure 25: DPI&F's gas sensor array system Mk 1.

2.1.13.3 Odour Discrimination Using Principal Component Analysis

Principal component analysis (PCA) is one of the multivariate methods of analysis and has been used widely with large multidimensional data sets such as outputs from a gas sensor array system. The use of PCA allows the number of variables in a multivariate data set to be reduced, whilst retaining as much as possible of the variation present in the data set. Therefore, the aim of PCA is to find the optimum (in terms of explained variance) description of a given data set in a dimension smaller than the number of sensors used in a sensor array, which span a vector space of *N* dimensions (*N* = 26 for the DPI&F sensor array system).

2.1.14 Piggery Waste Estimation

To complement the measurements of the waste output from the Dalby piggery, estimates of the piggery waste output were determined using the PIGBAL model (Casey *et al.*, 2003) and the DPI&F Piggery assessment spreadsheet (Skerman, 2004). These tools are commonly used for this purpose by industry service providers, consultants, researchers and regulators. The data collected during this project has provided a valuable opportunity for comparison and validation of waste estimation methods.

All pig feed used at the Dalby piggery is mixed on-site using ingredients grown on-farm and a range of imported ingredients. Details of the piggery feed usage, feed ingredients and average pig herd composition were provided by the producer. It should be noted that pig diets were varied throughout the duration of the trial. Consequently, the producer was requested to provide details that were representative of the majority of the trial period. It is understood that the pig herd composition varied very little during the trial. Table 11 and Table 12 provide details of the Dalby piggery herd composition, feed intake and feed ingredients entered in the PIGBAL model used to estimate the piggery waste output.

Table 11: Average Dalby piggery herd composition used in the PIGBAL model and DPI&F Piggery assessment spreadsheet.

Pig class	No of Pigs	No of SPU
Gilts	38	68
Boars	20	32
Gestating Sows	414	662
Lactating Sows	119	298
Suckers	599	60
Weaner pigs	964	482
Grower pigs	949	949
Finisher pigs	1,546	2,474
TOTALS:	**4,649**	**5,025**

Table 12: Details of Dalby piggery feed intake (provided by the producer) and wastage used in the PIGBAL analysis.

Pig Class	**No of pigs** (pigs)	**Weekly mix** (kg/week)	**Daily mix** (kg/day)	**Daily feed per pig** (kg/day/pig)	**Feed wastage** (%)	**Feed ingested** (kg/day/pig)	**PIGBAL defaults** (kg/day/pig)
Creep	599	910	130	0.22	20%	0.17	0.10
Weaner	964	2,580	369	0.38	15%	0.32	0.60
Gro1	387	5,030	719	1.86	10%	1.67	1.50
Gro2	562	6,510	930	1.65	10%	1.49	1.50
Gro4	740	12,890	1,841	2.49	10%	2.24	2.30
Gro5	806	17,060	2,437	3.02	10%	2.72	2.30
Wet sow	119	3,480	497	4.18	5%	3.97	4.50
Dry sow	414	7,820	1,117	2.70	5%	2.56	2.30

Table 13: Feed ingredients (as supplied by the producer) used in PIGBAL model to estimate the waste output of the Dalby piggery.

Feed ingredient	%DM	Sucker	Weaner	Growers		Finishers		Lactating Sows		Dry Sows	
				Diet 1	Diet 2	Diet 1	Diet 2	Diet 1	Diet 2	Diet 1	Diet 2
Major Grains											
Barley 10%	89.80						20.00	30.78	30.78	93.73	93.73
Sorghum 10%	87.00			68.43	74.23	74.16	47.13	30.00	30.00		
Wheat 13%	89.30	13.82	28.42								
Other Grains											
Wheat Extruded	89.30	45.00	40.05								
Meal Supplements.											
Canola 36	92.00			6.56	9.44	19.96	9.03	15.00	15.00		
Fish 65%	90.60	7.50	7.50								
Meat Meal (50%)	95.00		0.20	3.50	4.20	1.90	1.90	6.20	6.20	3.60	3.60
Recycled Oil	99.50	0.54		2.55		0.30	0.30	7.22	7.22	1.07	1.07
Soybean - full fat	90.00	9.00	10.10		3.23						
Soybean - solvent	91.00			18.00	7.80			8.20	8.20		
Sunflower 30	93.00					2.29	10.00				
Whey Powder	93.00	20.00	2.50								
Other Ingredients											
Bentonite	90.00	1.00	1.00								
Breeder Mix	100.00							0.25	0.25	0.25	0.25
Dicalphos	96.00				0.40	0.40	0.33	0.40	0.40	0.70	0.70
Grower Premix	100.00			0.20	0.15	0.15	0.10				
Limestone	100.00						0.49				
Lysine - HCL	99.00	0.36	0.17	0.37	0.35	0.40	0.36	0.39	0.39	0.19	0.19
Methionine	99.00	0.01	0.01	0.06	0.04	0.02	0.03	0.04	0.04	0.00	0.00
Salt	100.00							0.15	0.15	0.30	0.30
Threonine	99.00		0.01	0.09	0.07	0.07	0.08	0.07	0.07		
Weaner Premix	100.00	0.20	0.20								
User Defined Ingredients											
Admix 30	100.00	0.20	0.20					0.03	0.03		
Allzyme	100.00	0.10									
Betafin	100.00	0.20	0.20					0.20	0.20		

Feed ingredient	%DM	Sucker	Weaner	Growers		Finishers		Lactating Sows		Dry Sows	
				Diet 1	Diet 2	Diet 1	Diet 2	Diet 1	Diet 2	Diet 1	Diet 2
Brewers Yeast	100.00	1.00	1.00					0.50	0.50		
Solulyte concentrate	100.00	0.20									
Tylan 50	100.00	0.20				0.20	0.10				
Ultracid lac plus dry	100.00	0.25	0.25								
Vitamin E & selenium	100.00	0.12						0.15	0.15		
Zinc oxide	100.00	0.30	0.30								
Feedzyme	100.00		0.10	0.10							
Mould-nil dry	100.00		0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
OTC	100.00		0.20								
Soycomil	100.00		7.50								
Dox-R-Pan	100.00			0.10							
Rovabio enzyme	100.00				0.05	0.05	0.05				
Chromelate	100.00					0.06					
Mung Beans	90.90						10.00				
Paylean	100.00						0.05				
Acidlac	100.00							0.30	0.30		
Bioplex	100.00							0.08	0.08		
Biotin	100.00									0.10	0.10
Total (%)		**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

2.2 *DPI&F Wacol Piggery*

2.2.1 Description of Operation

Trials were carried out at the DPI&F Wacol piggery using a 10 000 L polythene tank to simulate a highly loaded primary pond. An additional electronic controller depicted in Figure 26 was installed to start and stop a smaller capacity electric submersible pump (Davey D15A sump pump, identical to the one used at the Dalby piggery) installed in the sump to pump effluent into the polythene primary tank, while the main sump pump was operating. The timing of the small submersible pump operation was varied from a keypad on the electronic controller to simulate a desired volatile solids (VS) loading rate in the settling tank. A schematic diagram of the tank and sump sampling arrangement is provided in Figure 27.

Throughout the trial, the 'pump on' and 'pump off' times were adjusted on the electronic controller so that the small submersible pump operated over six cycles spread evenly over the 35 minute sump pump-out cycle. By loading the settling tank with effluent pumped at regular intervals throughout the pumping cycle, the effluent entering the settling tank should have had similar characteristics to that being pumped into the anaerobic pond. The agitator operating in the sump throughout the pumping cycle should have also assisted in maintaining relatively uniform effluent characteristics throughout the pumping cycle.

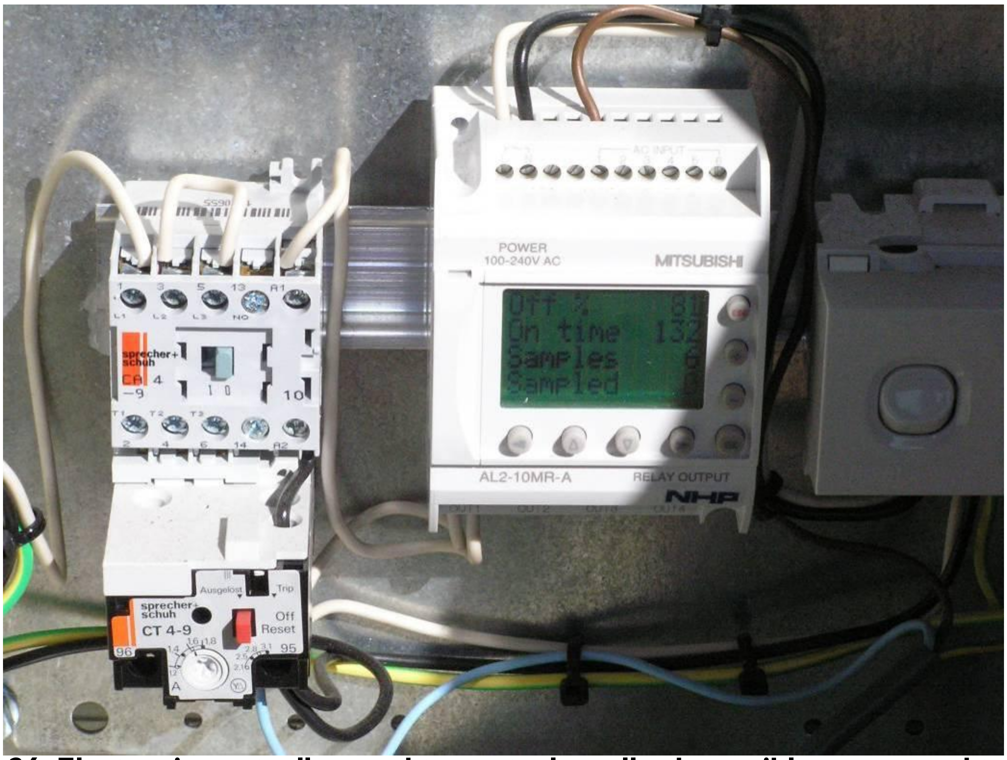


Figure 26: Electronic controller used to control small submersible pump used to pump effluent from the sump into the settling tank.

Table 14 provides details of the effluent sampling dates, electronic controller settings and estimates of the volumes of effluent pumped from the sump into the polythene settling tank at the DPI&F Wacol piggery.

Table 14: Effluent sampling dates, pump controller settings and estimates of the volume of effluent pumped from the sump into the polythene settling tank.

Sampling date	Pump off time (sec)	Pump on time (sec)	No of samples	Pump cycle duration (min)	Volume pumped (L)	Cumulative volume pumped (L)
24/04/2007	60	320	6	38	2,112	0
9/05/2007	132	132	6	26	871	15,840
24/05/2007	132	132	6	26	871	22,374
6/06/2007	132	132	6	26	871	28,037
3/07/2007	132	132	6	26	871	39,798
17/07/2007	132	132	6	26	871	45,896
1/08/2007	240	60	6	30	396	52,430
16/08/2007	180	120	6	30	792	55,400
24/08/2007	180	120	6	30	792	58,568
14/09/2007	180	120	6	30	792	66,884
15/10/2007	180	120	6	30	792	79,160
31/10/2007	180	120	6	30	792	85,496
6/11/2007	180	120	6	30	792	87,872
15/11/2007	300	120	6	42	792	91,436
22/11/2007	240	120	6	36	792	94,208
11/12/2007	180	120	6	30	792	101,732
10/01/2008	180	120	6	30	792	113,612
23/01/2008	180	120	6	30	792	118,760

2.2.2 Settling Tank Inlet and Outlet Sample Collection

To enable collection of samples that were representative of the effluent being pumped into the settling tank, a hand operated piston pump was initially installed on the walkway across the sump. This pump was manually operated to collect effluent samples from the sump when the small submersible pump was transferring effluent into the settling tank. The suction hose on the hand pump drew effluent from a similar depth to both the main sump pump and the small submersible pump. While the small submersible pump was going through its six pumping cycles, the hand pump was used to simultaneously collect a 4 L sub-sample from the sump during each of the six pumping cycles. This resulted in a 24 L composite sample that was representative of the effluent being pumped into the settling tank. The composite sample was stored in a 25 L plastic sampling drum for transport back to the laboratory. Photographs of the sampling process are provided in Figure 28 and Figure 29.

After several months of operation, the hand pump broke down and was replaced with an electric submersible pump (Davey D15A sump pump), identical to the one used to pump effluent into the polythene settling tank.

Immediately following collection of each settling tank inlet sub-sample, a 4 L sample was collected from the settling tank gravity outlet pipe which overflowed back into the sump, via a 100 mm PVC pipe. The resulting 24 L composite sample was also stored in a similar 25 L plastic drum for transport back to the laboratory. On the majority of the sampling visits to the piggery, additional 1 L samples of flushing medium were collected from a flushing tank located near the eastern end of one of the piggery sheds.

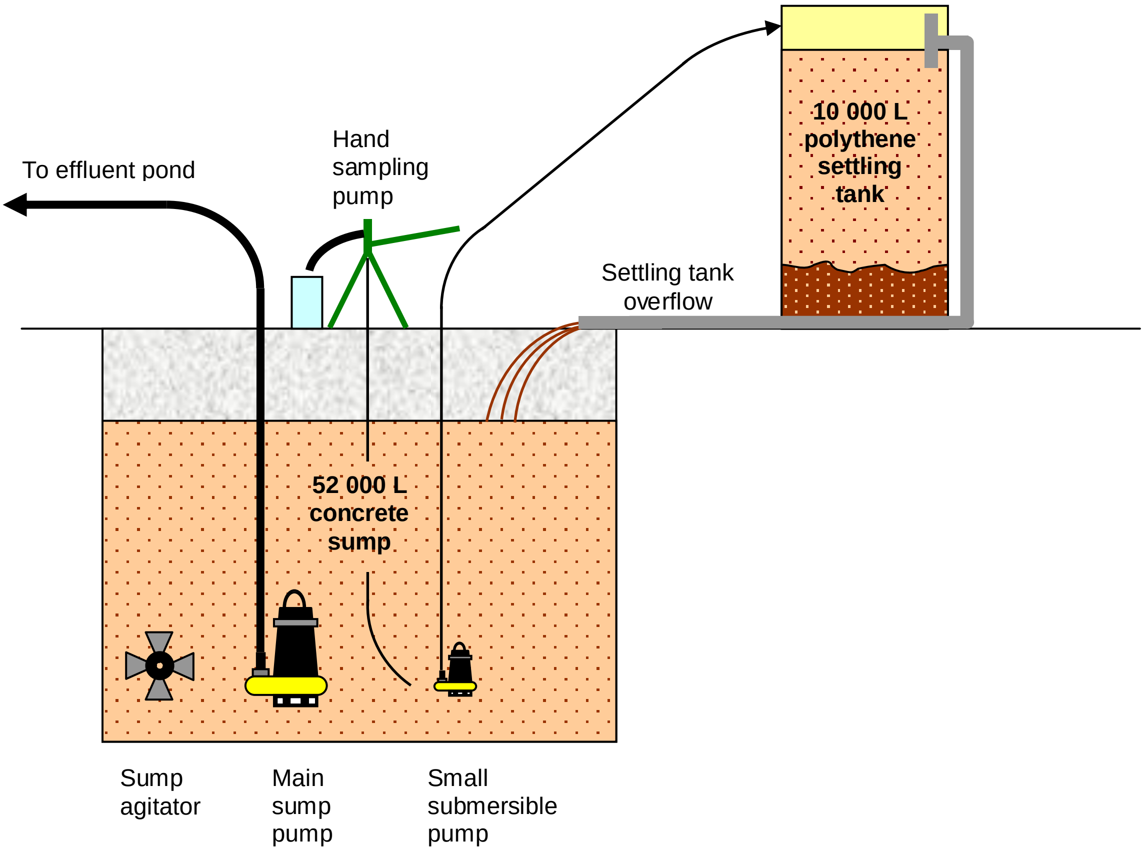


Figure 27: Schematic diagram of the settling tank and equipment used for sampling from the effluent sump at the DPI&F Wacol piggery.

Figure 28: Collecting settling tank inlet sample using hand pump.

Figure 29: Collecting settling tank outlet sample from overflow pipe.

2.2.3 *Settling Tank Loading Rate*

Table 15 provides details of the estimated VS loading entering the settling tank for the range of controller settings used during the trial. These loading rates were estimated based on the VS generation standard (0.249 kg VS/SPU/day) used in the DPI&F Piggery Assessment Spreadsheet (Skerman, 2004) for a total pig population of 1307 SPU in the grower/finisher sheds at the DPI&F Wacol piggery. The shed flushing volume was assumed to be 40 000 L every 48 hours.

Table 15: Settling tank volatile solids (VS) loading rates, based on DPI&F Piggery Assessment Spreadsheet (Skerman, 2004) generation estimates for the various loading regimes used throughout the trial.

Sampling date	Effluent volume pumped into tank [2, 3] (L/flush)	VS pumped into tank[1] (kg VS/day)	Tank VS loading rate (kg VS/m^3/day)
24/04/2007	2,112	18.93	1.89
9/05/2007	871	7.81	0.78
24/05/2007	871	7.81	0.78
6/06/2007	871	7.81	0.78
3/07/2007	871	7.81	0.78
17/07/2007	871	7.81	0.78
1/08/2007	396	3.55	0.35
16/08/2007	792	7.10	0.71
24/08/2007	792	7.10	0.71
14/09/2007	792	7.10	0.71
15/10/2007	792	7.10	0.71
31/10/2007	792	7.10	0.71
6/11/2007	792	7.10	0.71
15/11/2007	792	7.10	0.71
22/11/2007	792	7.10	0.71
11/12/2007	792	7.10	0.71
10/01/2008	792	7.10	0.71
23/01/2008	792	7.10	0.71

[1] Standard VS generation based on PIGBAL estimates is 0.249 kg VS/SPU/day

[2] Total shed flushing volume: approx 40 000 L/48 hr

[3] Small submersible pumping flowrate: 1.1 L/s

2.2.4 *Laboratory Sampling and Analysis*

Similar methods to those described in sections 2.1.8 and 2.1.9 for samples collected at the Dalby piggery were used to measure the pH and EC and to determine the TS and VS concentrations of the composite settling tank inlet and outlet samples and the flushing medium collected at the DPI&F Wacol piggery.

2.2.5 *Solids Accumulation Monitoring*

The build-up of solids in the 10,000 L settling tank were monitored using the nephelometer and sonar device used at the Dalby piggery, as described in section 2.1.10. The sonar sensor was permanently mounted on the top of the tank so that the electronic base unit could be simply plugged into the connecting cable on each site visit.

2.2.6 *Piggery Waste Estimation*

Similarly to the waste estimation carried out for the Dalby piggery, estimates of the DPI&F Wacol piggery waste output were determined using the PIGBAL model (Casey *et al*., 2003) and the DPI&F Piggery assessment spreadsheet (Skerman, 2004).

All feed used at the DPI&F Wacol piggery is mixed off-site by a commercial feed company. Details of the piggery feed usage, feed ingredients and average pig herd composition were provided by the feed company and piggery manager. It is understood that the pig diets varied to some extent during the trial. Consequently, the feed company representative was requested to provide details that were representative of the majority of the trial period. It is understood that the pig herd composition varied very little during the trial.

Table 16 and Table 17 provide details of the DPI&F Wacol piggery herd composition, feed intake and feed ingredients entered in the PIGBAL model used to estimate the piggery waste output.

Table 16: Average DPI&F Wacol piggery herd composition used in the PIGBAL model (Casey et al, 2003) and DPI&F Piggery assessment spreadsheet (Skerman, 2004).

Pig class	No of Pigs	No of SPU
Grower pigs	500	500
Finisher pigs	500	800
TOTALS:	**1,000**	**1,300**

Table 17: Details of DPI&F Wacol piggery feed intake (provided by the feed company and piggery manager) and wastage used in the PIGBAL (Casey et al, 2003) analysis.

Pig Class	**No of pigs** (pigs)	**Yearly feed** (t/yr)	**Daily feed** (kg/day/pig)	**Feed wastage** (%)	**Feed ingested** (kg/day/pig)	**PIGBAL defaults** (kg/day/pig)
Porker (Male)	250	125	1.37	10	1.24	1.50
Grower (female)	250	162	1.77	10	1.60	1.50
Boar finisher (All)	300	292	2.67	10	2.40	2.30
Paylean Finisher (All)	200	235	3.22	10	2.90	2.30
Total:	**1,000**	**815**				

Table 18: Feed ingredients (as supplied by the feed company) used in PIGBAL model to estimate the waste output of the DPI&F Wacol piggery.

Feed Ingredients	%DM	Growers		Finishers	
		Diet 1	Diet 2	Diet 1	Diet 2
Major Grains					
Barley 10%	89.80			6.90	6.90
Maize 8%	88.00	27.90	30.03	9.03	9.03
Sorghum 10%	87.00	40.00	30.00	50.00	50.00
Wheat 16%	89.30		7.50		
Meal Supplements.					
Bloodmeal 80	87.80	3.93	2.43	0.83	0.83
Buttermilk	95.00				
Canola 36	92.00	12.00	12.00	15.00	15.00
Meat Meal (50%)	95.00	3.37	3.27	1.63	1.63
Molasses	75.00			4.00	4.00
Soymeal 48%	90.00		5.00		
Sunflower 30	93.00	1.03		0.70	0.70
Tallow	99.50	0.60	1.40		
Other Ingredients					
Choline Chlorine	100.00	0.04	0.03	0.03	0.03
Grower Premix	100.00	0.10	0.10	0.10	0.10
Limestone	100.00	0.63	0.63	0.93	0.93
Lysine - HCL	99.00	0.05	0.24	0.32	0.32
Methionine	99.00	0.02	0.04	0.07	0.07
Salt	100.00	0.25	0.25	0.25	0.25
Threonine	99.00		0.02	0.08	0.08
User Defined Ingredients					
Mung Beans	90.90	10.00	7.00	10.00	10.00
Copper Sulphate	100.00	0.07	0.04	0.07	0.07
Phyzyme XP5000L Pigs (Phantom)	100.00	0.01	0.01	0.01	0.01
Paylean	100.00			0.03	0.03
Total (%)		**100.00**	**100.00**	**100.00**	**100.00**

3. Results

3.1 Variation in Dalby Piggery Shed Effluent Quality

As described in section 2.1.1, Figure 30 shows the total solids concentrations for the individual effluent samples collected from channels 1 to 10 in shed 5, in addition to a composite sample collected from channels 1 to 20 for comparison. Channels 1 and 2 are located under a laneway while channels 3 to 10 are located under a row of thirty-one grower/finisher pens. Because channels 11 to 20 collect waste products from an identical row of pens that are stocked similarly, it is expected that samples from channels 11 to 20 would have similar total solids concentrations to those from channels 1 to 10.

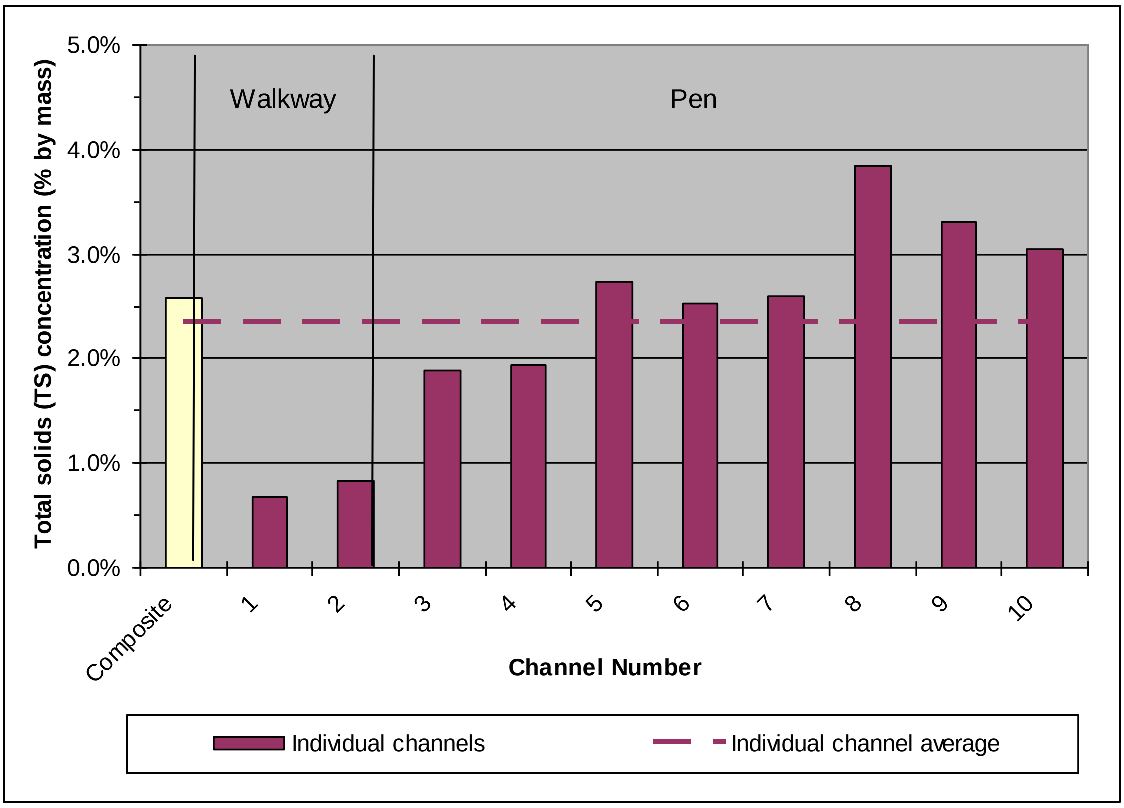


Figure 30: Shed 5 total solids concentrations in individual effluent samples collected from flushing channels 1 to 10 and from a composite sample collected from channels 1 to 20. The average concentration of the individual channel (1 – 10) samples is also shown as a dashed line.

In addition to the variation between channels, effluent composition also varied significantly throughout the flushing period in each channel. The initial discharge (first flush) from each channel was observed to contain high levels of solids (Figure 31), while it appeared that the solids concentration decreased gradually throughout the 5 to 10 minute channel flushing duration. Effluent from the end of the flushing period had a relatively low solids concentration.

Figure 31: Initial discharge from one of the shed 5 flushing channels showing relatively high solids content.

3.2 Solids Reduction in Highly Loaded Primary Pond

3.2.1 Dalby Piggery

Tables 19 and 20 outline the averages of the replicate total solids (TS) and volatile solids (VS) analysis results, respectively, for each sampling day. Results are provided for samples collected from the highly loaded primary pond influent discharged from piggery sheds, samples collected from the pond by bucketing and pumping, and samples of the recycled effluent used for flushing all sheds at this piggery.

Figures 32 and 33 present the average TS and VS data in graphical form over the 17 month sampling period.

Figure 34 includes box and whisker plots indicating the variability in the TS and VS replicate values recorded for the Dalby piggery while Tables 21 and 22 provide descriptive statistics for this data.

Table 19: Dalby piggery average total solids contents (%) for: (i) highly loaded primary pond influent discharged from piggery sheds, (ii) highly loaded primary pond effluent sampled from the pond by bucketing and pumping, and (iii) recycled effluent used for flushing all piggery sheds.

Sampling date	Pond influent source					Pond effluent		Shed flushing medium (recycled effluent))
	Shed 1	Shed 2	Shed 3	Shed 4	Shed 5	Bucketed	Pumped	
Stage 1								
17/04/2007						0.95%	1.00%	
19/04/2007					2.54%	0.84%	0.96%	0.61%
3/05/2007					2.57%	0.80%	0.91%	0.61%
15/05/2007					2.68%	0.76%	0.90%	0.62%
31/05/2007					3.01%	0.81%	1.03%	0.63%
14/06/2007					2.76%	0.90%	1.02%	0.61%
26/06/2007				1.80%		0.72%	0.76%	0.56%
12/07/2007				1.95%		0.90%	1.03%	0.57%
24/07/2007				2.48%		0.86%	0.98%	0.60%
7/08/2007				2.91%		1.16%	1.27%	0.59%
13/08/2007						1.35%	1.65%	
21/08/2007				2.12%		1.16%	1.19%	0.59%
28/08/2007				1.65%		1.01%	1.07%	0.60%
10/09/2007						0.82%	0.86%	
Stage 2								
30/01/2008		1.14%					0.61%	0.55%
6/02/2008			0.73%				0.83%	0.55%
13/02/2008			0.86%				0.65%	0.50%
27/02/2008							0.74%	0.53%
14/03/2008			0.92%				0.73%	0.55%
19/03/2008		1.20%					0.68%	0.51%
2/04/2008							0.64%	
23/04/2008			0.93%				0.70%	0.55%
2/05/2008		1.00%					0.79%	0.54%
9/05/2008	2.35%						0.66%	0.56%
4/06/2008	2.33%						0.75%	0.57%
26/06/2008							0.65%	
12/08/2008							0.67%	
Averages:	**2.34%**	**1.11%**	**0.86%**	**2.15%**	**2.71%**	**0.93%**	**0.88%**	**0.57%**

Table 20: Dalby piggery average volatile solids contents (%) for: (i) highly loaded primary pond influent discharged from piggery sheds, (ii) highly loaded primary pond effluent sampled from the pond by bucketing and pumping, and (iii) recycled effluent used for flushing all piggery sheds.

Sampling date	Pond influent source					Pond effluent		Shed flushing medium (recycled effluent))
	Shed 1	Shed 2	Shed 3	Shed 4	Shed 5	Bucketed	Pumped	
Stage 1								
17/04/2007						0.45%	0.47%	
19/04/2007					1.88%	0.37%	0.43%	0.20%
3/05/2007					1.91%	0.33%	0.42%	0.18%
15/05/2007					2.01%	0.30%	0.41%	0.20%
31/05/2007					2.36%	0.34%	0.51%	0.25%
14/06/2007					2.13%	0.43%	0.53%	0.20%
26/06/2007				1.26%		0.29%	0.39%	0.16%
12/07/2007				1.37%		0.45%	0.56%	0.24%
24/07/2007				1.82%		0.42%	0.51%	0.19%
7/08/2007				2.20%		0.66%	0.75%	0.21%
13/08/2007						0.80%	1.06%	
21/08/2007				1.57%		0.66%	0.68%	0.21%
28/08/2007				1.14%		0.52%	0.57%	0.20%
10/09/2007						0.38%	0.41%	
Stage 2								
30/01/2008		0.71%					0.23%	0.17%
6/02/2008			0.37%				0.42%	0.17%
13/02/2008			0.46%				0.29%	0.17%
27/02/2008							0.35%	0.17%
14/03/2008			0.47%				0.32%	0.18%
19/03/2008		0.75%					0.30%	0.17%
2/04/2008							0.26%	
23/04/2008			0.52%				0.31%	0.19%
2/05/2008		0.58%					0.39%	0.18%
9/05/2008	1.79%						0.28%	0.16%
4/06/2008	1.81%						0.35%	0.20%
26/06/2008							0.26%	
12/08/2008							0.28%	
Averages:	**1.80%**	**0.68%**	**0.45%**	**1.56%**	**2.06%**	**0.46%**	**0.44%**	**0.19%**

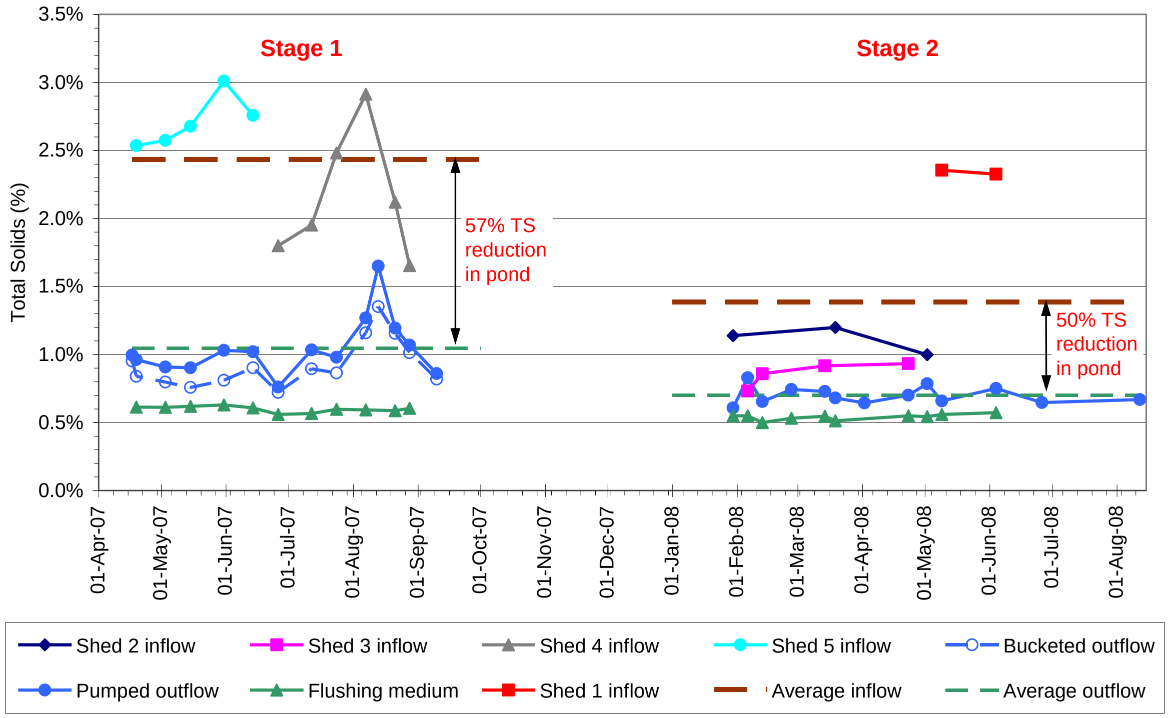


Figure 32: Average of replicate total solids (TS) concentrations in effluent entering and leaving the highly loaded pond, and in the recycled effluent flushing medium, at the Dalby piggery.

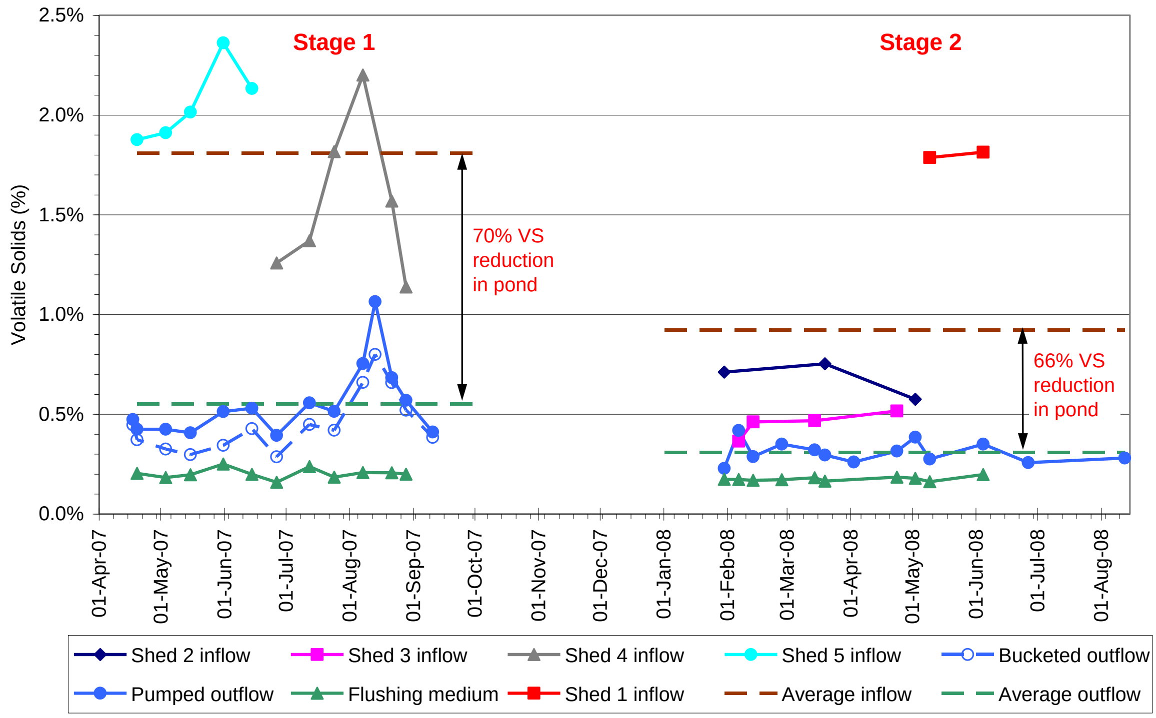


Figure 33: Average of replicate volatile solids (VS) concentrations in effluent entering and leaving the highly loaded pond, and in the recycled effluent flushing medium, at the Dalby piggery.

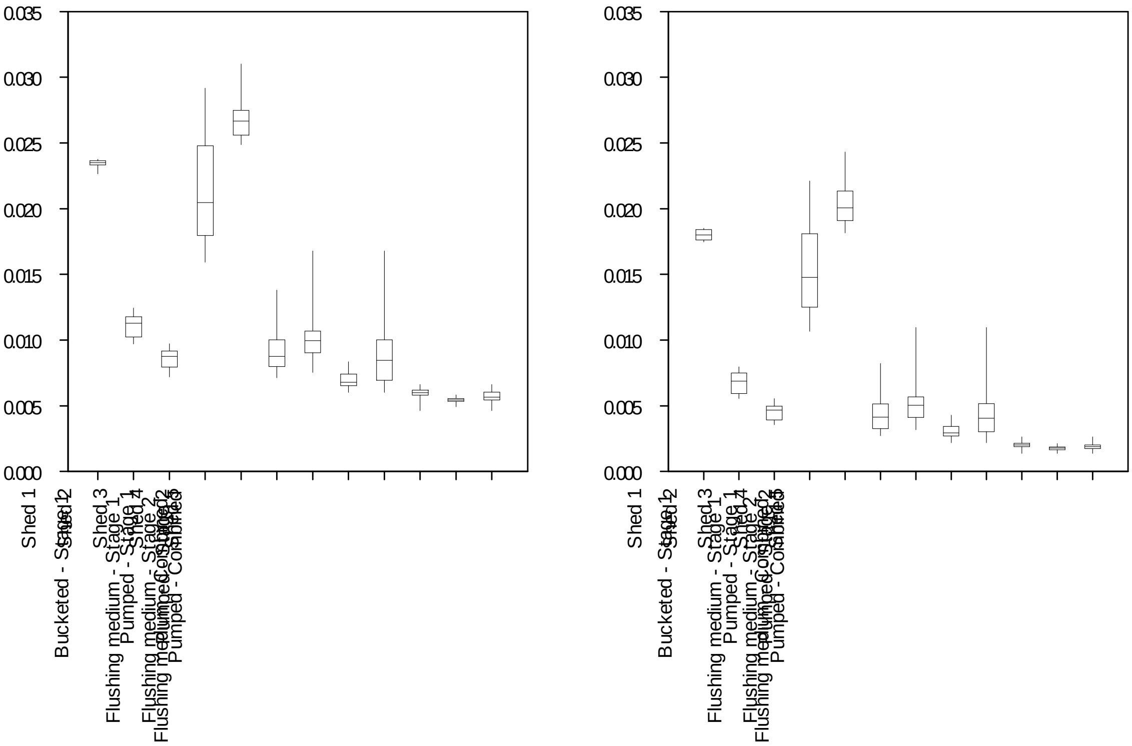


Figure 34: Box and whisker plots of the total solids and volatile solids concentrations in the effluent samples collected from sheds 1 – 5, samples collected from the highly loaded pond by bucketing from just below the pond surface and by pumping, and samples of the recycled effluent used for shed flushing.

Table 21: Descriptive statistics for effluent total solids (TS) samples collected at the Dalby piggery.

Parameter	Shed 1 TS	Shed 2 TS	Shed 3 TS	Shed 4 TS	Shed 5 TS	Pumped TS	Bucketed TS	Flushing medium TS
Stage 1								
Mean				2.15%	2.70%	1.04%	0.92%	0.60%
Standard Error				0.1041%	0.0394%	0.0309%	0.0262%	0.0062%
Median				2.05%	2.67%	0.99%	0.88%	0.60%
Standard Deviation				0.44%	0.17%	0.21%	0.18%	0.04%
Sample Variance				0.00%	0.00%	0.00%	0.00%	0.00%
Kurtosis				-78.76%	61.08%	326.76%	53.07%	580.52%
Skewness				67.26%	100.93%	170.71%	115.55%	-166.41%
Range				1.33%	0.61%	0.93%	0.67%	0.20%
Minimum				1.59%	2.49%	0.75%	0.71%	0.46%
Maximum				2.92%	3.10%	1.68%	1.38%	0.66%
Sum				38.75%	48.69%	46.60%	41.38%	19.75%
Count				18	18	45	45	33.0000
Confidence Level (95.0%)				0.22%	0.08%	0.06%	0.05%	0.01%
Stage 2								
Mean	2.34%	1.11%	0.86%			0.70%		0.54%
Standard Error	0.0161%	0.0314%	0.0248%			0.0101%		0.0043%
Median	2.35%	1.13%	0.88%			0.68%		0.54%
Standard Deviation	0.04%	0.09%	0.09%			0.06%		0.02%
Sample Variance	0.00%	0.00%	0.00%			0.00%		0.00%
Kurtosis	346.56%	-112.42%	-81.23%			-51.08%		-16.35%
Skewness	-175.83%	-37.26%	-65.45%			58.69%		-48.82%
Range	0.11%	0.27%	0.25%			0.23%		0.09%
Minimum	2.26%	0.97%	0.72%			0.60%		0.49%
Maximum	2.37%	1.24%	0.97%			0.83%		0.58%
Sum	14.04%	10.00%	10.32%			27.28%		16.23%
Count	6	9	12			39		30
Confidence Level (95.0%)	0.04%	0.07%	0.05%			0.02%		0.01%
Combined (stages 1 & 2)								
Mean						0.88%		0.57%
Standard Error						0.0251%		0.0053%
Median						0.85%		0.57%
Standard Deviation						0.23%		0.04%
Sample Variance						0.00%		0.00%
Kurtosis						256.00%		-27.12%
Skewness						140.96%		-15.54%
Range						1.08%		0.20%
Minimum						0.60%		0.46%
Maximum						1.68%		0.66%
Sum						73.87%		35.98%
Count						84		63
Confidence Level (95.0%)						0.05%		0.01%

Table 22: Descriptive statistics for effluent volatile solids (VS) samples collected at the Dalby piggery.

Parameter	Shed 1 VS	Shed 2 VS	Shed 3 VS	Shed 4 VS	Shed 5 VS	Pumped VS	Bucketed VS	Flushing medium VS
Stage 1								
Mean				1.56%	2.05%	0.54%	0.45%	0.20%
Standard Error				0.0878%	0.0409%	0.0264%	0.0223%	0.0048%
Median				1.48%	2.01%	0.50%	0.41%	0.20%
Standard Deviation				0.37%	0.17%	0.18%	0.15%	0.03%
Sample Variance				0.00%	0.00%	0.00%	0.00%	0.00%
Kurtosis				-75.76%	12.19%	320.31%	22.81%	68.32%
Skewness				64.69%	88.15%	177.77%	106.60%	35.23%
Range				1.14%	0.62%	0.78%	0.55%	0.13%
Minimum				1.07%	1.81%	0.32%	0.27%	0.14%
Maximum				2.21%	2.43%	1.10%	0.82%	0.26%
Sum				28.06%	36.93%	24.38%	20.07%	6.54%
Count				18	18	45	45	32
Confidence Level (95.0%)				0.19%	0.09%	0.05%	0.05%	0.01%
Stage 2								
Mean	1.80%	0.68%	0.45%			0.31%		0.18%
Standard Error	0.0173%	0.0292%	0.0187%			0.0086%		0.0030%
Median	1.80%	0.69%	0.47%			0.29%		0.18%
Standard Deviation	0.04%	0.09%	0.06%			0.05%		0.02%
Sample Variance	0.00%	0.00%	0.00%			0.00%		0.00%
Kurtosis	-193.33%	-135.80%	-96.99%			-32.55%		12.72%
Skewness	-0.79%	-29.04%	-21.97%			56.89%		-30.44%
Range	0.10%	0.24%	0.20%			0.21%		0.07%
Minimum	1.75%	0.55%	0.36%			0.22%		0.14%
Maximum	1.85%	0.80%	0.56%			0.43%		0.21%
Sum	10.80%	6.12%	5.43%			12.08%		5.29%
Count	6	9	12			39		30
Confidence Level (95.0%)	0.04%	0.07%	0.04%			0.02%		0.01%
Combined (stages 1 & 2)								
Mean						0.43%		0.19%
Standard Error						0.0194%		0.0034%
Median						0.41%		0.19%
Standard Deviation						0.18%		0.03%
Sample Variance						0.00%		0.00%
Kurtosis						395.94%		97.77%
Skewness						177.51%		68.71%
Range						0.88%		0.13%
Minimum						0.22%		0.14%
Maximum						1.10%		0.26%
Sum						36.47%		11.83%
Count						84		62
Confidence Level (95.0%)						0.04%		0.01%

The TS and VS concentrations of effluent leaving the highly loaded pond (outflow) showed major reductions in comparison to the effluent entering the pond (inflow). As outlined in Table 23, the average reductions in TS during stages 1 and 2 were 57% and 50% respectively, while the average reductions in VS during stages 1 and 2 were 70% and 66% respectively.

Table 23: Reductions in TS and VS in highly loaded pond at Dalby piggery determined based on shed flushing volumes.

Parameter	Pond Inflow							Pond outflow	Reduction (%)
Shed description	**1** Grower	**2** Farrow / Weaner	**3** Dry sow / DMA	**4** Grower	**5** Finisher	Note 1	**Total**		
Stage 1									
Flushing volume (L/week)				156,000	156,000	0	312,000	312,000	
TS (%)				2.15%	2.70%	0.60%	2.43%	1.04%	57%
TS (kg/week)				3,359	4,220		7,578	3,231	57%
VS (%)				1.56%	2.05%	0.20%	1.81%	0.54%	70%
VS (kg/week)				2,432	3,201		5,632	1,691	70%
Stage 2									
Flushing volume (L/week)	280,800	379,080	237,900	156,000	156,000	428,220	1,638,000	1,638,000	
TS (%)	2.34%	1.11%	0.86%	2.15%	2.70%	0.54%	1.39%	0.70%	50%
TS (kg/week)	6,569	4,213	2,046	3,359	4,220	2,316	22,723	11,456	50%
VS (%)	1.80%	0.68%	0.45%	1.56%	2.05%	0.18%	0.92%	0.31%	66%
VS (kg/week)	5,055	2,578	1,077	2,432	3,201	756	15,099	5,076	66%
Stage 2 (Note 2)									
Flushing volume (L/week)	280,800	379,080	237,900	156,000	156,000	0	1,209,780	1,209,780	
TS (%)	2.34%	1.11%	0.86%	2.15%	2.70%	0.54%	1.69%	0.70%	59%
TS (kg/week)	6,569	4,213	2,046	3,359	4,220	0	20,406	8,461	59%
VS (%)	1.80%	0.68%	0.45%	1.56%	2.05%	0.18%	1.19%	0.31%	74%
VS (kg/week)	5,055	2,578	1,077	2,432	3,201	0	14,343	3,749	74%

[1] The shed flushing pump is generally run for approximately 10 hours per day, from 7:00 AM to 5:00 PM while the piggery manager is on duty. Following the completion of the scheduled shed flushing, the shed flushing pump circulates recycled effluent flushing medium through Shed 1 for the remainder of the 10 hour period, as outlined in Table 2.

[2] The second set of stage 2 data outlines provides estimates of the performance of the primary pond if the shed flushing pump was turned off following the completion of the scheduled shed flushing.

3.2.2 DPI&F Wacol Piggery

Table 24 outlines the averages of the replicate total solids (TS) and volatile solids (VS) concentrations for the highly loaded settling tank influent discharged from piggery sheds and the effluent sampled from the settling tank overflow pipeline at the DPI&F Wacol piggery. Average TS and VS data is also provided for the recycled effluent used for flushing the sheds at this piggery.

Figures 35 and 36 present the TS and VS data in graphical form over the 9 month sampling period. Figure 37 includes box and whisker plots indicating the variability in the TS and VS replicate values recorded for the DPI&F Wacol piggery while Table 25 provides descriptive statistics for this data.

Table 24: DPI&F Wacol piggery average total and volatile solids contents (%) for effluent inflow to settling tank (pumped from the sump), effluent outflow from settling tank, and recycled effluent used for flushing the piggery sheds.

Sampling date	Total solids concentration (%)			Volatile solids concentration (%)		
	Settling tank inflow	Settling tank outflow	Shed flushing medium	Settling tank inflow	Settling tank outflow	Shed flushing medium
24/04/2007	2.40%	0.81%		1.85%	0.46%	
9/05/2007	1.85%	0.73%		1.33%	0.37%	
24/05/2007	1.55%	0.85%		1.06%	0.44%	
6/06/2007	1.40%	0.67%		0.94%	0.33%	
3/07/2007	3.38%	0.74%		2.69%	0.36%	
17/07/2007	4.59%	0.81%	0.45%	3.81%	0.44%	0.14%
1/08/2007	2.30%	1.05%	0.47%	1.73%	0.61%	0.16%
16/08/2007	2.18%	0.79%	0.52%	1.47%	0.38%	0.21%
24/08/2007	2.31%	0.92%	0.47%	1.66%	0.51%	0.16%
14/09/2007	2.65%	0.84%	0.46%	1.91%	0.46%	0.15%
15/10/2007	1.49%	0.80%	0.48%	1.04%	0.43%	0.15%
31/10/2007	1.80%	0.76%	0.51%	1.33%	0.39%	0.18%
6/11/2007	1.64%	0.68%	0.50%	1.22%	0.34%	0.19%
15/11/2007	1.75%	0.74%	0.48%	1.26%	0.37%	0.15%
22/11/2007	2.11%	0.73%	0.51%	1.53%	0.37%	0.19%
11/12/2007	2.26%	0.72%	0.50%	1.75%	0.40%	0.17%
10/01/2008	1.39%	0.86%	0.46%	0.99%	0.50%	0.15%
23/01/2008	2.44%	0.75%	0.46%	1.88%	0.45%	0.17%
Averages:	**2.19%**	**0.79%**	**0.48%**	**1.64%**	**0.42%**	**0.17%**

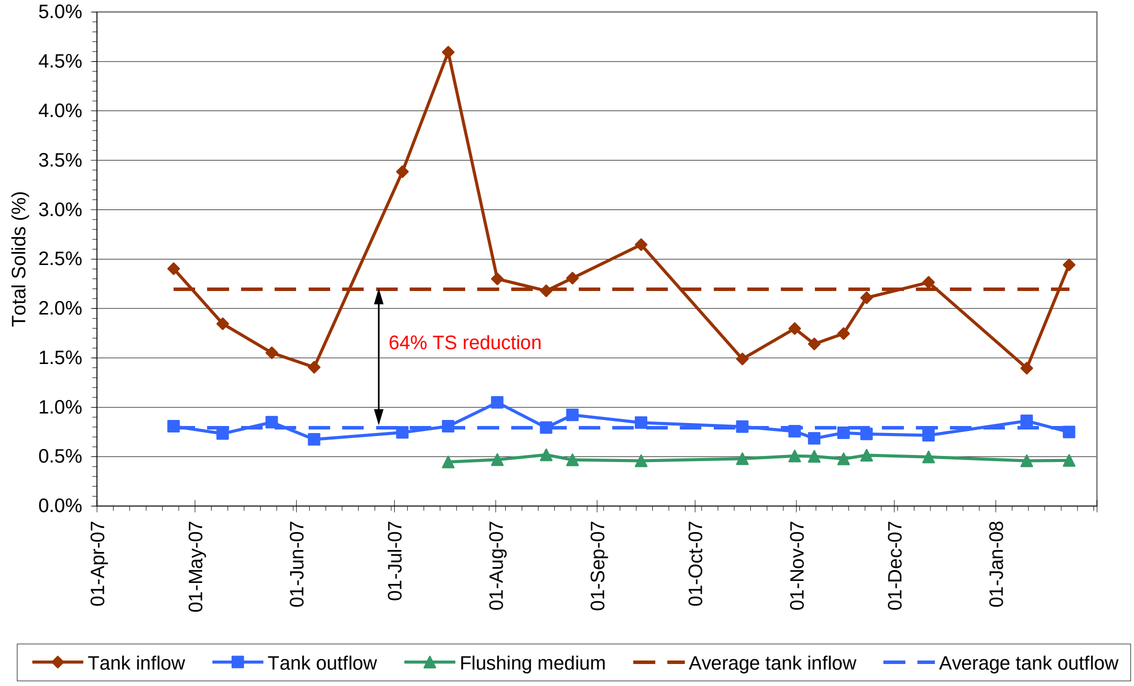


Figure 35: Average of replicate total solids (TS) concentrations in effluent entering and leaving the highly loaded settling tank, and in recycled effluent flushing medium, at the DPI&F Wacol piggery.

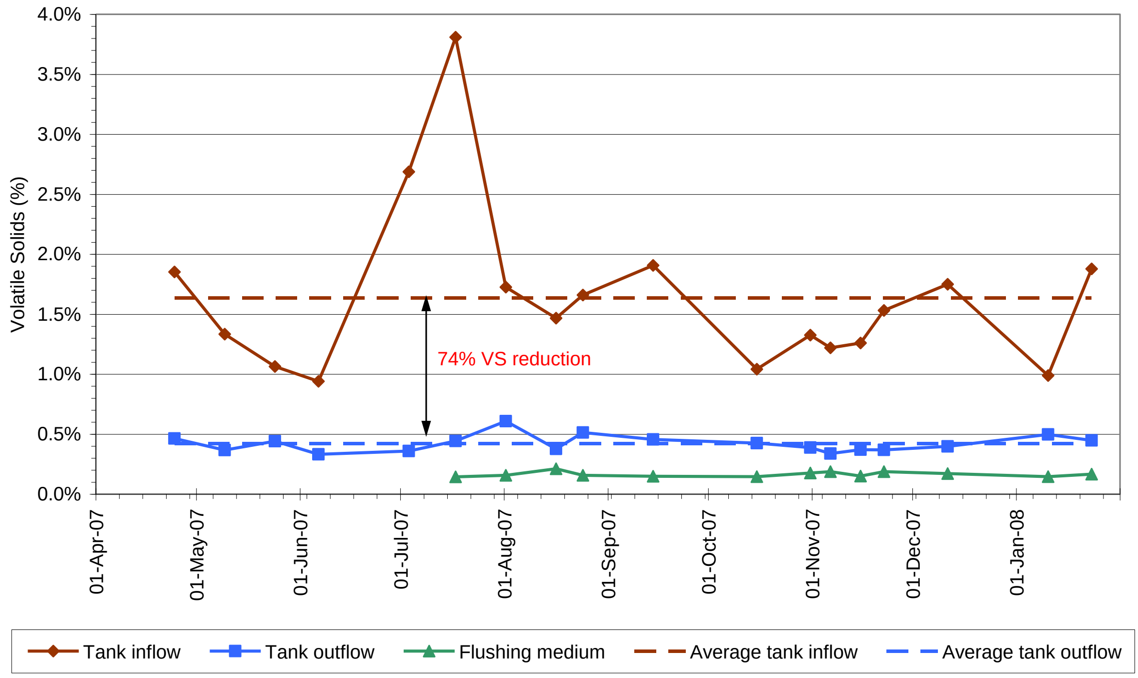


Figure 36: Average of replicate volatile solids (VS) concentrations in effluent entering and leaving the highly loaded settling tank, and in recycled effluent flushing medium, at the DPI&F Wacol piggery.

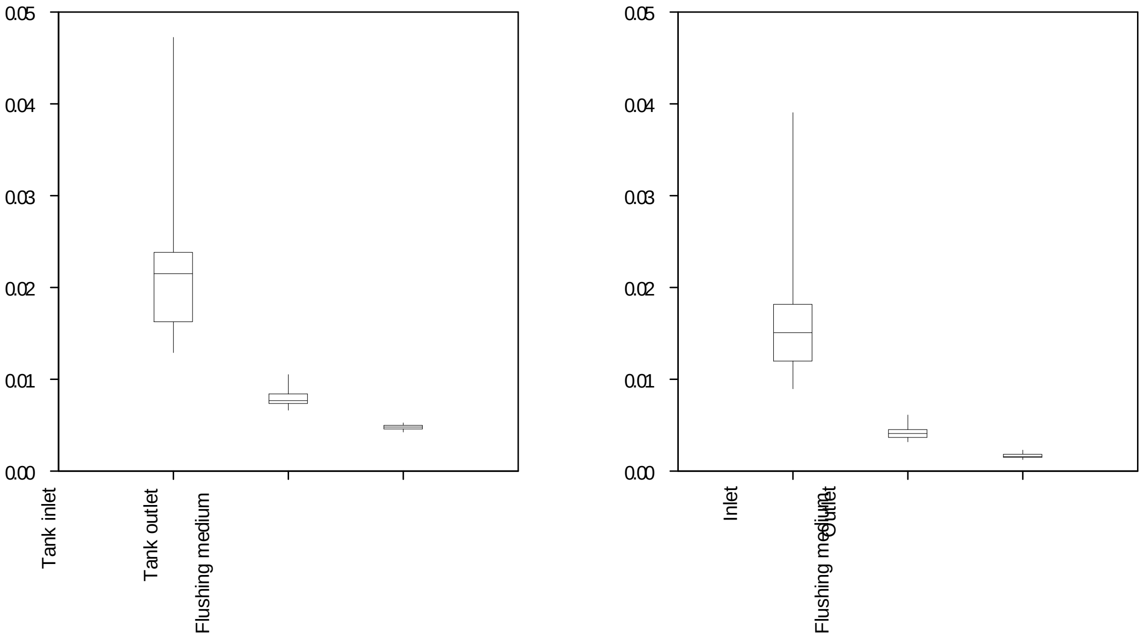


Figure 37: Box and whisker plots of the total and volatile solids concentrations in the effluent samples collected from the Wacol piggery.

Table 25: Descriptive statistics for effluent total and volatile solids (TS and VS) samples collected at the DPI&F Wacol piggery.

Parameter	Total solids (TS) concentration (%)			Volatile solids (VS) concentration (%)		
	Tank inflow	**Tank outflow**	**Flushing medium**	**Tank inflow**	**Tank outflow**	**Flushing medium**
Mean	2.19%	0.79%	0.48%	1.64%	0.42%	0.17%
Standard Error	0.1058%	0.0122%	0.0042%	0.0930%	0.0095%	0.0038%
Median	2.15%	0.77%	0.48%	1.51%	0.41%	0.16%
Standard Deviation	0.78%	0.09%	0.03%	0.68%	0.07%	0.02%
Sample Variance	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Kurtosis	340.31%	177.03%	-80.66%	405.33%	86.88%	35.68%
Skewness	175.48%	124.83%	-2.00%	193.53%	98.81%	49.67%
Range	3.43%	0.39%	0.10%	3.01%	0.29%	0.11%
Minimum	1.29%	0.67%	0.43%	0.90%	0.32%	0.13%
Maximum	4.72%	1.05%	0.53%	3.91%	0.61%	0.23%
Sum	118.44%	42.76%	18.77%	88.34%	22.80%	6.47%
Count	54	54	39	54	54	39
Confidence Level (95.0%)	0.21%	0.02%	0.01%	0.19%	0.02%	0.01%

The TS and VS concentrations of effluent leaving the highly loaded pond showed major reductions in comparison to the effluent entering the pond. The average reductions in TS and VS were 64% and 74%, respectively.

3.2.3 *Biometrical Analysis of Solids Reduction Data*

The results of an analysis of variance for the total solids and volatile solids data for effluent samples collected from both the Dalby and Wacol piggeries are provided in Table 26 and Table 27 respectively. A mixed model was fitted to this set of data, fitting terms for Sample Source, and using repeated treatments at the sites and stages of testing as duplicate data for LSD comparison.

Table 26: Analysis of variance results for Dalby and Wacol piggery total solids (TS) data.

Site	Stage	Sample source	Predicted value	Standard error	Significant differences
Dalby	Stage 1	Shed 5 inflow	0.0271	0.0008	a
Dalby	Stage 2	Shed 1 inflow	0.0234	0.0013	ab
Wacol	N/A	Tank inflow	0.0219	0.0004	b
Dalby	Stage 1	Shed 4 inflow	0.0215	0.0008	b
Dalby	Stage 2	Shed 2 inflow	0.0111	0.0011	c
Dalby	Stage 1	Bucketed outflow	0.0092	0.0005	cd
Dalby	Stages 1 & 2	Pumped outflow	0.0088	0.0004	cd
Dalby	Stage 2	Shed 3 inflow	0.0086	0.0010	cd
Wacol	N/A	Tank outflow	0.0079	0.0004	cd
Dalby & Wacol	Stages 1, 2 & N/A	Flushing medium	0.0054	0.0003	d
LSD (5%)			0.0047		

Table 27: Analysis of variance results for Dalby and Wacol piggery volatile solids (VS) data.

Site	Stage	Sample source	Predicted value	Standard error	Significant differences
Dalby	Stage 1	Shed 5 inflow	0.0205	0.0007	a
Dalby	Stage 2	Shed 1 inflow	0.0180	0.0012	ab
Wacol	N/A	Tank inflow	0.0164	0.0004	ab
Dalby	Stage 1	Shed 4 inflow	0.0156	0.0007	b
Dalby	Stage 2	Shed 2 inflow	0.0068	0.0009	c
Dalby	Stage 2	Shed 3 inflow	0.0045	0.0008	cd
Dalby	Stage 1	Bucketed outflow	0.0045	0.0004	cd
Dalby	Stages 1 & 2	Pumped outflow	0.0043	0.0003	cd
Wacol	N/A	Tank outflow	0.0042	0.0004	cd
Dalby & Wacol	Stages 1, 2 & N/A	Flushing medium	0.0018	0.0003	d
LSD (5%)			0.0041		

The results indicate that the total solids concentrations in the pond inflows from sheds 1, 4 and 5 at the Dalby piggery and inflow to the tank at the Wacol piggery are each significantly different (at the 5% level) from the pumped and bucketed pond outflows at the Dalby piggery and from the tank outflow at the Wacol piggery. However, the pond inflows from sheds 2 and 3 at the Dalby piggery were not significantly different from the outflows.

Similar outcomes were observed from the analysis of volatile solids data.

3.3 Effluent Chemical Composition

The results of the laboratory chemical analyses of the three sets of effluent samples collected at the Dalby piggery are provided in Table 28. The pH and electrical conductivity (EC) results for the Dalby piggery effluent samples analysed for TS and VS are provided in Table 29. The pH and EC results for the DPI&F Wacol piggery samples are provided in Table 30. The pH and EC results from the Dalby and DPI&F Wacol piggeries are presented graphically in Figures 38 to 41 respectively.

Table 28: Chemical analysis results for effluent samples collected from the Dalby piggery.

Parameter	Units	Shed 5 effluent	Outlet - pump	Outlet - bucket	Shed 2 effluent	Outlet - pump	Flushing medium	Shed 1 effluent	Outlet - pump	Flushing medium
Date		14/06/2007	14/06/2007	14/06/2007	2/05/2008	2/05/2008	2/05/2008	4/06/2008	4/06/2008	4/06/2008
pH		7.6	7.7	7.6	7.8	7.5	7.8	7.2	7.8	8.0
Conductivity	uS/cm	14,500	15,800	16,300	12,700	12,600	12,300	12,200	13,200	13,000
Total Dissolved Ions	mg/L				10,306	10,714	10,506	10,804	11,754	10,651
Total Dissolved Solids	mg/L				6,520	6,550	6,600	7,300	8,150	6,820
Ammonia Nitrogen		1,870	1,490	1,420				1,450	1,440	1,390
Nitrite	mg/L NO_2				<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nitrate	mg/L NO_3	<1.0	<1.0	<1.0	2.1	<1.0	<1.0	225	891	308
Nitrate Nitrogen	mg/L				0.47	<0.20	<0.20	50.8	201	69.5
Nitrite Nitrogen	mg/L				<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Total Kjeldahl Nitrogen	mg/L	2,710	2,000	2,020	1,560	1,240	1,500	2,430	1,450	1,680
Total Nitrogen	mg/L	2,710	2,000	2,020	1,560	1,240	1,500	2,480	1,650	1,750
Total Phosphorus	mg/L	329	185	166	86.5	64	62.9	341	93.9	36.4
Phosphate	mg/L PO_4				86.8	118	58.2	434	47.1	53.5
Potassium	mg/L	1,110	939	932	851	346	664	139	417	80.9
Sulphate	mg/L SO_4				28	11	38	113	113	74
Sodium	mg/L	699	695	622	594	591	609	468	586	593
Calcium	mg/L	46.5	43.3	45.2	31.2	35.8	27.9	52.1	39.1	81.9
Magnesium	mg/L	86.2	60.2	63	31.3	30.4	32.3	66.8	34.8	24.2
Total Iron	mg/L				2.78	1.13	2.26	14.7	2.03	0.87
Total Manganese	mg/L				1.34	0.72	1.28	5.95	1.04	0.23
Chloride	mg/L				984	988	1,050	1,170	1,350	1,100

Parameter	Units	Shed 5 effluent	Outlet - pump	Outlet - bucket	Shed 2 effluent	Outlet - pump	Flushing medium	Shed 1 effluent	Outlet - pump	Flushing medium
Molybdate Reactive Silica	mg/L				130	205	170	631	605	404
Total Alkalinity	mg/L $CaCO_3$	7,940	7,600	7,270	6,310	7,050	6,580	6,680	6,790	6,830
Residual Alkalinity	meq/L $CaCO_3$				122	137	127	125	131	130
Bicarbonate Alkalinity	mg/L $CaCO_3$	7,940	7,600	7,270	6,310	7,050	6,580	6,680	6,790	6,830
Carbonate Alkalinity	mg/L $CaCO_3$	<2	<2	<2	<2	<2	<2	<2	<2	<2
Hydroxide Alkalinity	mg/L $CaCO_3$				<2	<2	<2	<2	<2	<2
Temporary Hardness	mg/L $CaCO_3$				207	215	203	405	241	304
Total Hardness	mg/L $CaCO_3$				207	215	203	405	241	304
Sodium Adsorption Ratio		14	16	14	18	17.6	18.6	10.1	16.4	14.8
Figure of Merit					0.2	0.2	0.2	0.4	0.2	0.2
Saturation Index					1.49	1.3	1.46	1.14	1.62	2.15
Free Carbon Dioxide	mg/L				200	446	208	842	215	137
Exchangeable Sodium %	%	112	125	112						
pHc		5.4	5.5	5.5						

Table 29: Effluent pH and electrical conductivity data for Dalby piggery.

Sampling date	Source	pH				Electrical conductivity [EC] – (dS/m)			
		Shed outflow	Bucketed pond effluent	Pumped pond effluent	Shed flushing medium	Shed outflow	Bucketed pond effluent	Pumped pond effluent	Shed flushing medium
Stage 1									
14/06/2007	Shed 5	7.8	7.5	7.5	7.9	14.5	16.3	15.8	14.7
26/06/2007	Shed 4	8.0	7.5	7.4	7.9	13.7	14.6	14.5	14.0
12/07/2007	Shed 4	8.1	7.6	7.7	8.0	15.4	16.0	16.5	13.4
24/07/2007	Shed 4	7.9	7.3	7.3	8.1	16.5	16.9	16.8	15.9
7/08/2007	Shed 4	8.5	7.8	7.9	8.6	17.2	17.0	16.8	16.1
21/08/2007	Shed 4	8.8	8.3	8.5	8.8	16.4	17.3	17.3	15.7
28/08/2007	Shed 4	7.5	6.8	6.8	7.4	15.9	17.5	17.3	15.8
10/09/2007			7.2	7.5			17.6	17.5	
Stage 2									
30/01/2008	Shed 2	7.0		6.9	7.1	15.0		14.4	14.1
6/02/2008	Shed 3	7.3		6.9	7.3	11.5		13.9	14.2
13/02/2008	Shed 3	7.4		6.7	7.3	13.2		13.1	13.2
27/02/2008	Shed 2	7.0		7.0	7.0	13.3		14.0	13.5
14/03/2008	Shed 3	7.3		6.8	7.0	13.5		14.2	14.0
19/03/2008	Shed 3	6.7		6.7	7.1	14.4		14.4	14.0
2/04/2008				6.6					
23/04/2008	Shed 3	7.0		6.6	7.0				
2/05/2008	Shed 2	6.7		6.7	7.1	14.7		15.1	15.1
9/05/2008	Shed 1	6.1		6.4	6.7	14.4		14.8	14.7
4/06/2008	Shed 1	6.4		6.6	7.0	13.6		14.7	14.6
Average		**7.4**	**7.5**	**7.1**	**7.5**	**14.6**	**16.6**	**15.4**	**14.6**
Min		**6.1**	**6.8**	**6.4**	**6.7**	**11.5**	**14.6**	**13.1**	**13.2**
Max		**8.8**	**8.3**	**8.5**	**8.8**	**17.2**	**17.6**	**17.5**	**16.1**

Table 30: Effluent pH and electrical conductivity data for DPI&F Wacol piggery.

Sampling date	pH			Electrical conductivity (EC)		
	Tank inflow	Tank outflow	Flushing medium	Tank inflow	Tank outflow	Flushing medium
6/06/2007	7.5	7.3		13.8	11.6	
3/07/2007	7.3	7.6		18.6	19.7	
1/08/2007	7.7	7.5	7.6	13.8	15.3	12.9
16/08/2007	7.3	7.8	7.5	12.1	15.9	13.0
24/08/2007	6.9	7.1	6.9	11.1	13.9	12.3
14/09/2007	6.7	7.0	7.0	14.1	12.7	14.5
15/10/2007	6.9	7.1	7.0	13.5	14.6	13.0
31/10/2007	6.5	6.8	6.8	11.7	13.7	12.6
6/11/2007	6.8	7.1	7.0	11.4	14.1	12.8
15/11/2007	7.0	7.3	7.2	13.6	13.9	12.4
22/11/2007	7.3	7.3	7.1	13.2	13.5	12.5
11/12/2007	6.7	7.2	7.0	12.4	13.5	12.4
10/01/2008	7.2	7.4	7.8	10.9	12.0	11.9
23/01/2008	6.8	6.9	7.1	12.3	11.2	11.3
Average:	**7.0**	**7.2**	**7.2**	**13.0**	**14.0**	**12.6**
Min:	**6.5**	**6.8**	**6.8**	**10.9**	**11.2**	**11.3**
Max:	**7.7**	**7.8**	**7.8**	**18.6**	**19.7**	**14.5**

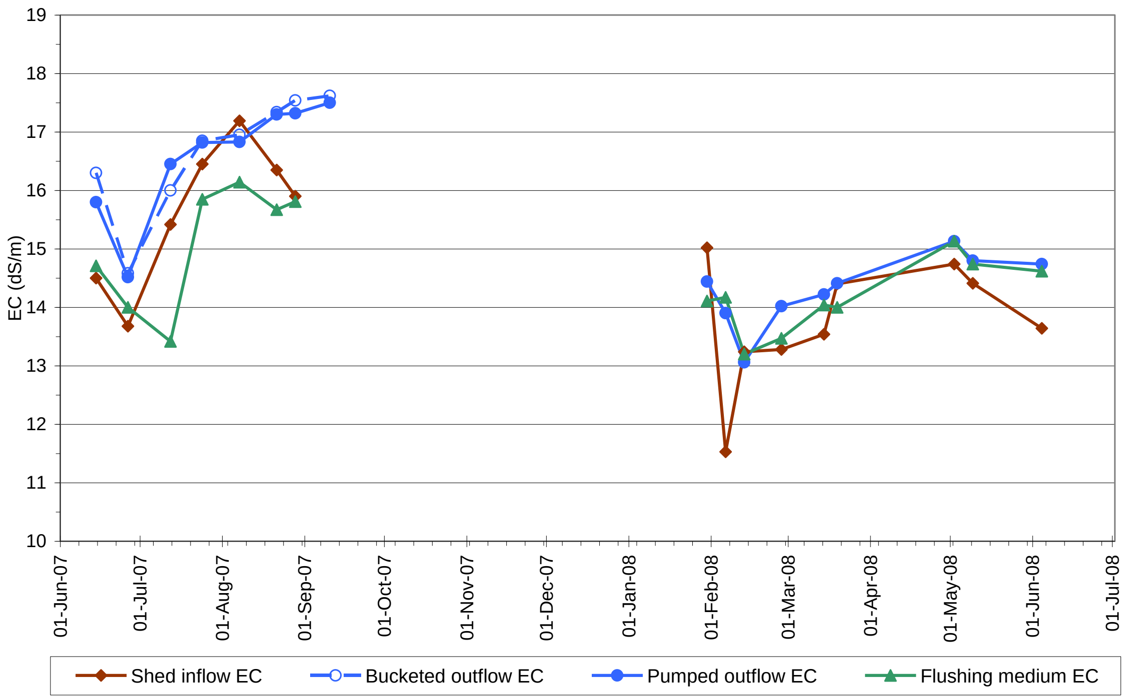


Figure 38: Electrical conductivity (EC) of effluent entering and leaving the highly loaded pond at the Dalby piggery.

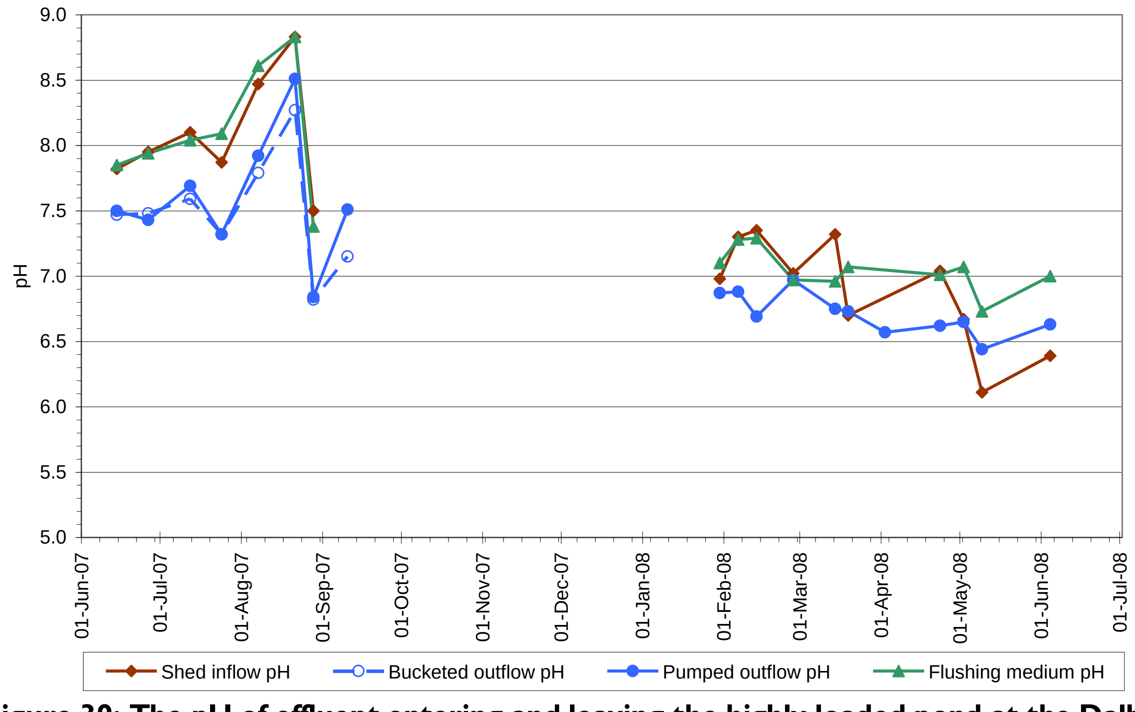


Figure 39: The pH of effluent entering and leaving the highly loaded pond at the Dalby piggery.

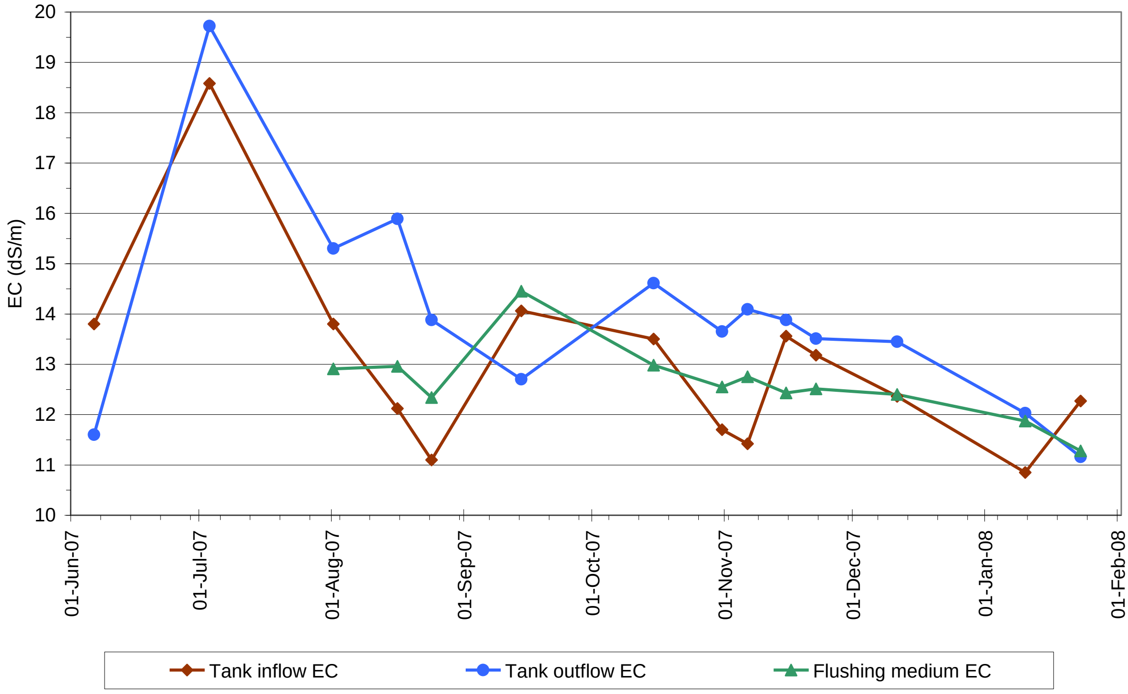


Figure 40: The electrical conductivity (EC) of effluent entering and leaving the highly loaded settling tank the DPI&F Wacol piggery.

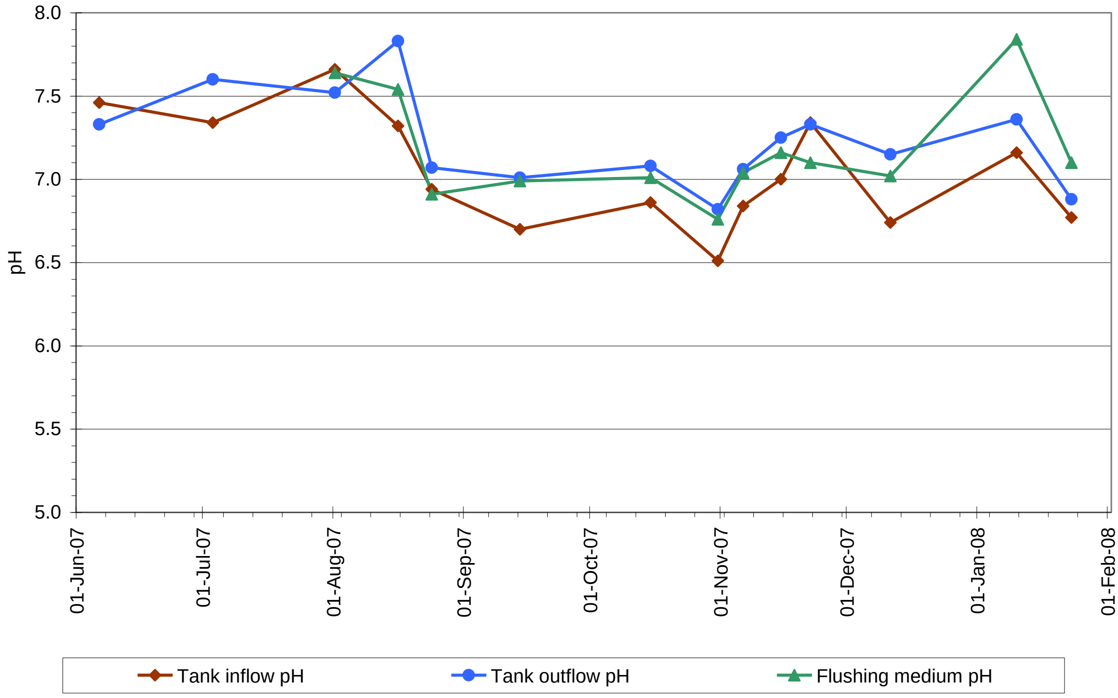
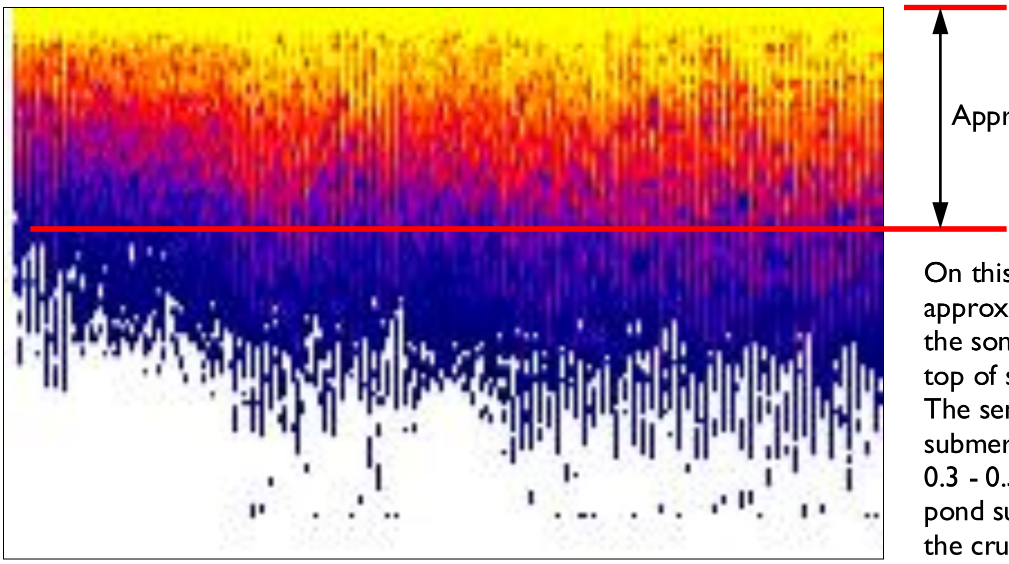


Figure 41: The pH of effluent entering and leaving the highly loaded settling tank the DPI&F Wacol piggery.

3.4 Solids Accumulation in Highly Loaded Primary Pond

3.4.1 Dalby Piggery

As noted in section 2.1.10, the depths to the top of the sludge were measured using the manually operated, graduated, aluminium tee-bar, the nephelometer (turbidity meter) and the sonar fish finder. The fish finder screen provided a digital readout of the depth to the sludge surface in addition to a visual representation of the pond profile. It was also possible to store and download visual images of the pond profile. An example is provided in Figure 42.



On this occasion, the approximate depth from the sonar sensor to the top of sludge was 2.7 m. The sensor was submerged approximately 0.3 - 0.5m below the pond surface, just below the crust layer.

Figure 42: Visual image of the highly loaded pond profile downloaded from the sonar fish finder.

The elevations of the top and bottom surfaces of the solids layer deposited in the highly loaded primary pond are plotted in Figure 43 for the various measurement dates and methods. The effluent from the sheds enters the pond at its eastern end.

This figure suggests that the level of solids build-up in the pond actually declined over the monitoring period. Furthermore, while the tee-bar operator believed that he was encountering the original base of the pond, comparison with the as-built survey data for the pond suggests that the bottom of the solids deposit was at least 0.5 m above the surveyed base of the pond. A possible explanation for this could be that the base of the pond was relatively narrow (approximately 3 m wide) and the solids monitoring may not have been carried out in the exact centre of the pond. Consequently, the tee bar may have been probing the adjacent pond batter, above the pond base. Alternatively, there may have been an error in the original survey or in relating the pond storage depths back to the original survey data.

Figure 44 provides an indication of the total solids loading entering the pond and the resulting rate of solids accumulation on the base of the pond. The solids loading rate clearly increases at the time of transition from stage 1 to stage 2 when effluent from additional sheds was directed into the pond.

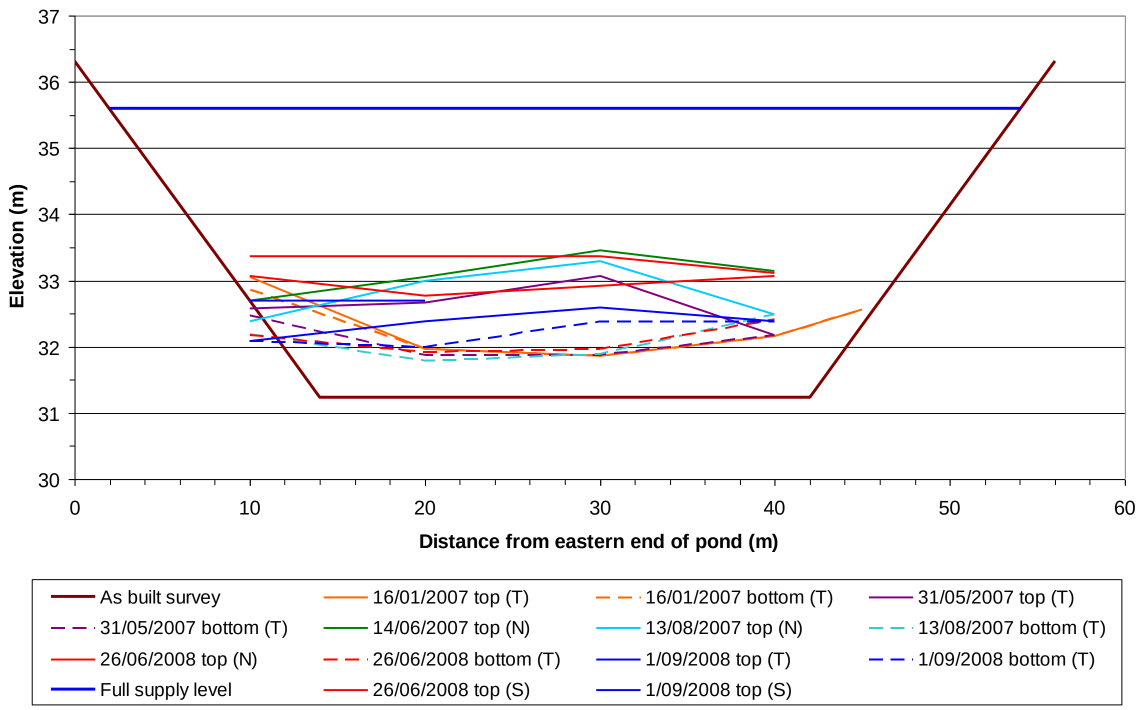


Figure 43: The tops and bottoms of the sludge layer in the highly loaded pond at the Dalby piggery determined using the manual tee bar (T), nephelometer (N) and sonar fish finder (S).

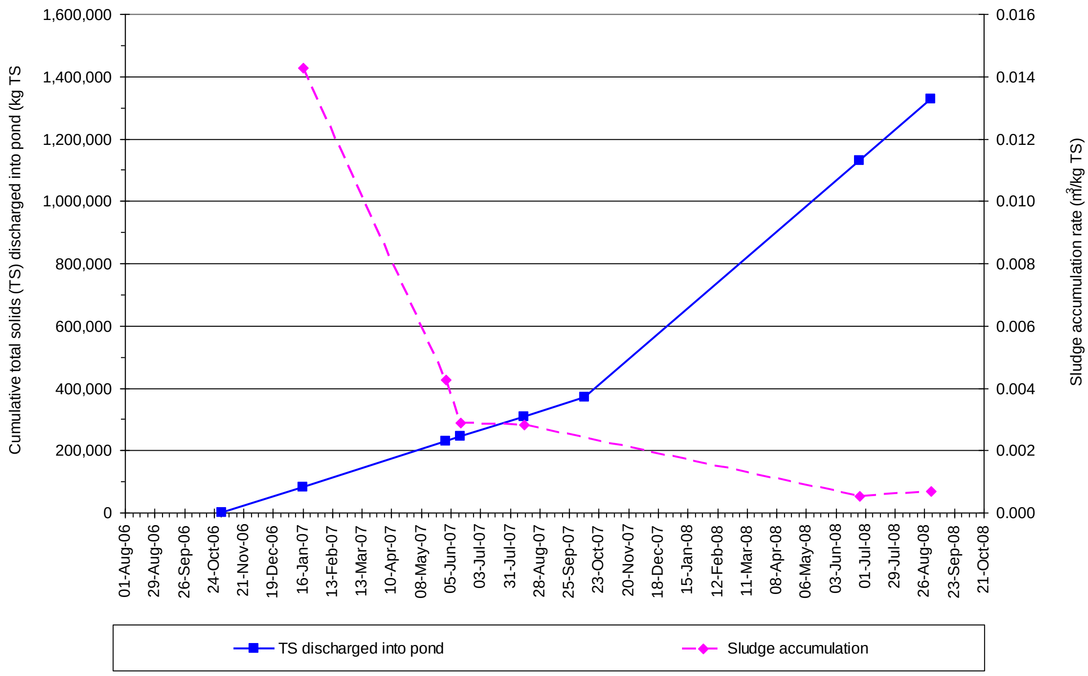


Figure 44: The mass of total solids entering the highly loaded primary pond and the rate of solids accumulation in the pond over the 22 month monitoring period.

The TS and VS analysis results for the sludge samples collected from the highly loaded pond at the Dalby piggery are provided in Table 31.

Table 31: Results of TS and VS analyses of sludge samples collected from the highly loaded pond at the Dalby piggery.

	Units	4/06/2008	13/08/2007	Average
TS concentration	%	6.64%	17.31%	11.98%
VS concentration	%	5.28%	12.52%	8.90%

The TS and VS analysis results for the crust samples collected from the highly loaded pond at the Dalby piggery are provided in Table 32.

Table 32: Results of TS and VS analyses of crust samples collected from the highly loaded pond at the Dalby piggery.

	Units	4/06/2008	18/03/2008	26/03/2008	Average
TS concentration	%	20.28%	20.38%	17.10%	19.25%
VS concentration	%	16.48%	16.04%	12.52%	15.01%
Density	kg/L				0.8

3.4.2 DPI&F Wacol Piggery

The depths to the top of the solids deposited in the settling tank at the Wacol piggery are indicated in Table 33, along with the turbidity measurements directly above and below this level.

Table 33: Depths to the top of the accumulated solids in the settling tank at the Wacol piggery, and turbidity measurements directly above and below this level.

Date	Depth to top of solids (m)		Nephelometer reading (NTU)	
	Sonar	Nephelometer	Above top of solids	Below top of solids
19/06/2007		2.0		
15/11/2007	1.0	1.0	1,300	2,500
22/11/2007	1.0	1.0	400	1,700
11/12/2007	0.9	0.9	400	1,400
10/01/2008	0.5	0.5	900	2,000

Figure 45 provides an indication of the total solids loading entering the settling tank and the resulting rate of solids accumulation on the base of the tank.

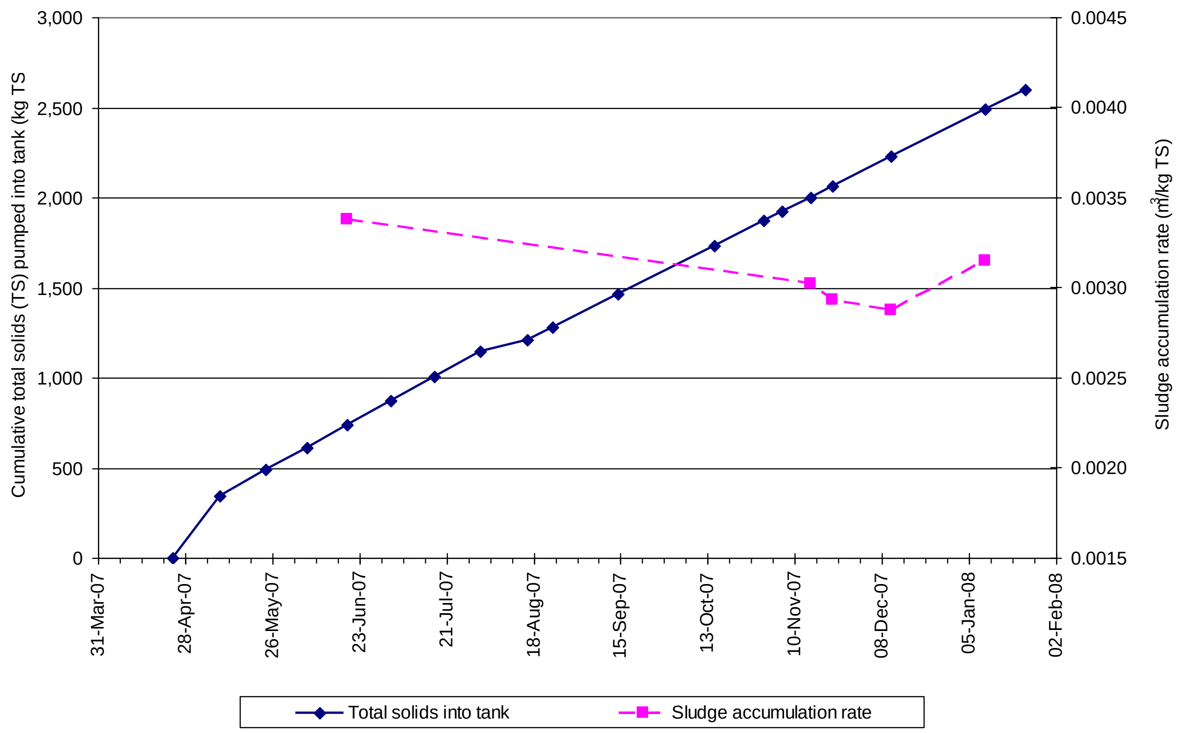


Figure 45: The mass of total solids entering the settling tank at the Wacol piggery and the rate of solids accumulation in the tank over the 9 month monitoring period.

3.5 Solids Balance

The basic equation used in deriving this mass balance is outlined below in Table 34, along with estimated numerical values for the various components. These values are also presented graphically in Figure 46.

Table 34: Solids mass balance equation and estimated numerical values of the various components for the Dalby piggery trial.

	Solids in pond inflow		Solids in pond outflow		Solids stored in pond sludge		Solids stored in pond crust		Solids stored in pond effluent		Gaseous losses from the pond
TS (kg)	1,435,099	–	694,621	=	111,607	+	155,105	+	14,700	+	459,066
VS (kg)	980,678	–	319,761	=	82,948	+	120,947	+	6,510	+	450,512
TS / VS	1.46		2.17		1.35		1.28		2.26		1.02

The solids mass values in the pond inflow and outflow outlined in Table 34 were determined from the estimated inflow and outflow volumes and the average solids concentrations measured throughout both stages 1 and 2 of this project. The solids in the stored sludge, crust and effluent were determined based on estimated storage volumes and the average measured solids concentrations.

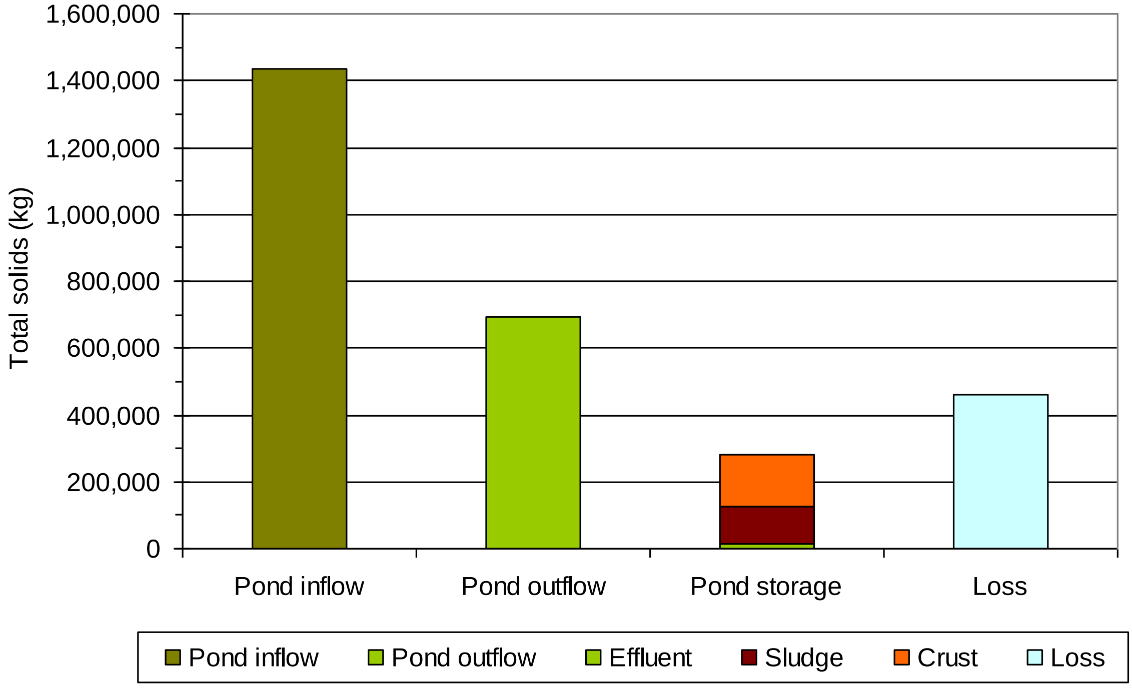


Figure 46: Total solids mass balance components.

When the highly loaded pond was constructed at the Dalby piggery, soil testing was carried out to confirm that the in-situ soil particle size distribution and plasticity characteristics were suitable for constructing a low permeability effluent pond. Compaction testing was carried out during and on completion of the pond construction to confirm that recommended compaction and soil moisture conditions had been achieved. The testing confirmed that the soil characteristics and compaction complied with the standards recommended in the DPI&F Note *'Clay lining and compaction of effluent ponds'* (Skerman *et al.*, 2005). Because the pond was constructed based on industry best practice to minimise the risk of seepage through the base and batters of the pond, it has been assumed that there were minimal solids losses via this pathway. Consequently, the estimated gaseous losses were calculated by subtracting the outflow and pond storage estimates from the pond inflow estimates.

Estimates of the various gaseous emissions from the pond were made for comparison with the total gaseous emissions determined by the mass balance procedure.

Anaerobic decomposition of organic material in an effluent pond generates biogas emissions. Typically biogas contains 60 – 65% methane (CH_4), 35 – 40% carbon dioxide (CO_2) and variable amounts (generally less than 0.5%) of other gases such as hydrogen sulphide (H_2S) (Birchall *et al.*, 2008).

The Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks – Agriculture (National Greenhouse Gas Inventory Committee, 2006) provides guidelines for estimating emissions of methane and ammonia from piggery ponds. These methods were used for estimating the methane and ammonia emissions from the highly loaded pond. The methane estimation method assumes an emission potential of 0.45 m^3 CH_4/kg VS and a methane conversion factor of 90% for lagoons in Queensland. The mass of carbon in the carbon dioxide emission was also accounted for assuming that the biogas contained 65% methane and 35% carbon dioxide. Details of the estimated emissions are outlined in Figure 47.

Table 35: Highly loaded pond solids mass balance component estimate calculations.

Parameter	Units	Stage 1	Stage 2	Total	% Inflow
Pond inflow					
Volume	L	15,288,000	76,518,000	91,806,000	
TS concentration	%	2.43%	1.39%		
VS concentration	%	1.81%	0.92%		
TS inflow	kg TS	371,498	1,063,600	1,435,099	
VS inflow	kg VS	276,713	703,966	980,678	
Pond outflow					
TS concentration out	%	1.04%	0.70%		
VS concentration out	%	0.54%	0.31%		
TS outflow	kg TS	158,995	535,626	694,621	48%
VS outflow	kg VS	82,555	237,206	319,761	33%
Stored pond sludge					
Volume	m^3			932	
TS concentration	%			11.98%	
VS concentration	%			8.90%	
TS in sludge	kg TS			111,607	8%
VS in sludge	kg VS			82,948	8%
Stored pond crust					
Volume	m^3			1007	
Density	kg/L			0.8	
Crust mass	kg			805,600	
TS concentration	%			19.25%	
VS concentration	%			15.01%	
TS in crust	kg TS			155,105	11%
VS in crust	kg VS			120,947	12%
Stored pond effluent					
Volume	m^3			2100	
TS concentration	%			0.70%	
VS concentration	%			0.31%	
TS in effluent	kg TS			14,700	1%
VS in effluent	kg VS			6,510	1%
Pond gaseous loss					
TS loss	kg TS			459,066	32%
VS loss	kg VS			450,512	46%

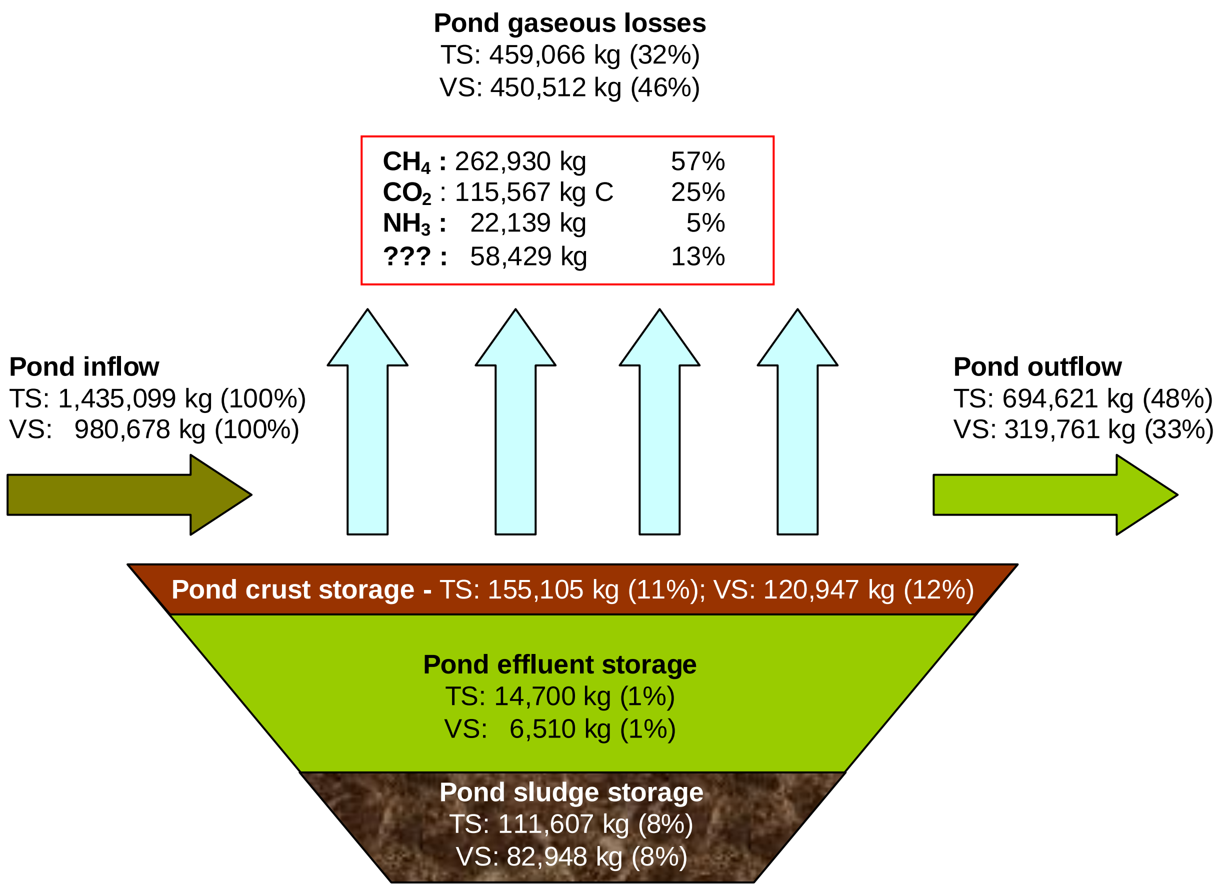


Figure 47: Schematic diagram representing the solids mass balance for the highly loaded pond at the Dalby piggery over the 22 month trial period.

3.6 Odour Emission from Highly Loaded Primary Pond

3.6.1 Olfactometry Analyses

The results of the olfactometry analyses of the odour samples collected from the Dalby piggery are outlined in Table 36, along with the sample collection locations and descriptions of the degree of crusting on the pond surface. Figure 48 provides a graphical representation of the variation in average odour emission rates over the four sampling dates, for the three sampling locations. Figure 49 plots average odour emission rates against the distance from the sampling site to the eastern end of the pond, for the range of pond surface conditions.

Table 36: Odour emission rates determined by dynamic olfactometry (AS/NZS 4323.3) for four sets of samples collected from the surface of the highly loaded primary pond at the Dalby piggery, using the DPI&F wind tunnel.

Sampling date	Distance from eastern end of pond (m)	Pond surface description	Crust condition	Odour emission rate (OU/m²/s)		
				Sample 1	Sample 2	Average
16/05/2007	32	Crust	Wet, thin (< 150mm)	73.7	48.8	61.3
16/05/2007	14	Crust	Wet, thin (< 150mm)	29.1	55.4	42.3
16/05/2007	32	Exposed liquor[2]	N/A	57.8	35.6	46.7
26/03/2008	44	Crust	Wet, thin (< 150mm)	7.2	8.5	7.9
26/03/2008	10	Crust	Dry, thick (> 300mm)	7.3	4.4	5.9
26/03/2008	3	Exposed liquor[2]	N/A	9.9	11.5	10.7
29/04/2008	42	Crust	Damp, medium (< 300mm)	16.4	16.4	16.4
29/04/2008	8	Crust	Dry, very thick (> 400mm)	1.1	1.4	1.3
29/04/2008	10	Exposed liquor[2]	N/A	41.6	43.5	42.6
12/08/2008	7	Crust	Dry, very thick (> 400mm)	BDL[1]	BDL[1]	—
12/08/2008	40	Crust	Dry, thick (> 300mm)	2.8	2.0	2.4
12/08/2008	40	Exposed liquor[2]	N/A	33.6	32.0	32.8

[1] BDL = Below detection limit.

[2] The exposed liquor samples were collected following manual removal of the crust from the pond surface.

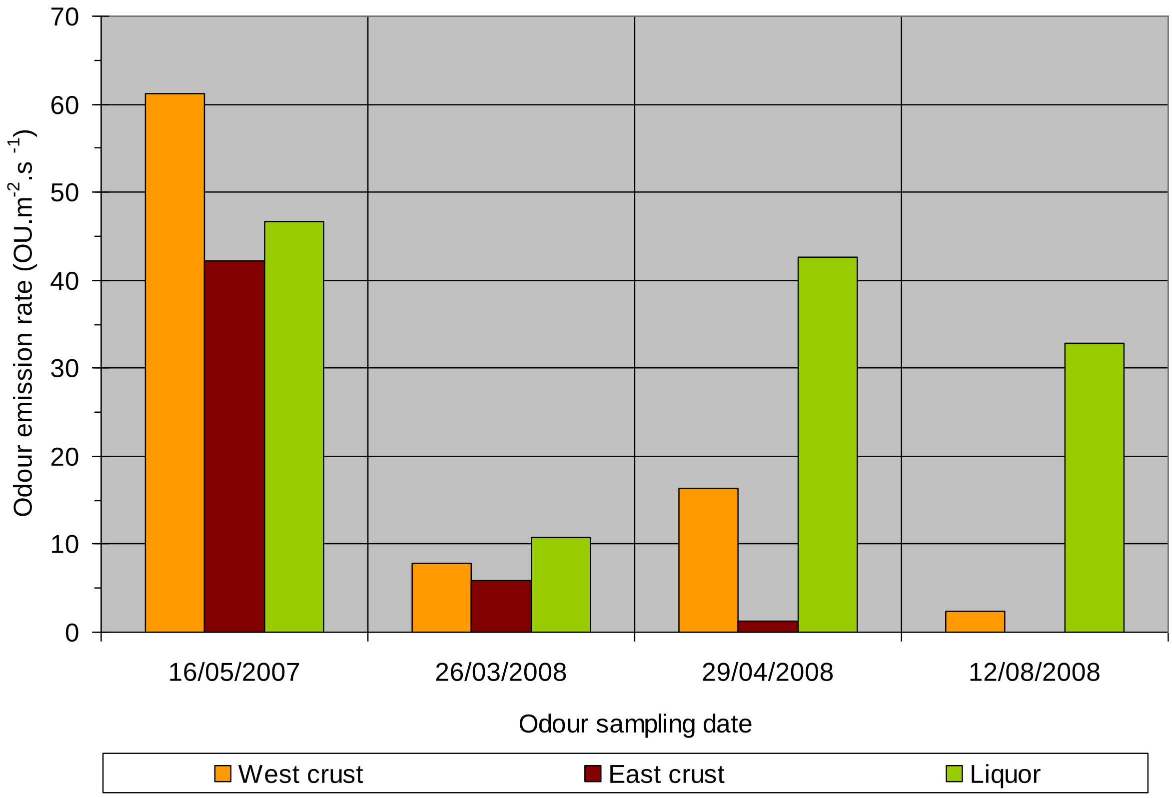


Figure 48: Bar graph showing the variation in odour emission rates from different sampling points on the highly loaded primary pond, for the four sampling dates at the Dalby piggery.

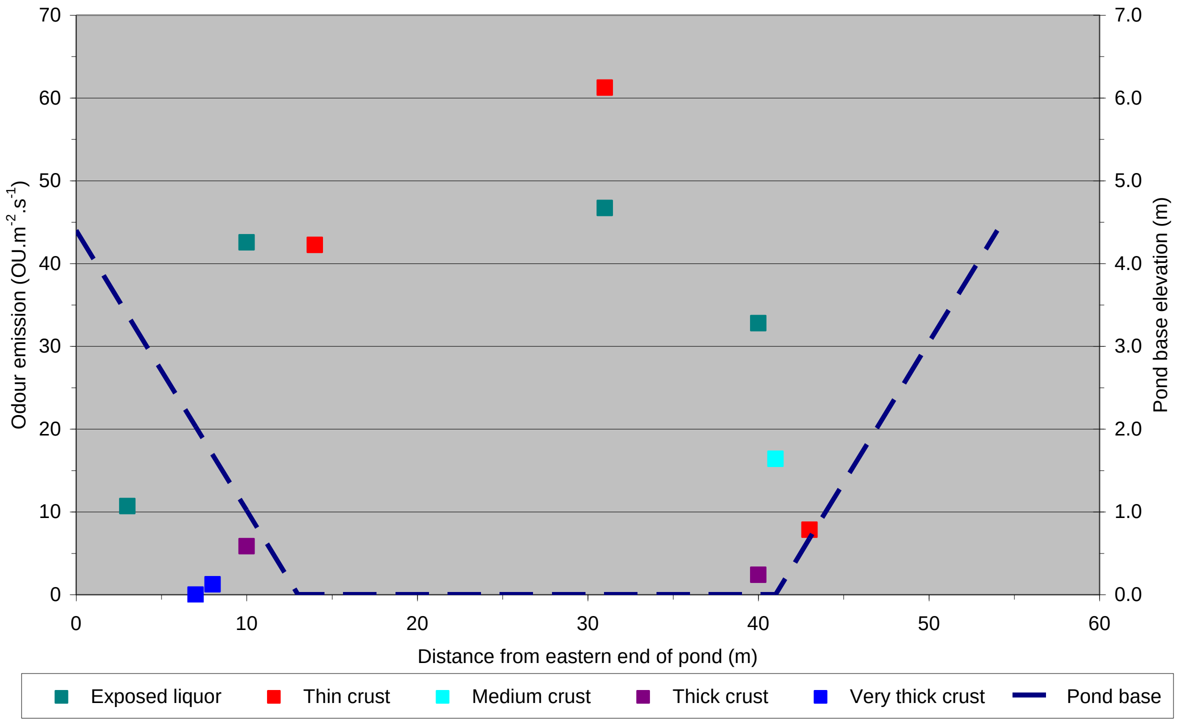


Figure 49: Odour emission rates for different pond crusting conditions plotted against the distance from the eastern end of the pond to the sampling site.

3.6.2 Gas Sensor Array Analysis

3.6.2.1 Effluent Pond Odour Discrimination

A scatter plot where the samples are represented by points distributed in the dimension of the principal components (PCs) is called a "scores plot". The distance between points corresponds directly to their overall likeness. Thus, the data points located together on the score plot represent samples with similar sensor array outputs (*i.e.* similar odour characteristics).

Any measurement instrument must be calibrated and suited to the target application. In the case of a non-specific gas sensor array system for environmental monitoring of piggery effluent pond odours, one of the prerequisites is to demonstrate that it can discriminate effluent pond odours from background odours, to avoid false positives. This is required because non-specific type sensors can react to odours which may be emitted from non-target sources.

To assess the discriminatory capability of the DPI&F sensor array system, a sensor array response data set was established using odour samples collected from different emissions sources, including the piggery effluent pond in this study and poultry farms. The sensor response to clean instrument grade air from a cylinder is included in the data set as the control.

Principal component analysis (PCA) was applied to the established data set to reduce its dimension for data interpretation for odour discrimination. Eleven latent variables (*i.e.* compression of the data to 11 dimensions) resulting from the PCA were used to develop an odour discrimination model. The 11 latent variables capture 99.14% of the variances of the original sensor array output. Therefore, the 11-dimensional compressed data adequately represented the original 26-dimensional data set. The PCA results are presented in Table 37.

Table 37: Percent variance captured by the PCA odour discrimination model

Principal component number	Eigenvalue of covariance	% Variance captured	Cumulative % Variance
1	1.51e+001	58.01	58.01
2	3.98e+000	15.29	73.31
3	1.84e+000	7.09	80.39
4	1.59e+000	6.11	86.50
5	1.00e+000	3.85	90.35
6	7.96e-001	3.06	93.41
7	5.81e-001	2.24	95.65
8	4.04e-001	1.55	97.20
9	2.27e-001	0.87	98.08
10	1.40e-001	0.54	98.62
11	1.36e-001	0.52	99.14

The two-dimensional PCA odour mapping from the PCA data compression process is depicted in Figure 50. Data points that plot close together on the map indicate a similar odour pattern and can, therefore, be classified as a similar odour source. As shown in Figure 50, the entire dataset can be classified into three distinct odour groups. This result demonstrated that the non-specific gas sensor array system is able to discriminate the effluent pond odours from another livestock odour (*i.e.* poultry odours).

It is possible to develop a better discrimination model using more sophisticated pattern recognition algorithms such as a Partial Least Square-Discrimination Analysis (PLS-DA). However, this was not attempted due to the limited number of effluent pond odour samples (n =7) in this case. The odour quantification technique also needs an adequate number of reliable odour results from dynamic olfactometry to train the model. As a rule of thumb, at least 50 olfactometry results are required to develop a reliable prediction model.

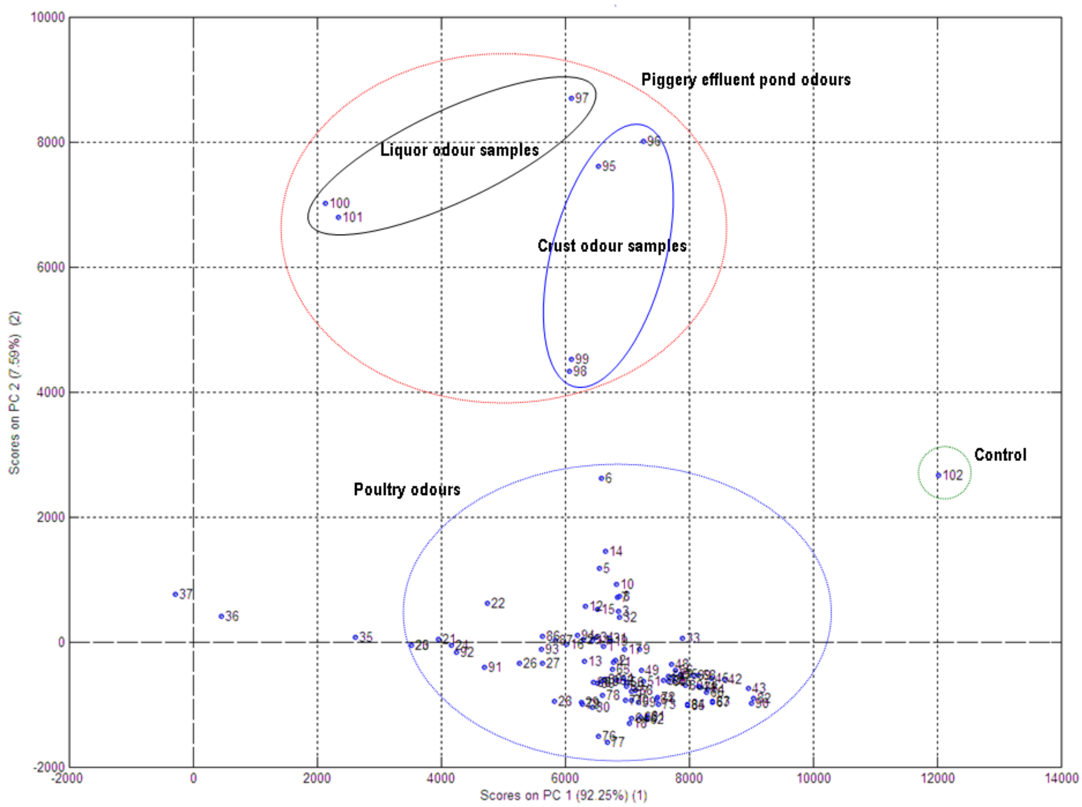


Figure 50: Two-dimensional odour mapping using principal component analysis from odour samples collected at various poultry farms, the heavily-loaded piggery effluent pond, and clean air (control)

3.6.2.2 Odour Discrimination among Effluent Pond Odour Samples

The capability of the sensor array system to discriminate between odours from the crusted and un-crusted pond surface is presented in Figure 51. As shown in Figure 51, the data points representing the crusted and un-crusted pond surface samples can be easily separated.

Mahalanobis distance is widely used in cluster analysis and other classification techniques. It is a method of determining "similarity" of an unknown sample set to a known one based on the distance measure for features (*i.e.* outputs from the sensor array).

In order to use the Mahalanobis distance to classify a test point as belonging to one of *N* classes, one first estimates the covariance matrix of each class, usually based on samples known to belong to each class. Then, given a test sample, one computes the Mahalanobis distance to each class, and classifies the test point as belonging to that class for which the Mahalanobis distance is minimal. Using the probabilistic interpretation given above, this is equivalent to selecting the class with the maximum likelihood (Wölfel & Ekenel, 2005).

The Mahalanobis distance between the crusted pond surface odours and the clean air is much shorter than the Mahalanobis distance between the un-crusted pond surface odours and the clean air. The Mahalanobis distance values of the crusted and un-crusted pond surface odour samples to the clean air are 12049.12 and 19749.36, respectively.

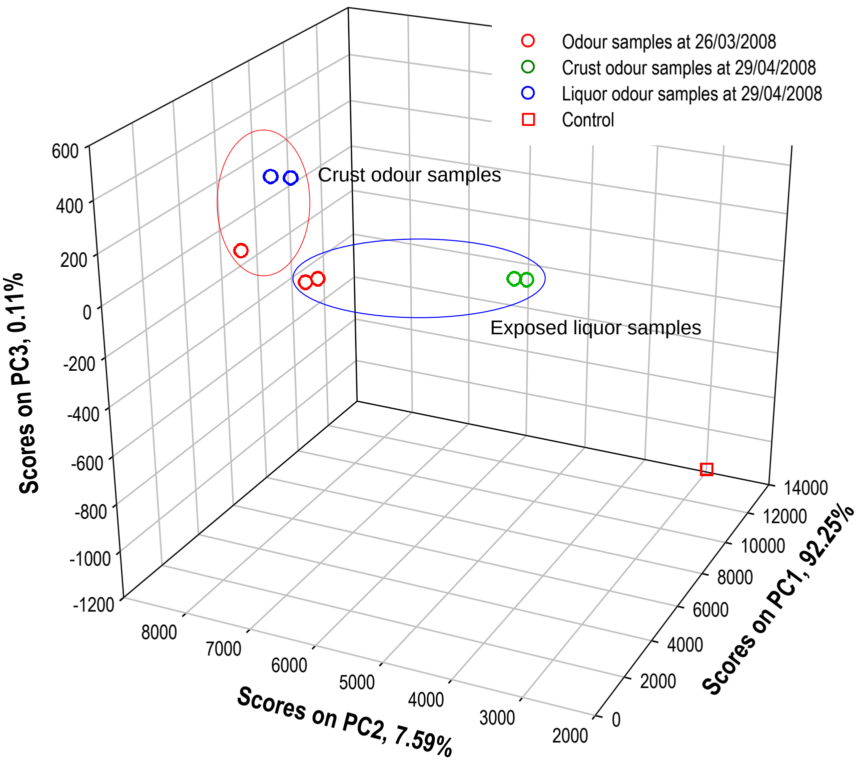


Figure 51: Three-dimensional odour mapping using principal component analysis from odour samples collected at different surface conditions (crusted and un-crusted) on an effluent pond.

These results indicate that the odour samples collected off the crusted pond surface have more similar sensor array characteristics to clean air than the odour samples collected off the un-crusted pond surface. They also indicate that the odour concentrations of the crusted pond surface samples are likely to be lower than those of the un-crusted pond surface samples. This was confirmed by olfactometry measurements. The average odour concentration value of crusted pond surface samples was 215 OU/m^3 while the average odour concentration value for the un-crusted pond surface odour samples was 623 OU/m^3 as presented in Table 7.

3.7 Waste Estimation

3.7.1 Dalby Piggery

The results of the PIGBAL (Casey *et al.*, 2003) modelling of the Dalby piggery are outlined in Table 38.

Because the Dalby piggery uses recycled effluent for flushing all sheds, it was necessary to subtract the contribution to the sampled TS and VS from the recycled effluent for comparison with the PIGBAL and Assessment spreadsheet estimates. The calculations involved in making these adjustments are outlined in Table 39. Graphical comparisons of the sampled and estimated TS and VS are provided in Figures 52 and 53.

Table 38: Dalby piggery waste estimation output produced by PIGBAL model (Casey *et al*, 2003).

Class of Animal	Total Daily Waste (kg)					
	Diet 1		Diet 2		Average Diet	
	TS	VS	TS	VS	TS	VS
Gilt -replacement	25	22	29	25	27	24
Boar	13	11	13	11	13	11
Sow - gestating	267	227	267	227	267	227
Sow - lactating	105	74	105	74	105	74
Suckers	34	31	34	31	34	31
Weaners	101	96	101	96	101	96
Growers	312	273	318	275	315	274
Finishers	930	821	1,067	934	998	877
Totals	**1,785**	**1,555**	**1,933**	**1,672**	**1,859**	**1,613**

Table 39: Adjustment of sampled total and volatile solids data for the Dalby piggery to account for use recycled effluent for shed flushing; and values estimated using the PIGBAL model (Casey *et al.,* 2003) and the DPI&F Piggery assessment spreadsheet (Skerman, 2004).

Pig class	Shed 1	Shed 2	Shed 3	Shed 4	Shed 5	Totals
Gilts			38			38
Boars			20			20
Gestating sows			414			414
Lactating sows		119				119
Suckers		599				599
Weaner pigs	270	694				964
Grower pigs	949					949
Finisher 1 pigs				641	905	1,546
Total (pigs):	1,219	1,412	472	641	905	4,649
Total (SPU):	1,084	704	763	1,026	1,448	5,025
Shed flushing vol (L/week)	280,800	379,080	237,900	156,000	156,000	
Sampled av TS conc (%)	2.34%	1.11%	0.86%	2.15%	2.70%	
Sampled av VS conc (%)	1.80%	0.68%	0.45%	1.56%	2.05%	
Total solids (kg/yr)						
Sampled TS	342,781	219,827	106,734	175,245	220,175	1,064,762
Flushing medium TS	79,259	107,000	67,150	44,033	44,033	341,475
Adjusted TS	263,522	112,827	39,584	131,212	176,142	723,286
PIGBAL TS	125,362	77,131	111,920	151,199	213,471	679,083
Assmnt spreadsheet TS	119,240	77,484	83,908	112,816	159,280	552,728
Volatile solids (kg/yr)						
Sampled VS	263,772	134,527	56,217	126,879	167,012	748,407
Flushing medium VS	25,855	34,904	21,905	14,364	14,364	111,392
Adjusted VS	237,917	99,623	34,312	112,515	152,648	637,015
PIGBAL VS	109,869	63,355	95,519	132,872	187,596	589,212
Assmnt spreadsheet VS	98,546	64,037	69,346	93,237	131,638	456,805

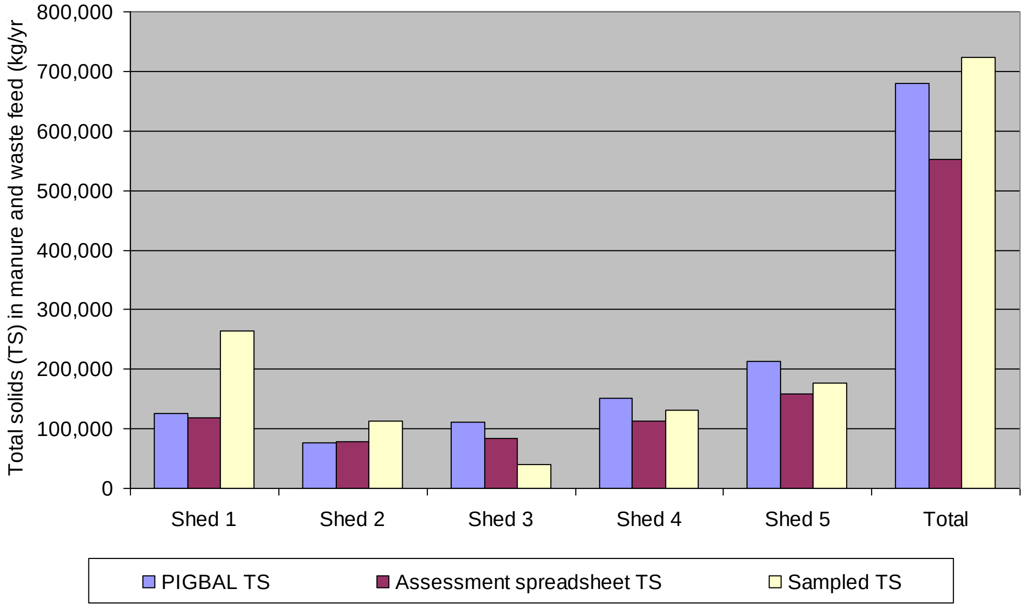


Figure 52: Comparison of sampled total solids produced by each of the five sheds at the Dalby piggery, with values estimated using the PIGBAL model and the DPI&F Piggery assessment spreadsheet.

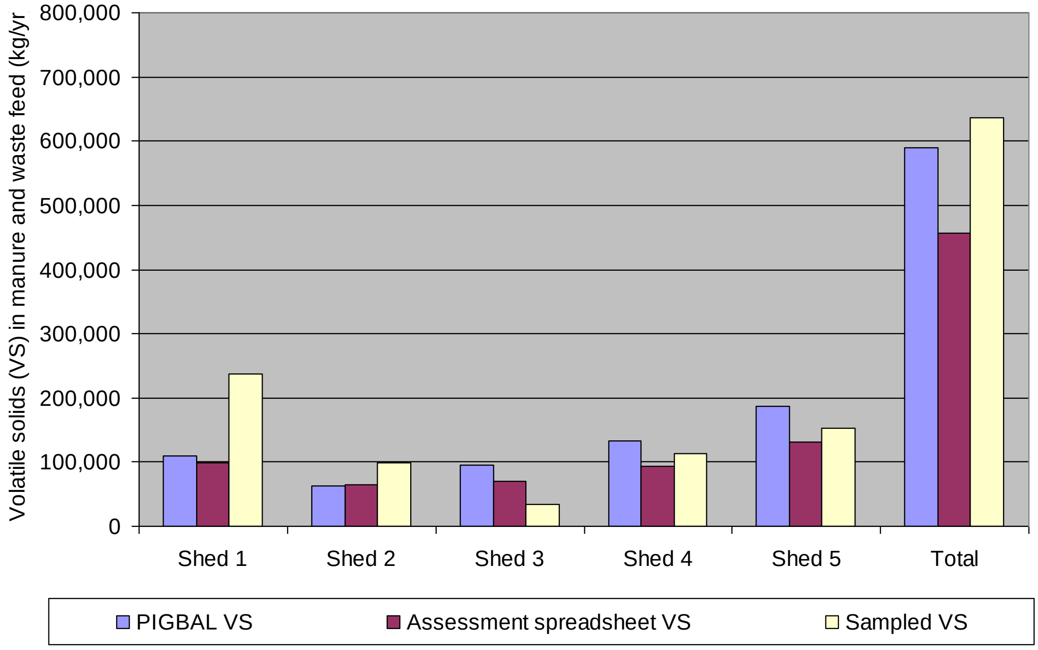


Figure 53: Comparison of sampled volatile solids produced by each of the five sheds at the Dalby piggery, with values estimated using the PIGBAL model and the DPI&F Piggery assessment spreadsheet.

3.7.2 DPI&F Wacol Piggery

Table 40 outlines the total and volatile solids waste output of the commercial grower / finisher sheds at the DPI&F Wacol piggery estimated using the PIGBAL model.

Table 40: DPI&F Wacol piggery waste estimation output produced by PIGBAL model.

Class of Animal	Total Daily Waste (kg)					
	Diet 1		Diet 2		Average Diet	
	TS	VS	TS	VS	TS	VS
Growers	157	134	154	131	156	132
Finishers	326	272	326	272	326	272
Totals	**484**	**406**	**481**	**403**	**482**	**405**

Because all of the effluent from the two commercial grower / finisher sheds is discharged into a single effluent collection sump and all sampling was carried out from this sump, it was not possible to assess the waste output of the sheds separately.

Similarly to the Dalby piggery, the DPI&F Wacol piggery uses recycled effluent for flushing all sheds. Consequently, it was necessary to subtract the contribution to the sampled TS and VS from the recycled effluent for comparison with the PIGBAL and Assessment spreadsheet estimates. The calculations involved in making these adjustments are outlined in Table 41. Comparisons of the sampled and estimated TS and VS are provided in Figure 54.

Table 41: Calculation of sampled total and volatile solids produced by the commercial grower / finisher sheds at the DPI&F Wacol piggery, and estimated values determined using the PIGBAL model and the DPI&F Piggery assessment spreadsheet.

Pig population (SPU)	1307	
Daily flushing volume (L/day)	20,000	
	TS	**VS**
Sampled effluent concentration (%)	2.19%	1.64%
Sampled flushing medium concentration (%)	0.48%	0.17%
Sampled effluent solids (kg/day)	439	327
Sampled flushing medium solids (kg/day)	96	33
Sampled manure & waste feed solids (kg/day)	342	294
PIGBAL (kg/day)	482	405
Assessment spreadsheet (kg/day)	392	324

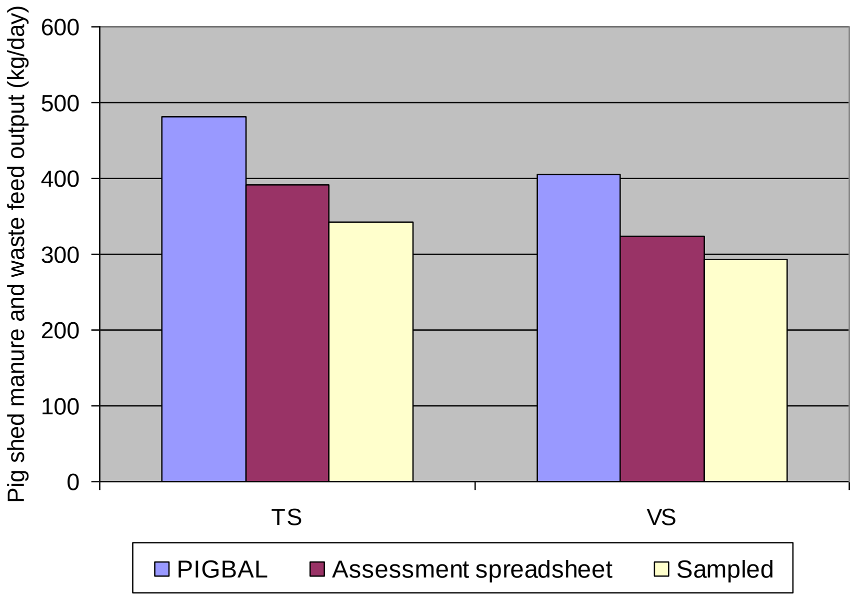


Figure 54: Comparison of sampled total and volatile solids produced by the commercial grower/finisher sheds at the DPI&F Wacol piggery, with values estimated using the PIGBAL model and the DPI&F Piggery assessment spreadsheet.

4. Discussion

4.1 Solids Reduction in Highly Loaded Pond

At the Dalby piggery, TS and VS reductions were higher for stage 1 (57% and 70%, respectively) than for stage 2 (50% and 66%, respectively) despite lower average TS and VS concentrations in the pond outflow during stage 2. This apparent reduced performance can be attributed to the lower average solids concentrations entering the pond during stage 2. There are two main reasons for this.

Firstly, sheds 4 and 5 which were the only sheds contributing effluent to the highly loaded pond during stage 1, were constructed more recently than the other sheds. The flushing channels servicing these sheds were constructed with a 1% gradient while the flushing channels under each of the other sheds (1, 2 & 3) were constructed with flat gradients. This meant that less flushing medium was required to effectively clean the shed 4 and 5 channels in comparison to the other sheds. For example, the 20 flushing channels servicing grower and finisher sheds 4 and 5 are flushed for 5 minutes each, resulting in a shed flushing time of 100 minutes per shed. By comparison, grower shed 1 houses less SPU than sheds 4 or 5 but has 18 flushing channels that are flushed for 10 minutes each, resulting in a total shed flushing time of 180 minutes. As sheds 1, 4 and 5 are each flushed four times per week, the concentration of solids in the shed 1 effluent would be expected to be considerably lower than for sheds 4 and 5. Similarly, sheds 2 and 3 house lower numbers of SPU and are flushed more frequently than sheds 4 and 5, resulting in lower solids concentrations.

Secondly, the stage 2 pond inflow solids concentration was further reduced by the producer's practice of running the flushing pump continuously for approximately 10 hours per day. The piggery manager turns the pump on at the start, and off at the end of each working day. Once all of the scheduled sheds have been flushed, the flushing flow is directed to one of the channels in shed 1 for the remainder of the 10 hour period. This practice results in 26% of the total pond inflow being 'clean' recycled flushing medium which does not perform any shed cleaning function, effectively diluting the pond inflow concentrations of TS and VS.

As indicated in Table 23, if the shed flushing pump was turned off each day following the completion of shed flushing, the pond inflow solids concentrations would increase, resulting in higher solids reduction percentages. It is predicted that the TS and VS reduction percentages could increase to 59% and 74%, respectively (assuming that the pond outflow solids concentrations are not affected by this changed practice).

The highly loaded tank trial at the DPI&F Wacol piggery gave similar levels of TS and VS reduction at 64% and 74% respectively.

Regardless of the actual level of solids reduction achieved in the highly loaded primary pond, the results are within the range normally expected for anaerobic treatment lagoons. Corbitt (1990) suggests typical BOD_5 removal rates of 70 – 80% and a range of 50 – 90%. Kruger *et al.* (1995) suggests that primary anaerobic ponds reduce BOD and VS by about 75%.

The results from the Dalby piggery also indicated relatively minor reductions in the solids concentrations of the highly loaded pond outflow from stage 1 to stage 2 (TS: 0.60% to 0.54%; VS: 0.20% to 0.18%). These reductions may reflect an increase in bacterial activity in the pond at the higher loading rate.

Most modern piggeries have flushing channels constructed on gradients that promote efficient cleaning while minimising water use, resulting in shed effluent having relatively high solids concentrations (TS: 2 – 3%, VS: 1.5 – 2.2%). Based on the results of these trials, relatively high levels of volatile solids reduction (approximately 75%) are likely to result from the use of highly loaded primary ponds in these situations.

4.2 Solids Accumulation in Highly Loaded Pond

Throughout the monitoring period at the Dalby and Wacol piggeries, the sludge deposited on the base of the pond and settling tank, respectively, did not appear to form a hard, dense layer and it was possible to push the tee-bar to the original base on all occasions when measurements were taken. The manually operated tee bar was not sufficiently sensitive to accurately detect the top of the sludge layer. This highlighted the need to use the more sensitive nephelometer and sonar instruments, which generally suggested similar depths to the top of the sludge layer.

Effluent pond sludge accumulation rates are generally expressed as a volume of sludge deposited per kg of total solids entering the pond. As depicted in

Figure 44 and Figure 45, following initial higher rates of sludge accumulation, the highly loaded pond and tank at the Dalby and Wacol piggeries, respectively, showed sludge accumulation rates similar to, or less than 0.00303 m^3/kg TS which is the rate suggested by Barth (1985) for the design of anaerobic piggery effluent ponds. At the Dalby piggery, the most recent sludge accumulation rates were less than 0.001 m^3/kg TS, which were significantly lower than the rate suggested by Barth (1985).

The initial high rate of sludge accumulation at the Dalby piggery (0.014 m^3/kg TS) may have been due to the release of effluent from secondary pond 3 into the highly loaded pond, to speed up the filling process. This pond appeared to be reasonably heavily loaded with sludge at that time and this may have resulted in the transfer of significant quantities of solids with the effluent. Alternatively, the anaerobic treatment capacity of the highly loaded pond may have taken some time develop, with the growth of the anaerobic bacteria population.

The decrease in the rate of solids accumulation on the base of the highly loaded pond at the Dalby piggery appeared to coincide with the start of stage 2 of the project, when the pond loading rate increased from 0.54 to 0.88 kg VS/m^3/day. This also coincided with the development of a thick crust on the pond surface and a reduction in the pond outflow solids concentration. This suggests that some of the solids that were previously accumulating on the base of the pond were now accumulating on the pond surface in the form of a crust. The development of the crust may have been influenced by the inability of the bacterial population to effectively break down the increasing load of organic material, in addition to a possible increase in anaerobic activity resulting in more bubbles of methane and carbon dioxide transporting fibrous material to the surface of the pond.

Effluent from sheds 1, 2 and 3 was introduced into the highly loaded pond during stage 2 of the project. Sheds 2 and 3 housed different classes of pigs (dry sows, lactating sows, boars, weaners and piglets) fed on different diets in comparison to the grower and finisher pigs contributing effluent to the pond during stage 1. The predominant grain in the grower and finisher diets was sorghum while the dry sows, lactating sows and weaners were fed higher percentages of barley and wheat. The different diets may have influenced the nature of the effluent in terms of its tendency to form a thick crust.

At the conclusion of the project, the level of solids accumulation in both the highly loaded pond at the Dalby piggery and the tank at the Wacol piggery did not appear to be having any detrimental effect on their performance, in terms of solids reduction. There were also no perceivable increases in the solids concentrations of the pond and tank outflows. This suggested that there was no apparent need to desludge either of the facilities at that point in time. In the case of the Dalby piggery, it is recommended that the total and volatile solids (TS and VS) concentrations of the effluent being discharged from the highly loaded primary pond should be monitored at six monthly intervals, to determine whether the pond is still performing satisfactorily in terms of removing solids from the piggery waste stream. These measurements should be used to determine the need for desludging the highly loaded primary pond.

The nephelometer and sonar fish finder proved to be useful tools for objectively detecting sludge levels in the highly loaded pond. In comparison to manual probing using a tee-bar, these instruments provided more precise depths to changes in the density and turbidity (light transmission qualities) of the stored effluent. The depth to the top of the denser layer detected using the sonar fish finder was very similar to the depth where a significant change in turbidity was detected using the nephelometer.

Some difficulties were experienced in using the sonar fish finder after the formation of the thick crust (> 1m thick) on the highly loaded pond. The mounting bracket on the sonar sensor was not long enough to successfully position the sensor below the bottom of the crust layer. This could be remedied by manufacturing a longer extension shaft incorporating a protective housing to enable the sensor to be pushed through the crust layer without damaging the sensor. After the formation of the thick crust, it became difficult to manually dig a hole through the crust to enable sludge accumulation measurement, as the hole tended to collapse.

The sonar fish finder worked effectively at the DPI&F Wacol piggery, where it was permanently fixed to the top of the settling tank, and the crust thickness did not exceed approximately 50 mm.

4.3 Piggery Solids Balance

The total estimated mass of the gaseous emissions of methane, the carbon content of the carbon dioxide, and ammonia is 58,429 kg less than the gaseous emissions derived from the solids mass balance, however, this shortfall only represents 18% of the mass of the estimated gaseous emissions or 4% of the total solids entering the pond. Given the uncertainty in many of the factors used in estimating the gaseous emissions and in the mass balance process in general, this appears to be a reasonable result.

It is also worthy of note that the total and volatile solids in the gaseous emissions estimated using the mass balance process are very similar. This is to be expected as all gaseous emissions must be derived from the volatile solids component of the total solids, as the fixed solids cannot be volatilised by definition.

In summary, the solids balance suggests that:

- The highly loaded pond at the Dalby piggery removed approximately 52% the TS entering the pond over the 22 month trial period. Approximately 20% of the incoming TS was stored in the pond while the remaining 32% was emitted in a gaseous form. Methane accounted for 57% of the mass of the gaseous emissions.
- The highly loaded pond at the Dalby piggery removed approximately 67% the VS entering the pond. Approximately 21% of the incoming VS was stored in the pond while the remaining 46% was emitted in a gaseous form.

4.4 Odour Emission from Highly Loaded Pond

As outlined in Table 36, odour emissions from the highly loaded primary pond were relatively low following the establishment of a thick crust during the second stage of the research project. The range of emission rates recorded during this project was within the range measured previously by Hudson *et al.* (2004) at seven southern Queensland piggeries over three seasons (APL Project 1628) [1.7 – 83.9 OU/m^2/s].

The emission rates recorded for the crusted pond surface also compare favourably with the emission rates suggested by the APL VEF Maker software, (Pacific Air and Environment, 2004), i.e. 9 (summer) to 19 (winter) OU/m^2/s, for a loading rate determined using the Rational Design Standard (Barth, 1985) (91 g VS/m^3/day) for the Dalby area.

When comparing measured odour emissions from the highly loaded primary pond with likely emissions from an anaerobic pond designed according to the RDS, because the surface area of the RDS pond would be more than six times larger than that of the highly loaded pond, the overall odour emission from the highly loaded pond would be less, even if the maximum emission rate measured during the research project is assumed. This comparison is outlined in Table 42.

Table 42: Comparison of measured odour emissions from the highly loaded pond versus potential emissions from an anaerobic pond designed using the Rational Design Standard.

	Rational design standard	Highly loaded pond
Pig population (SPU)	5022	5022
Pond storage volume (ML)	22.1 [a]	2.1
Pond surface area (m^2)	6304	1007
Odour emission rate ($OU/m^2/s$)	9 — 19 (APL VEF maker)	1 — 74 (measured)
Total odour emission (OU/s)	56,736 — 119,776	1,007 — 74,518

[a] Pond volume based on 5 year desludging interval.

The results of this project appear to support the hypothesis that naturally formed pond crusts significantly reduce odour emissions from highly loaded anaerobic ponds.

When this project was developed, it was not specifically intended to carry out a comprehensive study of odour emissions using the non-specific gas sensor array system. However, it was possible to carry out limited analyses of samples collected for olfactometry analysis using this technology. Based on a limited number of samples, it was demonstrated that the non-specific gas sensor array system successfully discriminated between piggery effluent pond odours and another livestock odour (*i.e.* poultry odour); and crusted and non-crusted pond surface odour samples.

While there were insufficient samples available for the development of an odour prediction model, the results from the gas sensor array system indicated that the odour concentrations of the crusted pond surface samples were lower than those of the un-crusted pond odour samples. These results were confirmed by olfactometry measurement.

4.5 Piggery Waste Estimation

The waste output values determined using the PIGBAL model, the DPI&F Piggery assessment spreadsheet and the adjusted average sampled values are summarised in Table 43.

In the case of the Dalby piggery results, the adjusted sampled values of TS and VS were in relatively close agreement with the values estimated using the PIGBAL model for the entire piggery. However, the values predicted using the DPI&F Piggery assessment spreadsheet were at least 24% and 28% lower than the sampled TS and VS values, respectively. Furthermore, while there was reasonable agreement between the values determined by the three methods for sheds 2, 4 and 5, there were discrepancies between the values determined for sheds 1 and 3.

Table 43: Summary of annual waste output values (kg/SPU/year) for the Dalby and Wacol piggeries, determined using the PIGBAL model, the DPI&F Piggery assessment spreadsheet and by adjusting the sampled values.

Source	Dalby		Wacol	
	TS	VS	TS	VS
PIGBAL	135	117	135	113
DPI&F Piggery assessment spreadsheet	110	91	110	91
Adjusted sampled values	144	127	96	82

Some possible explanations for these discrepancies include:

- The feed usage data supplied by the piggery owners was based on the number of mixes prepared weekly. While the overall tonnage of feed used appeared to be approximately in line with the PIGBAL default values, the distribution of feed rations between the various pig classes and sheds may not have been sufficiently accurate.
- The distribution of pig classes between the various sheds may not have been accurate. For example, inaccurate assumptions regarding the weight and age that weaner pigs are moved from shed 2 to shed 1 in the Dalby piggery may have affected the distribution of SPU between the sheds.
- The degree of feed wastage can significantly influence the sampled effluent values.

In the case of the DPI&F Wacol piggery, the TS and VS values predicted by the PIGBAL model and the DPI&F Piggery assessment spreadsheet were in relatively close agreement with the values predicted for the Dalby piggery; however, the adjusted sampled values were significantly lower.

The DPI&F Piggery assessment spreadsheet uses standard waste generation rates per SPU derived from PIGBAL modelling based on standard dietary, feed intake and feed wastage values. The discrepancies between the DPI&F Piggery assessment spreadsheet and PIGBAL estimates suggest differences in assumed diets and feed intakes between the modelled piggery scenario and the standard data used to derive the values adopted in the DPI&F Piggery assessment spreadsheet.

5. Conclusions

The solids reduction performance of the highly loaded primary pond at the Dalby piggery was within the range normally expected for anaerobic lagoons used to treat intensive livestock effluent. Similar results were obtained for the settling tank at the DPI&F Wacol piggery. Based on these results and previous findings of Payne *et al.* (1995) and Skerman and Collman (2006), it is anticipated that volatile solids removal rates in excess of 70% will be achievable in most piggery effluent systems employing suitably designed and managed highly loaded ponds. In this regard, highly loaded primary ponds appear to perform similarly to much larger ponds designed to operate at lower loading rates, in accordance with the Rational Design Standard (Barth, 1985).

The rate of sludge accumulation on the base of highly loaded ponds appears to be less than the rate suggested by Barth (1985). However, heavy crusting is likely to occur on ponds when loading rates exceed approximately 0.6 kg VS/m^3/day. This crust formation appears to be caused by the inability of the bacterial population to break down solids in the pond influent, in conjunction with an increase in anaerobic decomposition causing bubbles of methane and carbon dioxide to convey fibrous organic material to the pond surface.

The nephelometer and sonar fish finder proved to be useful tools for objectively detecting sludge levels in the highly loaded pond. They offer greatly improved sensitivity to changes in density within the effluent storage profile compared to manual probing using a graduated tee-bar. Special provisions are likely to be required to use these instruments in ponds that have developed thick surface crusts.

After 22 months of operation at loading rates ranging from 0.5 to 0.9 kg VS/m^3/day, the highly loaded primary pond at the Dalby piggery was performing satisfactorily in terms of solids reduction and odour emission, and therefore did not appear to require desludging at the end of the trial period. Monitoring of the TS and VS concentrations in the pond outflow is recommended as the main criterion for determining the need for future pond desludging.

A solids mass balance successfully accounted for all but 4% of the total solids in the inflow to the highly loaded pond at the Dalby piggery over the 22 month trial period. While it is acknowledged that some of the estimates used in the solids balance were approximate only, the solids balance suggested that the highly loaded pond removed approximately 52% of the TS entering the pond. Approximately 20% of the incoming TS was stored in the pond while the remaining 32% was emitted in gaseous forms. It was estimated that methane accounted for 57% of the mass of the gaseous emissions.

The highly loaded pond removed approximately 67% of the VS entering the pond. Approximately 21% of the incoming VS was stored in the pond while the remaining 46% was emitted in gaseous forms.

The odour emission rates recorded from the highly loaded primary pond at the Dalby piggery were within the range measured previously by Hudson *et al.* (2004) at seven southern Queensland piggeries over three seasons (APL Project 1628). However, following the establishment of a thick crust during the second stage of the project, the emissions from the highly loaded primary pond were generally less than the minimum emission rates recorded by Hudson *et al.* (2004) on the majority of their sampling days. The emission rates recorded for the heavily crusted pond surface were also significantly less than the emission rates suggested by the APL VEF Maker software (Pacific Air and Environment, 2004), for loading rates determined using the Rational Design Standard (RDS) for the Dalby area. These emission rates are commonly used for odour dispersion modelling carried out to support applications for new and expanding piggery developments.

When the anticipated lower odour emission rates are considered in conjunction with the significantly smaller surface area emitting odour, overall odour emissions from highly loaded ponds where thick crusts have been established are expected to be significantly lower than for conventional ponds designed according to the RDS. Even on ponds where thick crusts have not established, overall odour emissions are still expected to be lower than for conventional ponds designed according to the RDS, due to the effect of the reduced surface area.

Based on a limited number of samples, the non-specific gas sensor array system successfully discriminated between piggery effluent pond odours and another livestock odour (*i.e.* poultry odour); and crusted and non-crusted pond surface odour samples. While there were insufficient samples available for the development of an odour prediction model, the results from the gas sensor array system indicated that the odour concentrations of the crusted pond surface samples were lower than those of the un-crusted pond odour samples. These results were supported by olfactometry measurement.

In comparison to the adjusted sampled values, the PIGBAL model under-predicted the TS and VS generated by the Dalby piggery by 6% and 8%, respectively, while it over-predicted the TS and VS from the Wacol piggery by 41% and 38%, respectively.

Similarly, the DPI&F Piggery assessment spreadsheet under-predicted the TS and VS generation at the Dalby piggery by 24% and 28%, respectively, while it over-predicted the TS and VS from the Wacol piggery by 14% and 10%, respectively.

While these results suggest that both tools give reasonable predictions of piggery waste output, accurate recording of pig feed intakes, dietary ingredients, pig numbers and pig weights would be required to enable more comprehensive assessments of their performance. The issue of feed wastage would be difficult to address, even in a more controlled environment.

In general, highly loaded primary ponds appear to be a viable alternative piggery waste management system. In comparison to conventional effluent ponds, highly loaded ponds have the following potential benefits:

- Reduced earthworks costs due to smaller storage volume.
- Easier and less expensive to line to minimise the risk of seepage of contaminants into underlying groundwater resources.
- Easier and less expensive to cover to reduce odour and greenhouse gas emissions, or to capture methane for productive use.
- Greater ease and reduced cost of effluent solids removal (desludging).
- More regular and effective utilisation of the valuable nutrient and soil amendment values of piggery solids, resulting in reduced fertiliser costs and healthier soils, respectively.
- Lower odour emissions due to significantly reduced pond surface area and crusting on the pond surface.
- Potential to establish or expand piggeries at sites limited by separation distance to sensitive receptors.

Draft recommendations for the design and management of highly loaded ponds are attached in Appendix 3.

Implications for Industry

Before highly loaded ponds can be widely adopted at new and expanding piggeries throughout Australia, the relevant state regulatory agencies will have to formally accept the legitimacy and value of this significant departure from conventional design standards. APL representatives have expressed enthusiasm for the widespread adoption of this new technology. At the request of APL, the draft recommendations for the design and management of highly loaded ponds provided in Appendix 3, have been forwarded to the consultants preparing the revised National Environmental Guidelines for Piggeries (Tucker *et al*, 2006), for incorporation in the revised edition.

Officers of the DPI&F Intensive Livestock Environmental Regulation Unit (ILERU) who are responsible for the regulation of the environmental aspects of piggery developments in Queensland, have been kept informed regarding progress with this project since its commencement. These officers appear to be supportive of this alternative design approach. They have already suggested to some producers that highly loaded ponds could provide a viable option in certain circumstances and have referred the producers to the Principal Investigator of this project for further information.

It is intended to publish the results of this project in a reputable, peer reviewed journal to further enhance the credibility of the project outcomes and the resulting alternative effluent pond design concept.

6. References

Barth, C. L. (1985). *The Rational Design Standard for Anaerobic Livestock Lagoons*. Proceedings of the 5th International Symposium on Livestock Wastes, ASAE, 638-647

Birchall, S., Dillon, C. and Wrigley, R. (2008). Draft: Dairy Effluent and Manure Management Database for the Australian Dairy Industry, Dairy Australia, Project No DAN 11806

Bliss, P.; Jiang, K.; Schulz, T. (1995). *The development of a sampling system for the determination of odor emission rates from areal surfaces: Part II. Mathematical model*, Journal of Air & Waste Management Association 1995, 45, 989-994.

Casey, K.D., McGahan, E.J., Atzeni, M.A. Gardner, E.A. & Frizzo, R.E. (1996). *PIGBAL; A nutrient balance model for intensive piggeries*. Queensland Department of Primary Industries. (Version 3.1, 2003).

Casey, K. D. (2004). *Anaerobic ponds, piggery waste management*, DPI&F Note, Department of Primary Industries and Fisheries, Toowoomba, Qld.

Corbitt, R. A. (ed.) (1990), *Standard handbook of environmental engineering*, McGraw-Hill Inc, ISBN 0-07-013158-9.

Department of Primary Industries and Fisheries (2008). *Rainman,* version 4.3, Streamflow professional edition, Rainfall and streamflow information for better management, Computer software, DPI&F Publications, Brisbane, Qld.

Funk, T., Bartzis, G. and Treagust, J. (1993). *Designing and Managing Livestock Waste Lagoons in Illinois*. University of Illinois at Urbana-Champaign. College of Agriculture. Cooperative Extension Service. Circular 1326, available on-line: http://www.aces.uiuc.edu/vista/html_pubs/LAGOON/lagoon.html

Greenberg, A.E., Clesceri, L.S. and Eaton, A.D. (eds.) (1992). *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, Washington.

Hudson, N., Bell, K., McGahan, E., Lowe, S., Galvin, G., and Casey, K. (2007b). *Odour emissions from anaerobic piggery ponds. 2: Improving estimates of emission rate through recognition of spatial variability*, *Bioresource Technology*. **98:** 1888–1897.

Hudson, N., Duperouzel, D., Dunlop, M., Collman, G. and Gallagher, E. (2007). *Assessing the medium-term impact of permeable pond covers on pond performance and odour management*. Final report for Australian Pork Limited, Project 1829. Department of Primary Industries & Fisheries, Toowoomba, Queensland.

Hudson, N., Galvin, G. and Lowe, S. (2004). *The effect of loading rate and spatial variability on pond odour emission*, Final report for Australian Pork Limited, Project 1628. Department of Primary Industries & Fisheries, Toowoomba, Queensland, Australia.

Hudson, N., McGahan, E., Casey, K., Lowe, S., Galvin, G., Jeston, P. and Dunlop, M. (2007a). *Odour emissions from anaerobic piggery ponds. 1. Results of a three season, 14-month survey*, *Bioresource Technology*. **98:** 1877–1887.

Jiang, K., Bliss, P. and Schulz, T. (1995). *The development of a sampling system for determining odor emission rates from areal surfaces*: Part I. Aerodynamic performance. Journal of Air & Waste Management Association 45 917-922.

Jiang, K.; Bliss, P.; Schulz, T. (1995). *The development of a sampling system for determining odor emission rates from areal surfaces: Part I. Aerodynamic performance*, Journal of Air & Waste Management Association 1995, 45, 917-922.

Kruger, I., Taylor, G and Ferrier, M. (compiled and edited by) (1995). *Effluent at work*, Australian pig housing series, NSW Agriculture, Tamworth NSW.

Misselbrook, T. H., Siobhan, K. E., Brookman, K. A., Smith, T. C., Williams, A. G. and McCrory, D. F. (2005). *Crusting of stored dairy slurry to abate ammonia emissions: pilot-scale studies*, Journal of Environmental Quality, Mar/Apr 2005; 34, 2; ProQuest Agriculture Journals, p 411.

National Greenhouse Gas Inventory Committee (2006). *Australian methodology for the emission of greenhouse gas emissions and sinks 2005; Agriculture*, Australian Greenhouse Office.

Pacific Air and Environment (2004), *Variable emissions file (VEF) maker*, version 1, Computer software developed for Australian Pork Limited, Canberra, ACT.
Payne, R. W., Navarro, L., Davies, E. M. and Brough, C. (1995) *Formation and composition of sludges in piggery waste water treatment ponds*, A Report to the Pig Research and Development Corporation (PRDC), Project No. DAW 29 P, Department of Agriculture, Western Australia.
Pollock, T. J. (1997). *Proceedings of the National Workshop on Odour Measurement Standardisation;* UNSW: Sydney Australia, 1997; pp 95-104.
SA EPA (1998). *Guidelines for Establishment of Intensive Piggeries in South Australia*, South Australia Environmental Protection Agency, available on line: http://www.epa.sa.gov.au/pdfs/pigguide.pdf
Shatte, T. L. (2000a). *Procedure – total solids analysis*, Department of Primary Industries, Intensive Livestock Environmental Management Services, Toowoomba, Qld, ILEMS-PROC-01-28.
Shatte, T. L. (2000b). *Procedure – volatile solids analysis*, Department of Primary Industries (DPI), Intensive Livestock Environmental Management Services (ILEMS), Toowoomba, Qld, ILEMS-PROC-01-29.
Skerman, A. and Collman, G. (2006). *Evaluation of piggery effluent solids separation methods*, Final report to Australian Pork Limited, Project 1800.61, Department of Primary Industries & Fisheries, Toowoomba, Queensland.
Skerman, A. G. (2004). *Piggery Assessment Spreadsheet*, Version 10C, Department of Primary Industries and Fisheries (DPI&F) QZ03013.
Skerman, A. G., Redding, M. and McLean, D. (2002). *Clay Lining and Compaction of Effluent Ponds*, DPI Note, DPI Intensive Livestock Systems Unit, Toowoomba, Qld.
Smith, R.; Watts, P. (1994). *Determination of odour emission rates from cattle feedlots: Part 1, A review,* Journal of Agricultural Engineering Research 1994, 57, 145-155.
Sohn, J. H., Atzeni, M., Zeller, L. and Pioggia, G. (2008). *Characterisation of Humidity Dependence of a Metal Oxide Semiconductor Sensor Array using Partial Least Squares*, *Sensor & Actuators B*, 131(1), 230-235
Standards Australia and Standards New Zealand (2001). Stationary source emissions. Part 3: *Determination of odour concentration by dynamic olfactometry*. AS/NZS 4323.3:2001, Standards Australia: Strathfield, New South Wales.
Tucker, R.W., McGahan, E.J., Nicholas, P.J. and Howard, M.R. (2006). *National Environmental Guidelines for Piggeries*, (Australian Pork Limited, Deakin, ACT, 2600).
Wang, X, Jiang, J. and Kaye, R. (2001). *Improvement of wind tunnel sampling system for odour and VOC's.* 147-154 p. 1st IWA International Conference on Odour and VOCs: Measurement, Regulation and Control Techniques, University of New South Wales, Sydney.
Wölfel, M. and Ekenel, H. K. (2005). *Feature weighted Mahalanobis distance: Improved robustness for Gaussian classifiers*, *13th European Signal Processing conference EUSIPCO2006,* Antalya, Turkey, September 2005

Appendix I

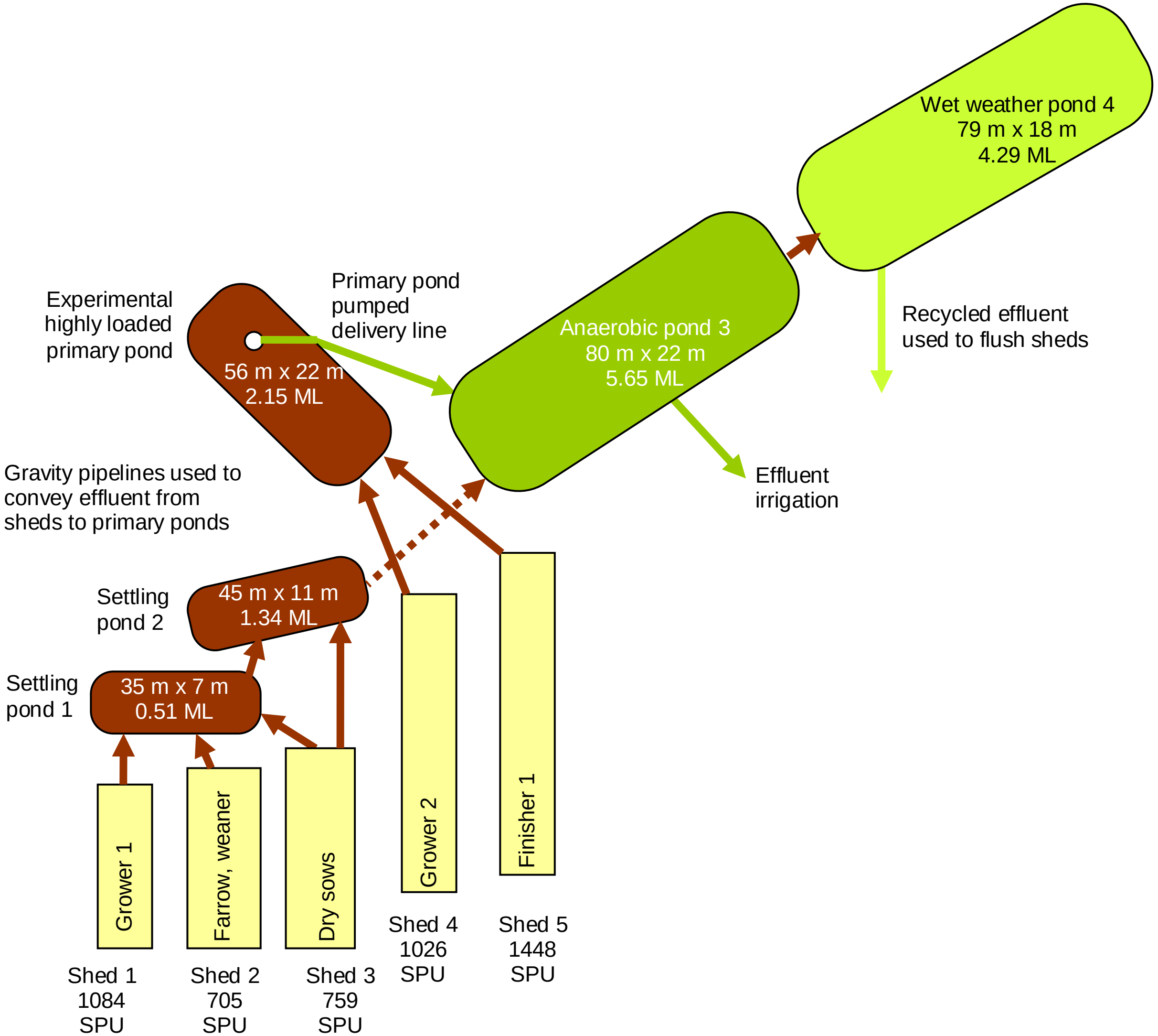


Figure 1: Schematic diagram of Dalby piggery for Stage 1 trials.

Appendix 2

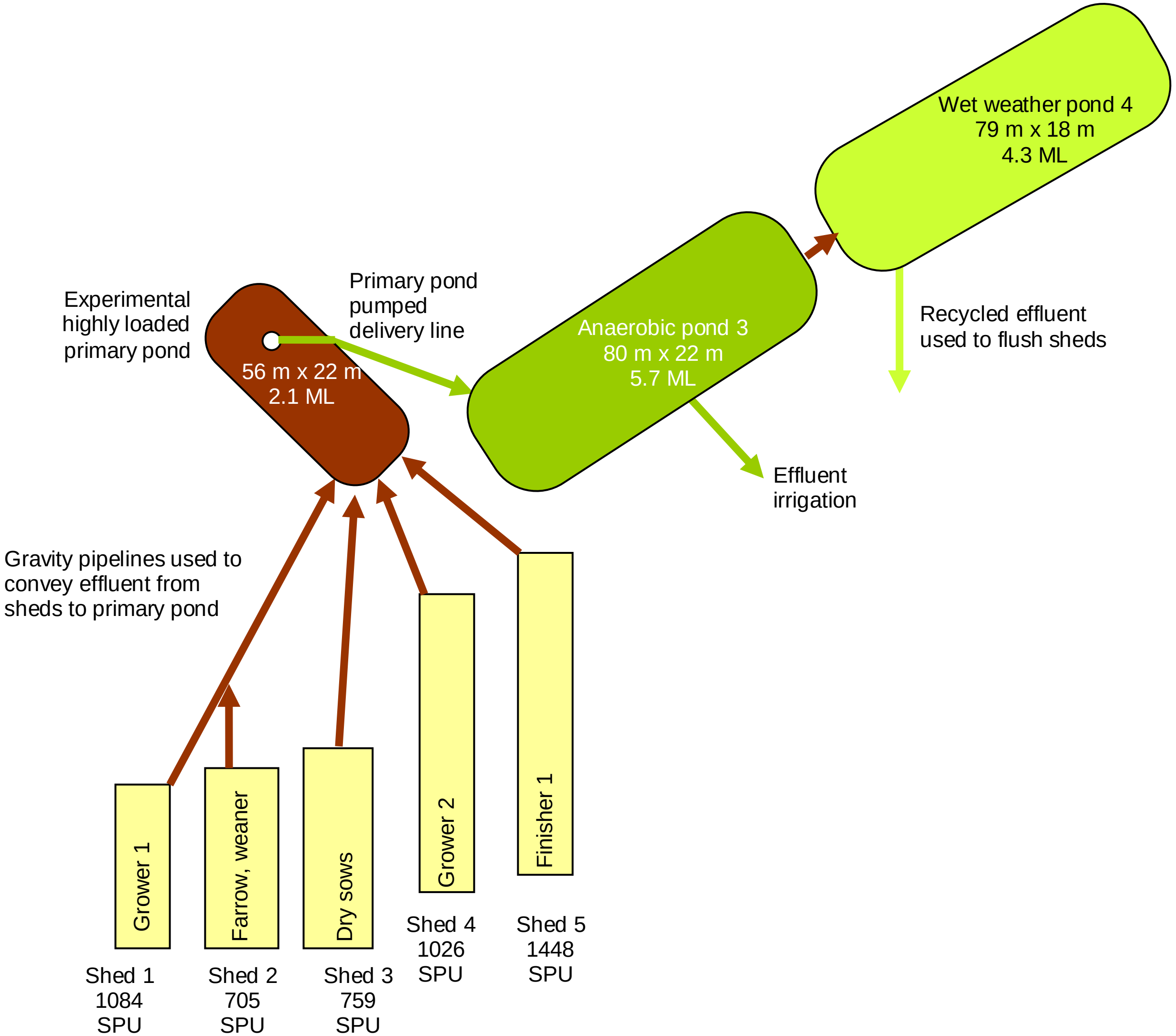


Figure 1: Schematic diagram of Dalby piggery for Stage 2 trials.

Appendix 3 - Draft Recommendations for the Design and Management of Highly Loaded Primary Ponds Used for the Treatment of Piggery Effluent

Alan Skerman, Principal Environmental Engineer,
Department of Primary Industries and Fisheries, Toowoomba, Qld

1. Background

The Rational Design Standard (RDS) (Barth, 1985) is commonly used throughout Australia for designing anaerobic ponds used to treat the effluent discharged from conventional piggery sheds. Application of the RDS results in relatively large anaerobic pond volumes. While ponds designed using the RDS generally perform satisfactorily over their design lifespans, because of their large storage volumes, they are difficult and expensive to desludge and may emit high levels of odour over their relatively large surface areas.

Limited scientific and anecdotal evidence suggested that smaller ponds (loaded at a higher rate) performed at least as well as larger ponds designed using the RDS. To investigate these perceptions more thoroughly, Skerman *et al* (2008) carried out trials on a commercial piggery pond constructed based on a design loading rate approximately 6 to 10 times the rate determined using the RDS. The commercial piggery trials were complemented with additional trials on a highly loaded settling tank installed at the DPI&F Wacol piggery.

The trial results suggest that suitably designed and managed highly loaded ponds:

- Perform similarly to larger ponds designed according to the RDS in terms of effluent treatment, reducing volatile solids in the pond inflow from piggery sheds by at least 70%.
- Accumulate sludge at rates less than the rate suggested by Barth (1985) for ponds designed according to the RDS.
- Develop heavy surface crusting when loading rates exceed approximately 0.6 kg VS/m^3/day.
- Emit lower levels of offensive odours due to the significantly reduced surface areas and lower emission rates from heavily crusted pond surfaces.

In comparison to conventional effluent ponds, highly loaded ponds have the following potential benefits:

- Reduced earthworks costs due to smaller storage volume.
- Smaller areal footprint, occupying less potentially valuable land.
- Easier and less expensive lining to minimise the risk of seepage of contaminants into underlying groundwater resources.
- Easier and less expensive covering to reduce odour and greenhouse gas emissions, or to capture methane for productive use (e.g. shed heating or power generation).
- Greater ease and reduced cost of effluent solids removal (desludging).
- More effective utilisation of the valuable nutrient and soil amendment values of piggery solids, resulting in reduced fertiliser costs and healthier soils, respectively.
- Lower odour emissions due to reduced pond surface area and the development of a crust on the pond surface.
- Potential to establish or expand piggeries at sites limited by separation distance to sensitive receptors.

In general, highly loaded primary ponds appear to represent a viable alternative to conventional piggery waste management systems. Subject to approval by the relevant regulatory authorities, it is recommended that these ponds should be designed and managed according to the following recommendations.

2. Pond Loading Rate and Storage Volume

It is recommended that the highly loaded primary pond storage volume be calculated using a baseline volatile solids (VS) loading rate of 0.75 kg VS/m^3/day. The baseline loading rate is multiplied by the climate dependent anaerobic activity ratio (k) to determine the adjusted loading rate. Table 1 in the Appendix provides values of the anaerobic activity ratio (k) for a range of localities in Queensland.

Assuming a VS generation rate of 90.91 kg VS/SPU/year (0.25 kg VS/SPU/day) entering the pond (based on PIGBAL (Casey *et al*, 1996) modelling), the following equation can be used to calculate the required pond storage volume:

$$\text{Pond storage volume (m}^3\text{)} = \frac{\text{Pig population (SPU)} \times 0.25 \text{ (kg VS/SPU/day)}}{0.75 \text{ (kg VS/m}^3\text{/day)} \times k}$$

Table 1 provides anaerobic activity ratios, adjusted loading rates and recommended storage volumes for highly loaded primary ponds located within three broad climatic categories found in Australia. As suggested by Tucker *et al.* (2004), examples of regions and localities within these three climatic categories are provided below the table. More specific anaerobic activity ratios for various localities are provided by Kruger *et al.* (1995) and Casey (2004).

Table 1: Anaerobic activity ratios, adjusted loading rates and recommended storage volumes for highly loaded primary ponds located in three climatic categories within Australia.

Climate	Units	Hot[1]	Warm[2]	Cool[3]
Anaerobic activity ratio (k)		1.00	0.80	0.60
Adjusted loading rate	kg VS/m^3/day	0.75	0.60	0.45
Pond storage volume	m^3/SPU	0.3319	0.4148	0.5531

[1]Examples of hot climates: Central and north Qld, Moree (NSW) and Goondiwindi (Qld)
[2]Examples of warm climates: Most of inland NSW, south-east Qld (Darling Downs and Burnett), SA and southern WA
[3]Examples of cool climates: Armidale (NSW), southern & central Vic, southern SA and Tas.
Based on Tucker *et al.* (2004).

Figure 1 is a nomograph for determining recommended pond storage volumes based on the number of pigs generating effluent for a range of anaerobic activity ratios representing the three climatic categories outlined above. It should be noted that the recommended pond storage volumes do not include any additional allowance for the storage of sludge. The results of APL Project 2108 suggest that highly loaded ponds continue to operate satisfactorily at the recommended loading rate despite the ongoing accumulation of settled sludge on the base of the pond.

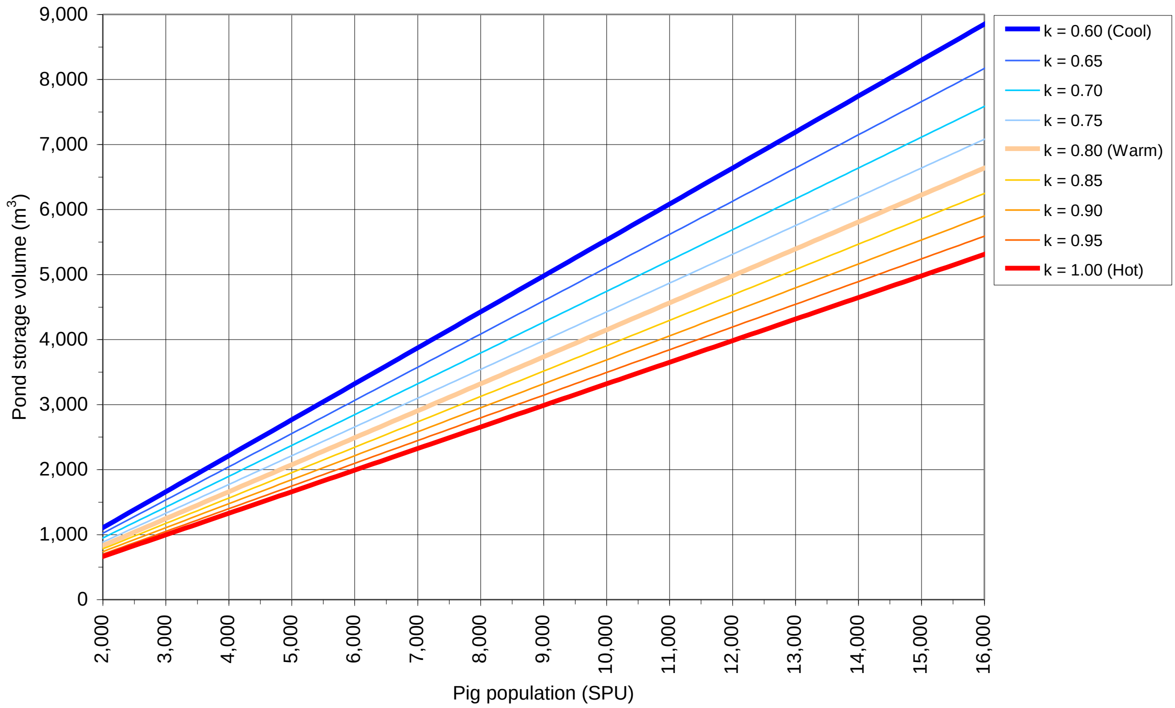


Figure1: Nomograph for determining recommended pond storage volume based on the pig population contributing effluent to the pond for three broad climatic categories.

3. Pond Dimensions

To maximise the ease and practicality of sludge removal, it is important to keep highly loaded primary ponds as narrow as possible. The minimum width of the base of the pond is generally limited to the width of the machinery used to construct the pond. This is typically approximately 3 m. The pond batters extending from the base to the top water level of the pond should be as steep as possible without compromising the structural stability of the pond. It is generally recommended that pond batters should not be constructed any steeper than 1 vertical : 2 horizontal (26.6˚ from horizontal). In some soil types, flatter batters may be required to avoid pond failure due to slumping of the sides.

It is anticipated that the majority of highly loaded ponds will be constructed using a scraper. If this is the case, the end batters may be flattened to 1 vertical: 4 horizontal (14.04˚ to horizontal) to allow the scraper to drive into and out of the ends of the excavation during pond construction.

Pond depths are typically 4 to 5 m to enhance anaerobic decomposition while limiting the pond surface area.

Table 2 provides suggested dimensions for highly loaded ponds having storage depths ranging from 4.0 to 5.0 m. The required pond lengths can be interpolated from the nomographs provided in Figure 3, Figure 4 and Figure 5. It is anticipated that ponds will generally be restricted to a maximum length of approximately 100 to 150 m. Multiple highly loaded ponds could be used for larger piggeries requiring ponds with greater storage capacity.

Table 2: Suggested dimensions for highly loaded ponds, for three pond storage depths ranging from 4 m to 5 m.

Pond storage depth	m	D	4.0	4.5	5.0
Freeboard	m	F	0.5	0.5	0.5
Pond width at base	m	W_B	3.0	3.0	3.0
Pond width at TWL	m	W_{TWL}	19.0	21.0	23.0
Pond width at bank crest	m	W_C	21.0	23.0	25.0
Pond length at TWL [1]	m	L_{TWL}	$\frac{7.542 \times N}{1000 \times k} + 12.12$ **Figure 3**	$\frac{6.146 \times N}{1000 \times k} + 13.50$ **Figure 4**	$\frac{5.106 \times N}{1000 \times k} + 14.87$ **Figure 5**
Pond length at base	m	L_B	$= L_{FSL}-16$	$= L_{FSL}-18$	$= L_{FSL}-20$
Pond length at bank crest	m	L_C	$= L_{FSL} + 4$	$= L_{FSL} + 4$	$= L_{FSL} + 4$

[1] The pond length at the top water level (L_{TWL}) can be calculated from the equations provided, where N = pig population (SPU) and k = anaerobic activity ratio, described in section 2. Alternatively, it can be interpolated from Figure 3, Figure 4 or Figure 5.

The dimensions outlined in the above table assumes 1 vertical : 2 horizontal width-wise batters on the longer pond sides and 1 vertical : 4 horizontal length-wise batters on the shorter ends of the pond.

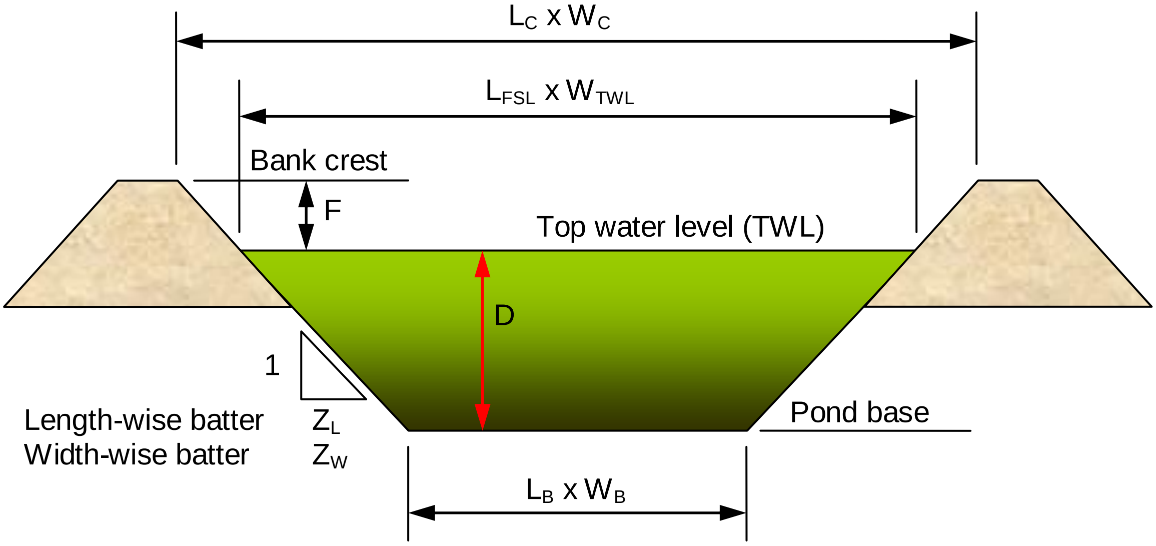


Figure 2: Schematic drawing of highly loaded pond showing the dimensions referred to in Table 2.

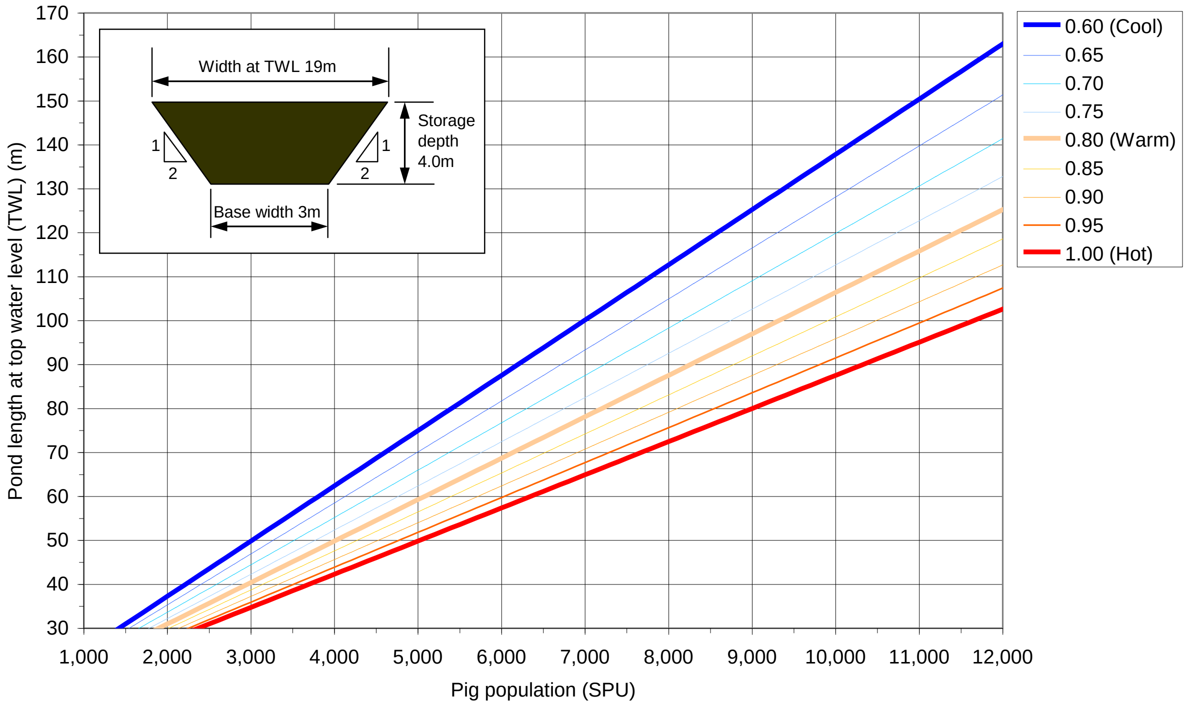


Figure 3: Nomograph for determining recommended pond length at top water level (TWL) for an effluent storage depth of 4.0 m.

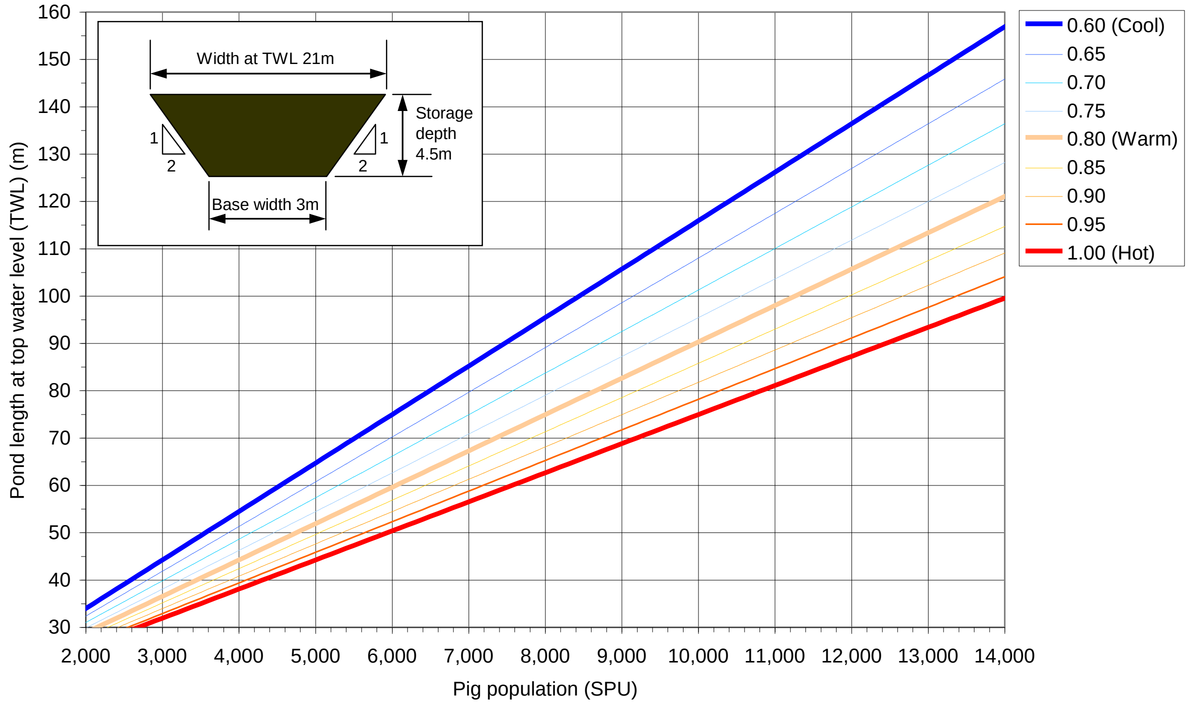


Figure 4: Nomograph for determining recommended pond length at top water level (TWL) for an effluent storage depth of 4.5 m.

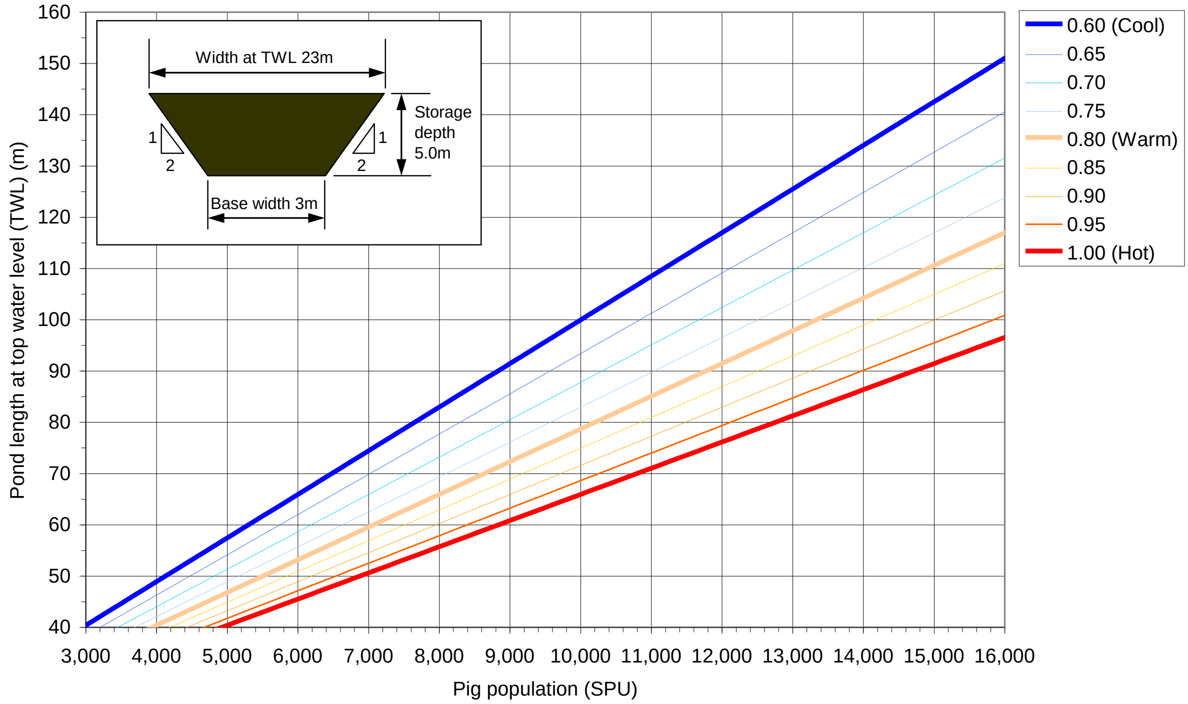


Figure 5: Nomograph for determining recommended pond length at top water level (TWL) for an effluent storage depth of 5.0 m.

4. Pond Permeability

It is important to ensure that effluent ponds are constructed with low permeability to minimise the risk of contaminants leaching through the base and batters of the pond, potentially resulting in the contamination of underlying groundwater resources.

To achieve the required high level of impermeability, it is recommended that the pond be constructed in accordance with the specifications provided in the DPI&F Note: *Clay Lining and Compaction of Effluent Ponds* (Skerman *et al*, 2002).

5. Pond Inlet and Outlet

It is recommended that all pipelines delivering effluent from piggery sheds to highly loaded ponds be designed for free outfall into the pond. This means that the pipeline invert at the point of entry into the pond should be above the top water level in the pond. If the pipeline enters the pond below the top water level, the thick crust which is likely to form on the highly loaded pond surface may obstruct the flow of effluent from the sheds causing pipeline blockages and possible ponding of effluent in the sheds.

It is recommended that gravity outlet pipelines conveying effluent from highly loaded primary ponds to wet weather storage (secondary) ponds be fitted with tees on the upstream end, as shown in Figure 6. This will prevent floating crust material from entering the outlet pipeline, potentially resulting in blockages and the transfer of solids into the secondary pond. It may be advisable to fit an extension onto the bottom of the tee to ensure that the overflow effluent is being drawn from beneath the surface crust.

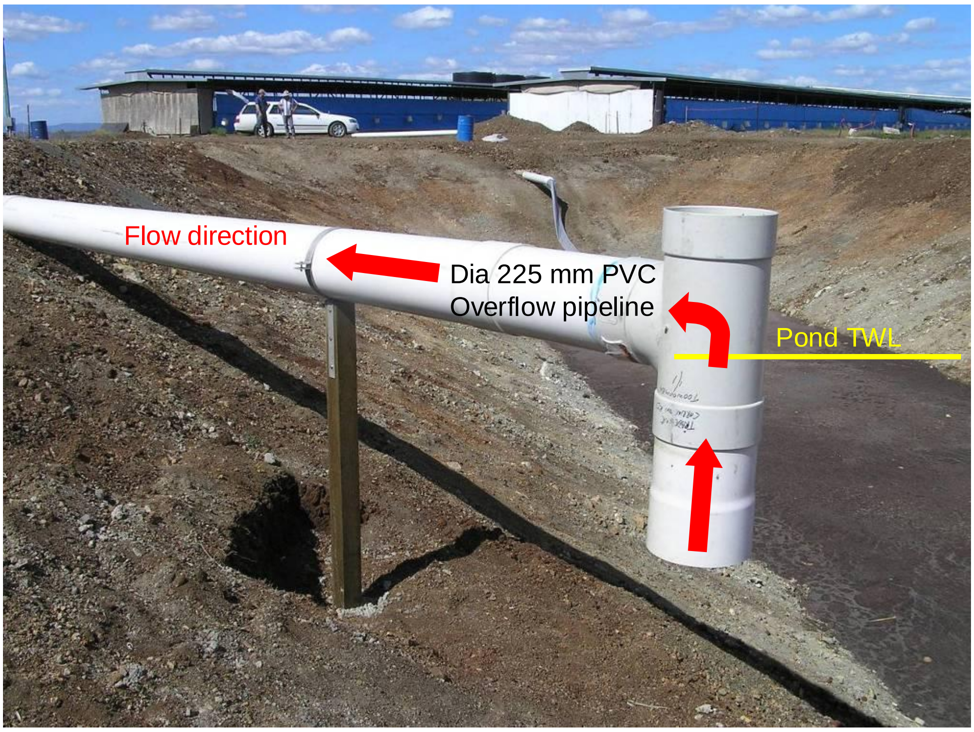


Figure 6: Gravity overflow pipeline from highly loaded primary pond to wet weather (secondary) pond showing tee used to prevent entry of floating surface crust material.

6. Pond Management

The main consideration required in managing a highly loaded pond is determining when to desludge the pond. Determining the depth to sludge by manual probing generally requires the use of a boat which may be difficult to manually pull through a heavily crusted pond and potentially dangerous for the operators. Furthermore, the findings of APL Project 2108 suggest that manual probing is not a sufficiently sensitive method for accurately determining the depth to sludge deposited in a pond. While other methods such as the use of a nephelometer or sonar depth sounder can be used for more accurately determining the depth to sludge, the most useful performance indicator for anaerobic pond function is the volatile solids (VS) concentration of the effluent discharged from the pond.

The results of APL Project 2108 showed that the volatile solids (VS) concentration in the effluent discharged from the highly loaded pond was generally less than 0.5%. It is suggested that samples of the effluent discharged from the highly loaded primary pond should be sampled regularly, for example, at six monthly intervals, and analysed for VS. If the VS exceeds 0.6%, a second sample should be collected and analysed to check the first result. If the second result exceeds 0.6%, it may indicate that the pond is not functioning effectively and/or that the pond sludge level is sufficiently high for sludge to enter the outlet pipeline or pump used to convey effluent into the secondary pond. In either case, pond desludging should be carried out.

7. Secondary Pond

It is recommended that effluent discharged from highly loaded ponds should be stored in a secondary pond prior to reuse as a shed flushing medium or irrigation onto crop or pasture. The secondary pond should be designed based on the water balance approach generally used for determining wet weather storage capacity. This involves ensuring that there is sufficient storage capacity to hold excess effluent following extreme rainfall events and during prolonged periods of wet weather when the soil in the effluent irrigation area remains too wet to commence irrigation without risking runoff or leaching of contaminants through the soil profile. Regulatory agencies generally require piggery developers to demonstrate that the proposed wet weather storage capacity is sufficient to limit pond spills to a frequency not exceeding 1 in 10 years, on average (subject to a range of site specific factors). Computer models such as MEDLI (Casey *et al*, 1996) and Waterbal (Skerman, 2001) can be used to carry out the required analysis, based on historical daily rainfall and evaporation data from a representative site near the piggery development.

8. References

Barth, C. L. (1985). *The Rational Design Standard for Anaerobic Livestock Lagoons*. Proceedings of the 5th International Symposium on Livestock Wastes, ASAE, 638-647

Casey, K. D. (2004). *Anaerobic ponds, piggery waste management*, DPI&F Note, Department of Primary Industries and Fisheries, Toowoomba, Qld.

Casey, K.D., McGahan, E.J., Atzeni, M.A. Gardner, E.A. & Frizzo, R.E. (1996). *PIGBAL; A nutrient balance model for intensive piggeries*. Queensland Department of Primary Industries. (Version 3.1, 2003).

Kruger, I., Taylor, G and Ferrier, M. (compiled and edited by) (1995). *Effluent at work*, Australian pig housing series, NSW Agriculture, Tamworth NSW.

Skerman, A. G. (2001). *Waterbal - Daily Water Balance Model for Intensive Livestock Industries*, Department of Primary Industries and Fisheries, Intensive Livestock Systems Unit, Toowoomba.

Skerman, A., Collman, G., Duperouzel, D., Sohn, J., Atzeni, M. and Kelly, A. (2008). *Improved piggery effluent management systems incorporating highly loaded primary ponds,* Final report to Australian Pork Limited (APL), Project 2108, Department of Primary Industries and Fisheries (DPI&F), Toowoomba, Queensland.

Skerman, A. G., Redding, M. and McLean, D. (2002). *Clay Lining and Compaction of Effluent Ponds*, DPI Note, DPI Intensive Livestock Systems Unit, Toowoomba, Qld.

Tucker, R.W., McGahan, E.J., Nicholas, P.J. and Howard, M.R. (2006). *National Environmental Guidelines for Piggeries*, (Australian Pork Limited, Deakin, ACT, 2600).

Appendix

Table 1: Anaerobic activity ratios (k values) for a range of localities in Queensland, based on Casey (2004) and Kruger *et al* (1995).

Locality	k value
Atherton	0.98
Ayr	1.18
Beaudesert	0.94
Biloela	0.98
Bollon	1.00
Bowen	1.21
Brisbane	1.00
Bundaberg	1.04
Cairns	1.24
Cambooya	0.79
Cardwell	1.16
Charleville	1.04
Charters Towers	1.18
Childers	1.04
Clermont	1.09
Collinsville	1.13
Cooktown	1.30
Dalby	0.91
Emerald	1.11
Gatton	0.96
Gayndah	1.00
Gladstone	1.09
Goondiwindi	0.95
Gympie	0.98
Injune	0.93
Innisfail	1.17
Ipswich	0.99
Isisford	1.15
Killarney	0.76
Kingaroy	0.82
Mackay	1.09
Mareeba	1.13
Maryborough	1.04
Miles	0.94
Mitchell	0.93
Monto	0.96
Mt. Morgan	1.04
Nanango	0.82
Pittsworth	0.84
Proserpine	1.17
Rockhampton	1.14
Roma	0.98
Samford	0.91
Springsure	1.06
Stanthorpe	0.69
St. Lawrence	0.96
St. George	1.01
Surat	0.98
Tamborine	0.81
Tambo	1.02
Taroom	1.00
Texas	0.87
Thargomindah	1.07
Theodore	1.05
Toowoomba	0.79
Townsville	1.24
Wallangarra	0.64
Warwick	0.82