Piggery Odour Emission Rate Validation Study

Final Report
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Acronyms, abbreviations and definitions

APL	Australian Pork Limited
CAP	covered anaerobic lagoon – biogas capture system, as defined in the NEGIP (Tucker, 2018)
CO_2	carbon dioxide gas
DAF	Department of Agriculture and Fisheries, Queensland Government
Geomean	Geometric mean – used to calculate the average of olfactometry results (Standards Australia/Standards New Zealand, 2001). It is used instead of the more commonly used arithmetic mean (which is calculated by summing a group of results and dividing by the number of results) because olfactometry results are determined using an exponentially increasing odour concentration series (i.e. 64, 128, 256, 512, 1024, 2048…32,768). The geometric mean normalizes the calculation and prevents skewing of the data. The formula for geomean is: $Geomean = \sqrt[n]{x_1 \times x_2 \times x_3 \ldots x_n}$
HLA ponds	highly loaded anaerobic ponds, as defined in the NEGIP (Tucker, 2018)
NEGIP	APL National Environmental Guidelines for Indoor Piggeries (Tucker, 2018)
OER	odour emission rate
ou	odour unit – units used for odour concentration as determined by dilution olfactometry according to '*AS/NZS 4323.3-2001 — Determination of odour concentration by dynamic olfactometry*' (Standards Australia/Standards New Zealand, 2001)
RH	relative humidity
RPM	revolutions per minute – referring to the rotational speed of fan blades
SEPS	sedimentation and evaporation pond system, defined in the NEGIP (Tucker, 2018)
SPU	standard pig unit, as defined in the NEGIP (Tucker, 2018)
VEF Maker	APL Variable Emissions File Maker — software package used to calculate odour emission rates from Australian piggeries (Pacific Air and Environment, 2004)
VS	volatile solids, as defined in the NEGIP (Tucker, 2018)

Executive Summary

Piggeries have the potential to cause odour impacts, and this therefore needs to be considered at all stages of piggery planning, construction and operation. The Australian pork industry invested heavily in odour research in the 1990-2000's with a strong focus on measuring odour emission rates (OER) from effluent systems and production sheds, as well as developing separation distance guidelines. Since that time, industry practices have evolved and there are new aspects in farm design, waste treatment systems and farm management practices, which may affect odour emissions.

As well as evolutions in piggery design and operations, there have also been advances in odour impact assessment modelling, with increased capability in meteorological inputs and more detailed dispersion modelling. Advancements in odour modelling have brought with them an increased expectation of more precise odour impact prediction, but modelling piggeries is a challenging task that requires accounting for multiple, highly dynamic odour sources, complex terrain and complex meteorology. While modelling practitioners attempt to model potential odour impacts using best available modelling practices, the models are largely reliant on rudimentary OER data that may not accurately reflect current odour sources at piggeries.

Measuring OER from piggery odour sources is a complex and expensive exercise, which is the leading reason for limited OER data. There are many challenges involved in measuring odour emissions from the main sources of odour—pig sheds and effluent treatment systems. Odour from all of these sources change dynamically over time and vary spatially, making it extremely challenging to completely characterise the odour emissions from any odour source, and it makes it difficult to describe the many factors that affect odour emissions. Despite all the challenges associated with accurately measuring OER and modelling odour dispersion, they are both necessary for estimating potential odour impacts from proposed or expanding piggeries. Odour measurements only provide a snap-shot of progressively changing conditions, and there are limitations to appropriately transpose odour data measured at one farm to others in the industry due to localised and individual farm characteristics.

The objectives of this project were to review existing OER data for Australian piggeries, to measure OER from a range of piggery odour sources that are representative of current infrastructure design and management practices, and to review current odour models and modelling methods that are used for assessing odour impacts and calculating separation distances.

Consultation meetings were held with pork industry representatives and State environmental regulators to find out about the industry's current issues relating to odour, farm designs and operating practices that may affect odour emissions (currently and into the future), gaps in the knowledge relating to OER, and preferred odour sampling methodologies, especially from area sources of odour (such as ponds and compost piles). The consultation process resulted in prioritising odour sampling from mechanically ventilated sheds, pull-plug effluent sheds and effluent systems that include covered anaerobic ponds (CAP) for biogas capture. The State environmental regulators requested that all area source odour emissions be measured using flux chamber methods according to *AS/NZS 4323.4-2009*.

OER was measured from five piggeries, located in Queensland, New South Wales, and Victoria. Odour emissions were measured from pig sheds (effluent flushing; pull-plug; weaner; grower/finisher; mechanically ventilated; naturally ventilated; and deep litter), effluent ponds, sedimentation and evaporation pond systems (SEPS), and compost piles. A focus was placed on measuring odour emissions from farms that had a CAP. Odour was measured during winter and summer to assess seasonal influences.

OER measured in this project is a snap-shot of current conditions. Readers must remember that piggery odours are produced by non-steady state systems that undergo progressive changes daily, seasonally and over longer periods (e.g. relating to desludging events), which means that interpreting grab sampling data requires great caution.

- OER from sheds (0.5-115 ou s^{-1} per SPU with average value 29.8 ou s^{-1} per SPU) were similar to previously reported values.
- OER from primary anaerobic ponds (0.4-3.9 ou m^{-2} s^{-1} with an average of 2.0 ou m^{-2} s^{-1}) were similar to previously reported values.
- OER from active SEPS (0.14-92.6 ou m^{-2} s^{-1} with an average of 10.4 ou m^{-2} s^{-1}) was generally higher than previously reported values.
- OER from secondary/holding ponds were similar to or higher than the primary pond or active SEPS before it (1.9-3.9 ou m^{-2} s^{-1} with an average of 3.0 ou m^{-2} s^{-1} in pond systems and 16.2-89.4 ou m^{-2} s^{-1} with an average of 34.1 ou m^{-2} s^{-1} in SEPS systems).
- OER was considerably lower from offline ponds or SEPS that were in their drying phase (0.03-2.8 ou m^{-2} s^{-1} with an average of 0.40 ou m^{-2} s^{-1}).
- Mortality or manure compost piles/windrows OER (0.02-1.16 ou m^{-2} s^{-1} with an average of 0.22 ou m^{-2} s^{-1}) were consistently the lowest emitting area sources, and comparable with compost systems in other animal industries.

APL Variable Emission File (VEF) Maker is currently the recommended method for estimating OER values for piggery sheds and ponds. We found that the OER that we measured from sheds were similar to the range of OER that were used to develop the VEF Maker formulas in the first place. Also, the OER measured on primary anaerobic effluent ponds were similar or slightly higher than those calculated by VEF Maker (using the wind speed and mixing conditions assumed to exist in a flux chamber). Despite VEF Maker being developed using wind tunnel OER measurements, we recommend that there be no changes to the VEF Maker formulations.

This project focussed on farms with a CAP for biogas capture. Some of the OER from the SEPS, which followed a CAP, were higher than previously reported values. It is unknown if the CAP was a contributing factor or not. We recommend further investigation into CAP effluent systems to ensure that they are equally as effective at reducing the OER from the treated effluent as they are at producing biogas. These studies should assess the loading rates, volatile solids (VS) and nitrogen reduction, hydraulic retention times, effluent and sludge chemistry, microbiology and sludge accumulation associated with a CAP in effluent systems. Studies should include hybrid CAP systems that are continuously stirred and heated.

An investigation of recommended odour assessment methods (Level 1, 1.5 and 2 in the NEGIP) has demonstrated that odour modelling produces similar odour contours when the NEGIP impact criteria (98^{th} percentile, 1 hour average, 1–3 ou), but modelling produces much larger odour contours than the separation distance formula when State-based odour criteria are used. This unfortunately means that prospective new or piggeries that use odour modelling may be required to have substantially larger separation distances than may actually be needed to mitigate odour nuisance. Further investigation into the combined effects of emission estimation methods (i.e. VEF Maker) and odour impact criteria, is required. Odour complaint history or survey data, will be required to determine whether odour modelling and separation distance calculations are most likely to mitigate potential odour impacts.

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1. Background to Research

Odour assessment of proposed piggery developments or expansions continues to create challenges for the Australian pork industry when there are disagreements between odour consultants and environmental regulators about selection of odour emission rate (OER) data, odour modelling methods and odour impact criteria. The methods recommended in the APL National Environmental Guidelines for Indoor Piggeries (NEGIP; Tucker (2018)) have attempted to address these disagreements by providing methods that have a demonstrated history of successfully mitigating odour impacts when farms are operating normally, with few established piggeries contributing to ongoing odour impacts.

The Australian pork industry invested significantly in odour research during the 1990-2000's with a strong focus on measuring OER from effluent systems and production sheds, as well as developing separation distance calculations. Since that time, industry practices have evolved and there are new aspects in farm design, waste treatment systems and farm management practices, which may affect the odour emissions. As well as evolutions in piggery design and operations, there have also been advances in odour impact assessment modelling, with increased capability in meteorological inputs and more detailed dispersion modelling (more inputs, 'puff' models rather than Gaussian, smaller time-steps, finer spatial resolution). Advancements in odour modelling have brought with them an increased expectation of more precise odour impact prediction; however, modelling piggeries is a challenging task that requires accounting for multiple, highly dynamic odour sources, complex terrain and complex meteorology. While modelling practitioners attempt to model potential odour impacts using best available modelling practices, the models are largely reliant on rudimentary OER data that may not accurately reflect current odour sources at piggeries.

Measuring OER from piggery odour sources is a complex and expensive exercise, which is the leading reason for limited availability for OER data. Challenges involved in measuring odour emissions from pig sheds include finding a location to collect a representative sample as well as being able to calculate ventilation rates, especially from naturally ventilated sheds. Measuring odour emissions from effluent treatment systems is also challenging because they are known to vary spatially (Hudson *et al.*, 2004; Tucker, 2018) and over time because "ponds are non-steady state systems and so undergo progressive change between desludging events, making interpretation of grab-sampling data difficult….sampling of specific ponds over a usual project period of 2-3 years only gives a snap-shot of progressively changing conditions" (Skerman *et al.*, 2019). There are also limitations to appropriately transposing odour data measured at one farm to others in the industry due to localised and individual farm characteristics.

Despite all the challenges associated with accurately measuring OER and modelling odour dispersion, they are both necessary for estimating potential odour impacts from proposed or expanding piggeries.

2. Objectives of the Research Project

- Investigate and report on existing OER data for Australian piggeries.
- Provide updated OER data representative of the range of current infrastructure designs and management practices used at Australian piggeries, based on consultation with industry and stakeholders.
- Review current odour models and modelling methods used for assessing odour impacts from Australian piggeries.

3. Introductory Technical Information

3.1 Odour impact assessment

The Australian pork industry is constantly focussed on understanding and reducing odour emissions from piggeries. The capacity to expand existing piggeries or establish new sites often hinges on the availability of adequate separation distances to mitigate odour nuisance at surrounding sensitive receptors (primarily rural residences and towns). The industry recommends using a staged approach to odour assessment, Table 1 (Tucker, 2018).

Table 1. Odour assessment process for new piggeries or piggery expansions (Tucker, 2018)

Odour assessment	Method for determining separation distances
Level 1	Empirical separation distance formula
Level 1.5	Empirical separation distance formula with wind frequency factor
Level 2	Odour dispersion modelling with 'standard' odour emission data and representative meteorological data
Level 3	Odour dispersion modelling with site-specific odour emission and meteorological data

3.2 Previously reported OER data for piggery sources

The OER data used in developing current Level 1 separation distance formulae and the majority of the data used in Level 2 odour modelling are based on odour measurements that were determined using superseded standards and sampling methodologies, potentially overestimating the odour impacts of Australian piggeries. The industry, has previously funded research into piggery odour emissions, including reviews of Australian and international pig odour research (Nicholas *et al.*, 2003; Smith *et al.*, 1999; Watts, 2000). The information generated from these reviews is still being widely used in the assessment of piggery developments in Australia; however, much of this data is no longer representative of the continually improving standards of Australian piggeries. For example, many larger piggeries are now employing biogas systems, including a CAP or digester for primary treatment of piggery effluents, and many modern sheds are mechanically rather than naturally ventilated and employ pull-plug rather than flushing or static pit effluent management systems.

Odour emissions from anaerobic ponds were previously identified as the primary source of odour emissions from Australian piggeries, with Smith *et al.* (1999) suggesting that OER from anaerobic ponds may be responsible for up to 75% of overall odour emissions from piggeries. Anaerobic waste treatment systems are largely still based on the initial concept designs using volatile solids loading rates, and with increasing intensification of the Australian pork industry, primary treatment ponds remain an odour source (Skerman *et al.*, 2008). In contrast, OER from secondary ponds, storing effluent treated in a primary CAP or digester, have not yet been investigated in Australia and thus will require exploration to determine potential impact.

In addition to traditional anaerobic ponds, the Australian pork industry has increased the number of effluent system design options (Tucker, 2018) to include:

- heavily loaded anaerobic (HLA) ponds

- sedimentation and evaporation pond systems (SEPS)
- covered anaerobic ponds (CAP, for biogas utilisation).

Odour emissions from some of these effluent systems have previously been measured, while other systems, and combinations of multiple systems, have had limited or no odour measurements undertaken.

Odour emissions from piggery sheds (with effluent or deep litter waste management systems) have also been identified as a major contributor (14–30%) to overall farm OER (Dalton *et al.*, 1997). However, most of these estimates are based on naturally ventilated shed systems, and very little is known about the potential effects of modern mechanically ventilated piggery sheds on OER. With this style of ventilation being more widely adopted in parts of Australia, further investigation of the OER from mechanically ventilated sheds is needed.

The introduction of new and emerging technologies at Australian piggeries may also influence odour emissions. Biogas systems are becoming increasingly common at Australian piggeries, primarily for reducing on-farm energy costs and GHG emissions. While it is generally accepted that the adoption of biogas systems (a CAP or digesters) significantly reduces overall odour emission compared with the normal practice of using uncovered anaerobic ponds, the effects of these systems on overall OER has not yet been confirmed. Furthermore, untreated biogas contains relatively high concentrations of hydrogen sulphide (H_2S) (typically 1000-4000 ppm). While most biogas combusted in engines and boilers is treated to remove the majority of the H_2S, biogas burnt in flares is commonly not treated, resulting in the emission of sulphur dioxide (Skerman *et al.*, 2012)—a known odorant. Further emissions of untreated biogas have also been observed around the perimeter of an improperly sealed CAP, potentially resulting in a fugitive odour emission source, which would be extremely difficult to measure but could be eliminated with repairs or maintenance. While these odour emissions are expected to be minimal compared to overall farm emission rates, they may still need to be considered.

In addition to traditional sheds, effluent ponds and anaerobic digestion systems, odour emissions from the following miscellaneous sources may also contribute to overall OER from modern piggeries:

- mortality composting
- sludge drying
- waste solids storage and processing facilities
- facilities to receive, store and process by-products imported from external sources for co-digestion with piggery waste
- outdoor or free range pig production (OER from these systems previously reported by Banhazi (2013))

These sources normally contribute very little to overall farm OER although it may be of interest to quantify their OER.

3.3 Odour sampling methods

Odour sampling methods have changed since odour measurements studies were undertaken at Australian piggeries in the early 2000's. The introduction of a Standard for area source odour sampling, *AS/NZS 4323.4-2009—Area source sampling—Flux chamber technique* (Standards Australia/Standards New Zealand, 2009), has seen a shift away from the use of wind tunnels for odour emission rate measurement in Australia. This is not because wind tunnels are an inappropriate area enclosure, but because the Standard only included the so-called 'USEPA emission isolation flux chamber' based on

design and testing information by Kienbusch (1986), and Australian regulatory authorities have a preference for the use of standardized methods to improve comparison of measurements between practitioners and sampling campaigns.
One consequence of the move away from wind tunnels is that the majority of OER values previously measured from Australian piggeries using wind tunnels are not comparable to the OER measured in this study. Previous paired comparisons of OER measured using wind tunnels and flux chambers have demonstrated large and highly variably differences in OER, with wind tunnels measuring higher odour emission rates. This is because flux chambers operate at low sweep air flow rates that restrict the emission of odorants from a surface and underestimate true OER values (Parker *et al.*, 2013). Wind tunnels, however, are not immune from criticism, and have been reported to have unknown accuracies (Parker *et al.*, 2013). Additionally, the selection of wind tunnel sweep air velocity is known to affect the emission rate of odour, and can potentially over-estimate the true OER value if the sweep air flow rate is too high compared to the ambient conditions. The selection and reporting of sweep air flow rates in wind tunnels are therefore critical for the measurement and subsequent use of OER data for assessing the potential for odour impacts.

Another consideration with previous OER measurements using wind tunnels is that they potentially over-predict the relative importance of ponds over the sheds. Previous estimates suggested that 75% of the odour was from the ponds and 25% from the sheds. If wind tunnel OER measurements from the ponds were unnecessarily elevated, then it may suggest that the sheds may contribute more to odour impacts than previously estimated.

4. Research Methodology

Research activities in this project were divided into four discreet activities:

- Review of literature to identify existing OER data for Australian piggeries
- Consultation with industry and stakeholders to determine current and future trends in piggery design and operations that may have implications for odour emissions. Also to identify potential gaps in OER data
- Odour sample collection, focussing on priority areas identified during the industry and stakeholder consultation
- Odour modelling to compare the influence of the various State-based odour impact criteria and the methods described in the NEGIP (Tucker, 2018).

The methods for these activities are described in the following sections.

4.1 Methods for the literature review

The Australian pork industry has previously invested in a significant literature review on odour (Watts, 2000), which was subsequently revised by Nicholas *et al.* (2003). No more recent reviews relating to pig odour were found that were relatable to Australian pork production.

The intent of the literature review undertaken in this project was to update the state of knowledge with odour related research and OER measurements that have occurred since 2003. Feedback from the industry and stakeholder consultation process (detailed in the section below) narrowed the focus of the literature review to only include area source (ponds and manure/compost) OER that were measured with a flux chamber using *AS/NZS 4323.4-2009 — Area source sampling—Flux chamber technique* (Standards Australia/Standards New Zealand, 2009).

The review focussed on final reports from research projects, nearly all of which were funded by Australian Pork Limited. The research reports considered in the review were focussed on measuring emission rates from typical indoor piggery odour sources, or development and testing of production or waste management practices including:

- Measuring the effect of loading rate and spatial variability on OER from primary anaerobic effluent ponds (Hudson *et al.*, 2004)
- Developing and evaluating permeable pond covers to reduce odour emissions from primary anaerobic effluent ponds (Duperouzel, 2009; Hudson *et al.*, 2006a; Hudson *et al.*, 2006b; Hudson *et al.*, 2007; Hudson *et al.*, 2008)
- Evaluating SEPS in Queensland (Skerman, 2013)
- Developing and evaluating HLA primary ponds (Skerman *et al.*, 2008)

In addition to research reports, independent odour assessment has been carried out by some farms and they provided their data for the benefit of this project (referred to in this report as *Third-Party* OER data).

The only data considered for inclusion in the literature review was OER from typical piggery odour sources (i.e. sheds, effluent system or compost piles).

4.2 Methods for industry and stakeholder consultation

Participants for industry and stakeholder consultation were identified and agreed with APL prior to any discussions taking place. Meetings were held with several producers to get an understanding of the industry's current issues relating to odour, as well as farm designs and operating practices. The industry participants were also asked to give their opinions about likely future direction relating industry growth, farm design and practices, and how these were anticipated to affect the potential for odour impacts.

The consultation process then engaged State regulatory authorities in Queensland, South Australia, Victoria and New South Wales to understand their perspectives on odour, odour nuisance and odour impact assessment processes relating to pork production. Environmental regulators were asked if there were any particular odour sources that they believed needed additional OER data, and the odour sampling methods that they preferred, especially relating to area sources (i.e. wind tunnel or flux chamber).

At the conclusion of the industry and stakeholder consultation phase, a list of priority odour sources was identified for OER measurements, and a decision made to use only flux chamber methods for measuring OER from area sources as described in *AS/NZS 4323.4-2009* (Standards Australia/Standards New Zealand, 2009).

4.3 Methods for odour sampling

4.3.1 Selection and description of farms

Farms were selected following consultation with industry representatives, State regulatory authorities and consultants who are actively involved in the design and development of new and expanding piggeries. Farms were selected if they had the following features identified during the consultation process:

- secondary effluent ponds (especially after a CAP or biogas system)
- SEPS
- HLA ponds
- mechanically ventilated sheds
- naturally ventilated sheds
- flushing sheds
- deep litter sheds
- pull-plug sheds
- CAP or biogas facilities

Biogas systems are being introduced to more piggeries, and minimal OER data is available for farms with these systems. Priority was therefore given to measuring odour emissions from farms with biogas systems.

A further outcome from the consultation process was a request from the NSW regulatory authority to conduct odour sampling at farms in NSW. After consultation with APL, it was decided to undertake odour measurements on NSW farms to meet this request.

Consideration was also given to logistical constraints associated with olfactometry, especially the requirement to analyse odour samples within 30 hours of collection, and travelling distance to commercial olfactometry laboratories.

Five piggeries were sampled during the project (Table 2) including farrow-to-finish and grow-out piggeries, with a variety of waste collection (deep litter; effluent pull-plug or flushing) and effluent treatment/storage systems (CAP, SEPS, anaerobic ponds and evaporation/drying storages).

Table 2. Piggery characteristics where odour emission rates were measured

Farm	State	Type of piggery	Piggery occupancy (SPU)*	Waste systems	Effluent pull-plug or flushing	Compost area	Biogas CAP§	Recycled effluent to flush sheds
A	Qld	Farrow-to-finish	40,000	Effluent – Ponds	Flushing and pull-plug	Yes - mortality	Yes	Yes
B	NSW	Farrow-to-finish	15,000	Effluent – SEPS	Flushing	No	Yes	Yes
C	NSW	Grow-out	16,000	Effluent – SEPS	Flushing	Yes - mortality	Yes	Yes
D	NSW	Grow-out	10,000	Deep litter & effluent - ponds	Pull-plug	No	No	Yes
E	Vic	Grow-out	10,000	Deep litter & effluent - ponds	Pull-plug	Yes – deep litter	No	Yes

*Standard pig unit (SPU)
§Covered anaerobic Pond (CAP)

4.3.2 Measuring OER from area sources – effluent ponds and compost

Effluent ponds and compost piles are area sources. Measuring odour emission rates requires the odour to be captured within an enclosure. For this project, odours from area sources were captured using a flux chamber, that was designed and operated according to *AS/NZS 4323.4-2009 — Area source sampling—Flux chamber technique* (Standards Australia/Standards New Zealand, 2009). The flux chamber was chosen over other enclosures, for example wind tunnels, because the State regulatory authorities each stated that they preferred the flux chamber, and some stated that they would not accept OER from wind tunnels.

The methodology for using a flux chamber has previously been described by Skerman (2013), and similar methods were followed in this project. Prior to each sampling day, the equipment was thoroughly cleaned and dried, with each component checked to ensure that it had no perceptible odour. Blank samples were not collected due to logistical constraints; however, the procedure of cleaning the equipment reduced the risk of the equipment affecting measured odour concentrations. The effectiveness of the equipment cleaning was subsequently demonstrated by collecting samples on each day that had low odour concentration.

Cylinders of either high purity nitrogen or air were provided to the flux chamber as sweep air (Table 3). The sweep air flushing rate was set to 5.0–5.6 L min^{-1} (at local conditions) using a calibrated TSI Series 4143 flow meter (TSI Inc., Shoreview MN, USA). Flow rate was controlled by setting the sweep gas line pressure with a dual-stage regulator (for high purity gases) and then finely adjusting the flow rate with a Uniflux 0-13 L min^{-1} rotameter (model SSVI1S9A108, Influx Measurements Ltd, Hampshire). The flow rate was visually monitored during sampling using the rotameter.

Odour samples were collected into new sample bags (15–20 L volume) that were either polyethylene terephthalate (PET, 25 μm film) or Polytetrafluoroethylene (PTFE; Table 3), depending on the olfactometry lab. Samples were drawn out of the flux chamber with a sampling pump set at 2.1 L min^{-1} (SKC model PCXR8 Universal pump, SKC Inc. Pennsylvania). The pump was connected to a rigid sampling container in order to draw the air from between the inner surface of the rigid container and the outer surface of the sampling bag, thereby drawing odorous air into the bag using the 'lung' method. The flux chamber was allowed to stabilise for a period of 26 min after the sweep air began to flow and before the samples were collected. During the stabilisation time, the sample bag was pre-conditioned with the odour by filling and then emptying the bag from the flux chamber sample line just prior to the sample being collected. At the end of the stabilisation period, the sample was collected over a period of approximately 8 min, by drawing odorous air from the flux chamber through the PTFE sample line.

The flux chamber was used for collecting samples from liquid and solid (porous) surfaces (Figure 1). On solid surfaces, the chamber was gently placed to minimise disturbance and penetration into the surface, while still ensuring a complete seal. On liquid surfaces, the flux chamber was supported by a raft. The raft was positioned on effluent pond surfaces using an extruded aluminium pole (extendable from 1.5 to 7.5 m), which enabled it to be located approximately 6 m from the banks of ponds, and centrally in the SEPS.

Figure 1. Flux chamber used to capture odour emissions from compost and effluent surfaces

Once a sample was collected into a bag, the bag was labelled, capped and individually sealed into an opaque container for transport to the olfactometry lab. All samples were analysed as quickly as possible following collection (Table 3). All Samples were analysed within 27 hours of collection, which is within the limit prescribed by AS/NZS 4323.3-2001.

Table 3. Flux chamber configuration for each sampling day

Farm	Sample date	Sources sampled							Biogas CAP before effluent ponds and/or SEPS?	Sample bag material[§]	Sweep air[†]	Time of day	Ambient temp (°C)	Duration between sample and analysis (hours)
		Solids settling pond	Primary anaerobic pond	Active SEP	Secondary pond[*]	Drying pond/SEPS (liquid)	Drying pond/SEPS (solids)	Mortality or deep litter						
A	Jul 2019	X	X					X	Yes	PET	N_2	08:35–12:45	12.2–18.1	3.0–4.0
	Aug 2019	X	X		X					PET	N_2	08:10–12:55	10.2–17.2	1.5–5.5
	Feb 2020	X	X		X			X		PET	N_2	08:45–12:05	19.6–22.8	2.5–5.5
B	Sep 2019			X	X	X			Yes	PET	N_2	08:56–10:50	18.1–21.9	25.0–25.5
	Oct 2019			X	X	X	X			PTFE	N_2	09:35–13:25	21.9–31.6	24.0–26.5
	Feb 2020			X	X		X			PTFE	N_2	07:40–10:55	20.9–26.3	22.5–27.0
C	Aug 2019			X	X	X	X	X	Yes	PET	N_2	09:40–17:20	9.9–13.7	22.0–25.0
	Oct 2019			X	X	X	X	X		PTFE	N_2	09:15–13:15	19.8–25.3	23.0–25.5
	Feb 2020			X	X		X	X		PTFE	N_2	07:45–10:35	21.5–25.6	24.0–27.0
D	Sep 2019			X	X				No	PET	N_2	15:40–17:59	18.2–25.3	23.0–23.5
E	Jan 2020		X			X	X	X	No	PTFE	Medical grade air	10:25–12:10	24.0–39.0	22.5–24.0
	Feb 2020		X			X	X			PTFE	Medical grade air	09:55–13:55	29.0–35.0	12.0–22.5

[*]Follows primary anaerobic pond or Active SEPS; [§]PET=polyethylene terephthalate (Nalophan®), PTFE=Polytetrafluoroethylene (Teflon®); [†]N_2 was Grade 5.0 (High Purity)

4.3.2.1 *Calculation of OER for area sources using the flux chamber*

Flux chamber OER was calculated using Equation 1.

$$OER = \frac{CQ}{A} \qquad \text{Equation 1}$$

Where:

OER = Odour emission rate (ou.m^{-2}.s^{-1}) at 0°C and 101.3 kPa

C = Flux chamber atmospheric odour concentration as measured with olfactometry (ou)

Q = Flux chamber sweep air flow rate (m^3 s^{-1}) at 0°C and 101.3 kPa

A = Area enclosed by chamber (0.13 m^2)

The flow rate of the sweep air into the flux chamber needed to be corrected according to the requirements of AS/NZS 4323.3-2001 to enable reporting of the results at standardised conditions of 0 °C and 101.3 kPa (Equation 2)

$$Q = Q_l \times \frac{(273+0)}{(273+T_l)} \times \frac{(P_l)}{(101.3)} \qquad \text{Equation 2}$$

Where:

Q = Flux chamber sweep air flow rate at 0°C and 101.3 kPa

Q_l = Sweep air flow rate at local conditions (temperature and barometric pressure)

T_l = Air temperature at the time of odour sampling (˚C)

P_l = Barometric pressure at the sample site and altitude (kPa)

The air temperature was measured while the odour samples were being collected. The barometric pressure at the sample site was calculated from Bureau of Meteorology (http://www.bom.gov.au/) "Latest Weather Observations" from the nearest weather station site, which are reported at MSL (mean sea level), and then correcting for the altitude of the sampling site.

4.3.3 *Measuring OER from sheds*

Feedback from the consultation with industry and State regulatory authorities resulted in prioritising odour sampling from the following types of sheds:

- mechanically ventilated sheds
- naturally ventilated sheds
- flushing sheds
- deep litter sheds
- pull-plug sheds.

OER was measured from a selection of sheds that had different effluent/manure and ventilation systems (Table 4).

Table 4. Pig shed characteristics at each farm

Farm	Type of shed	Effluent or manure system	Ventilation type*	Inlet vent configuration	Number of fans§	SPU
A	Weaner	Effluent flushing	Mechanical	Ceiling and side ventilation	3 x 915 mm (a) 2 x 610 mm (b)	550–585
		Effluent pull-plug	Mechanical	Ceiling and side ventilation	3 x 915 mm (c) 3 x 610 mm (d)	550–570
	Grower/ Finisher	Effluent flushing	Mechanical	Ceiling and tunnel ventilation	4 x 1270 mm (e) 1 x 610 mm (d)	1150–1680
		Effluent pull-plug	Mechanical	Ceiling and tunnel ventilation	4 x 1270 mm (e) 2 x 915 mm (c)	1150–1680
B	Grower/ Finisher	Effluent flushing	Natural	Wall curtain	—	350–450
C	Grower/ Finisher	Effluent flushing	Natural	Wall curtain	—	110–1215
D	Grower/ Finisher	Deep Litter	Natural	Wall curtain	—	550–990
E	Weaner	Effluent pull-plug	Mechanical	Side ventilation	2 x 610 mm (d) 2 x 460 mm (f)	210
	Grower/ Finisher	Deep Litter	Natural	Wall curtain	—	410-670
		Effluent pull-plug	Natural	Wall curtain	—	420-655

*'Natural' refers to curtain side sheds where wind powers the ventilation;
§fan labels (a)–(f) are different fan models, described in Table 5

Measuring the OER from the pig sheds required collecting a representative odour sample from the shed and measuring the ventilation rate. Some sheds were divided into individual rooms, which were physically separated from neighbouring rooms by solid walls. In these cases, odour emissions were measured from the room, and numbers of pigs, average pig weights, SPU, temperature, relative humidity and effluent/manure conditions recorded were specific to the room where the odour sample was collected. The room selected for odour sampling was believed to be representative of the larger shed based on conversations with the piggery manager. The floor plan for the sheds were different at each farm (Figure 2 to Figure 10). For simplicity, rooms and sheds will both be described as 'sheds' for the remainder of this report.

The methods for odour sample collection and calculation of OER differed slightly depending on whether the shed was mechanically ventilated (using exhaust fans to extract odorous air from the shed) or naturally ventilated (where air is changed through openings on the side wall and/or roof by wind or thermal convection). The following sections describe how OER was measured from mechanically and naturally ventilated sheds.

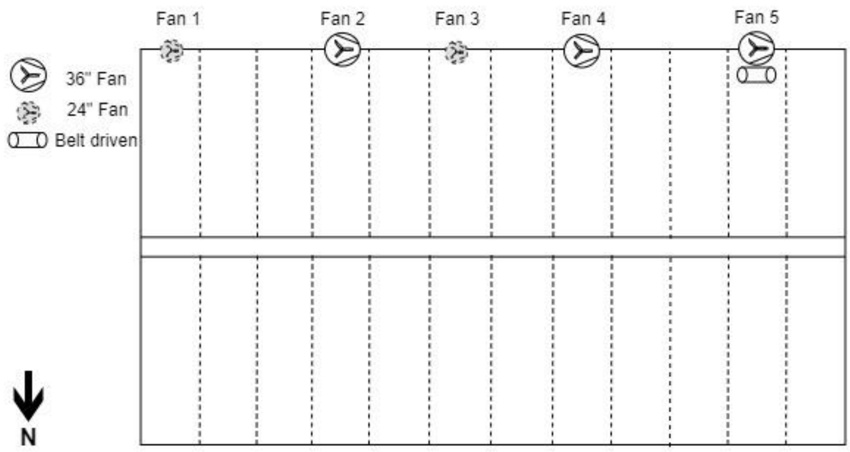

Figure 2. Weaner shed at Farm A – mechanically ventilated with effluent flushing system

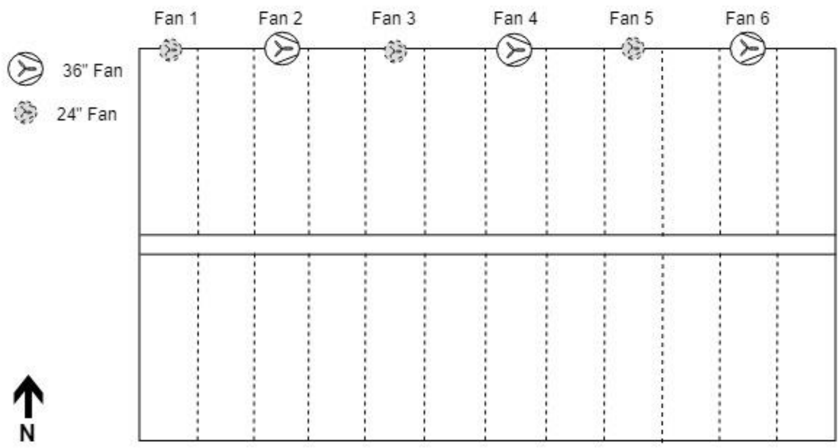

Figure 3. Weaner shed at Farm A – mechanically ventilated with pull-plug effluent system

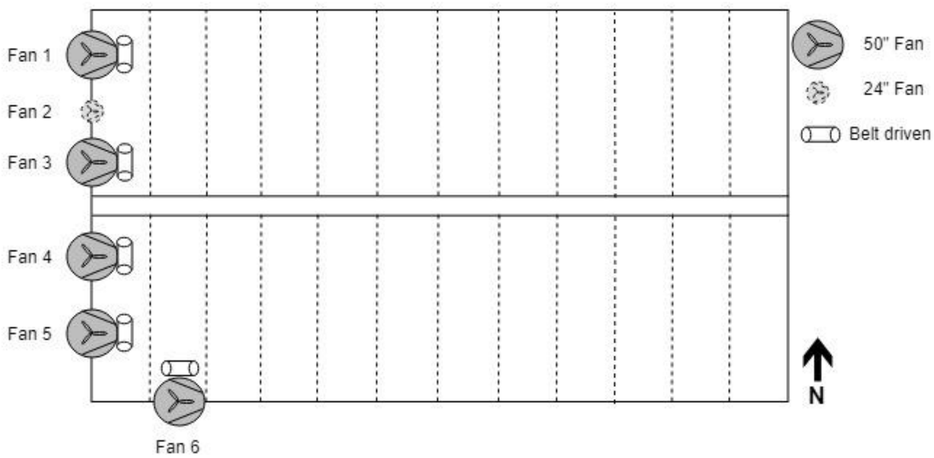

Figure 4. Grower/finisher shed at Farm A – mechanically ventilated with effluent flushing system

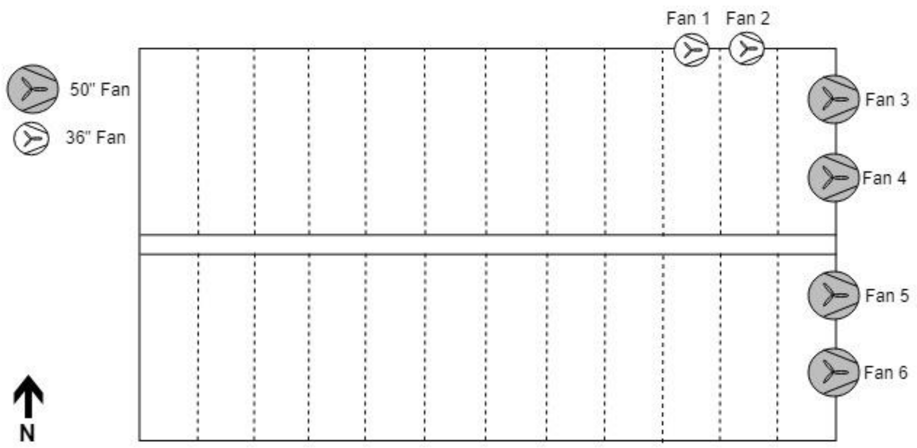

Figure 5. Grower/finisher shed at Farm A – mechanically ventilated with pull-plug effluent system

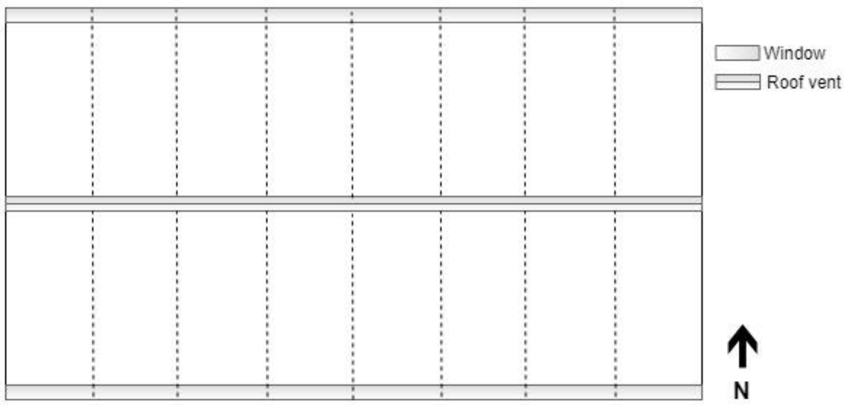

Figure 6. Grower/finisher shed at Farm B – naturally ventilated with effluent flushing system

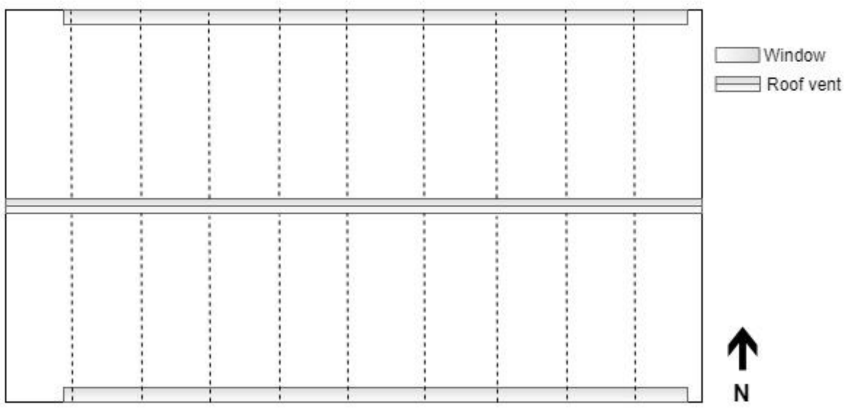

Figure 7. Grower/finisher shed at Farm C – naturally ventilated with effluent flushing system

Figure 8. Grower/finisher shed at Farms D & E – naturally ventilated with deep litter

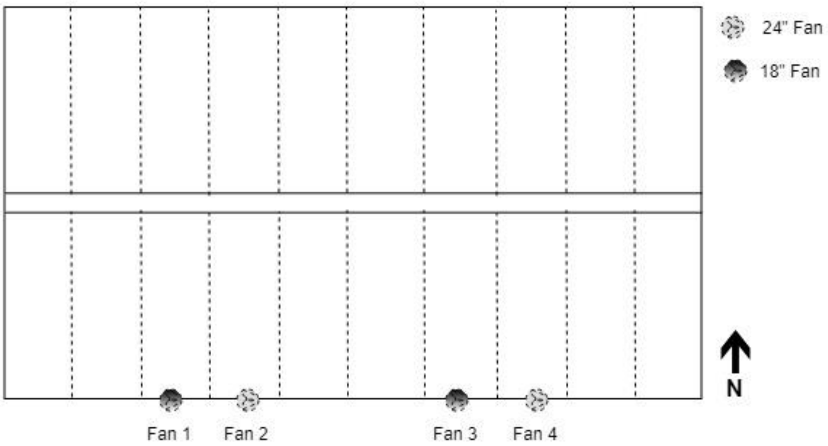

Figure 9. Weaner shed at Farm E – mechanically ventilated with pull-plug effluent system

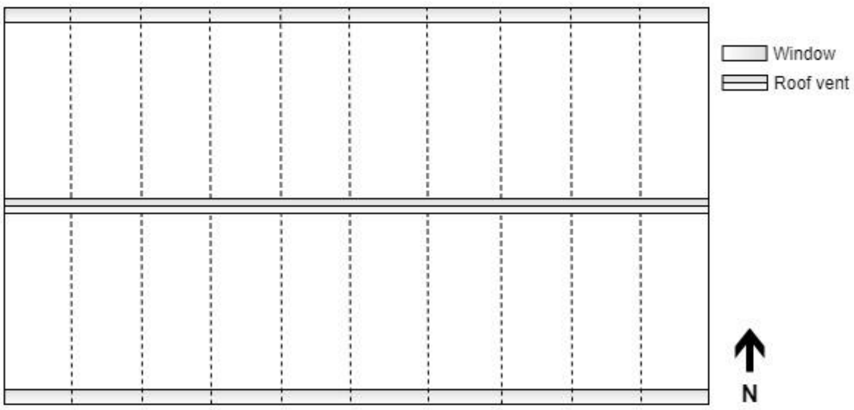

Figure 10. Grower/finisher shed at Farm E – naturally ventilated with pull-plug effluent system

4.3.3.1 Measuring OER in mechanically ventilated sheds

Mechanically ventilated sheds have fresh air entering the shed through specifically designed inlet vents and odorous air is exhausted from the shed through electric fans. This configuration provides a clearly-defined location for odour sampling, and consequently, odour samples were collected from the outside of an active fan on the shed. All of the fans on the sheds in this study were fitted with external cones.

A PTFE tube was used for the odour sampling line. One end was secured within the exhaust fan exit cone, as close as possible to the fan blades, while the other end was connected to the odour sample bag. The sample line used was as short as possible (typically 2-3 m long). The sample bag was filled in the same manner as pond odour samples, with the exception that the sampling pump flow rate was increased to approximately 5 L min^{-1}, which enabled odour samples to be collected in about 3 min after the sample bag was pre-conditioned (primed and purged with odorous air from the shed).

At the time of odour sample collection, the ambient temperature, ambient relative humidity, shed temperature, fan types (make, model, configuration), fan activity, differential pressure across the fans (relating to the shed static pressure), fan revolutions per minute (RPM), herd details and time since last effluent/manure flush/removal were recorded.

Following the odour collection, fan make and model information was used to source fan test data for the specific fan. Fan test data was checked to ensure that the fans were tested with the same shutters, grills and exit cones as were fitted to the fans on the pig sheds. Fan RPM[1], was measured using an optical tachometer, was cross-checked with the fan test data to ensure the fan was operating within 5% of the tested RPM (adjusted for the static pressure at the time of sampling). Most of the fans were direct-drive fans, and their on-farm RPM closely aligned with the test data values. A few of the belt-driven fans deviated from the RPM in the test reports, most likely due to worn belts and sheaves, and so the flow rate of these fans were adjusted proportionally with the fan speed when they deviated by more than 5% from the test data.

The air flow rate through each active fan was calculated using fan test data (Table 5), and the static pressure measured in the shed using differential pressure meter (TSI Inc. DP-Calc model 8705 Shoreview MN, USA) at the time of sampling. This is because the air flow rate of a fan decreases as the static pressure of the shed becomes more negative (Figure 11; sheds operating under negative pressure). The air flow rate was calculated for each active fan, and then all active fans were summed to get the shed ventilation rate. The shed ventilation rate was then adjusted to standard conditions (0 °C, 101.3 kPa) as required by AS/NZS 4323.3-2001 (Equation 2).

[1] Revolutions per minute

Table 5. Fan information from test data

Fan*	Manufacturer	Diameter (mm)	Drive	Maximum flow rate ($m^3\ s^{-1}$)	Air flow rate formula based on test data ($m^3\ s^{-1}$)§
a	APP fans	915	Direct	348	$Q = -0.0253p^2 - 1.4496p + 347.5$
b	APP fans	610	Direct	211	$Q = -0.0033p^2 - 0.9395p + 211.4$
c	Big Dutchman	915	Direct	363	$Q = -0.0079p^2 - 1.2363p + 363.2$
d	Big Dutchman	610	Direct	217	$Q = -0.0031p^2 - 1.053p + 216.9$
e	Big Dutchman	1270	Belt	813	$Q = -0.0147p^2 - 2.865p + 813.1$
f	Big Dutchman	460	Direct	115	$Q = -0.0028p^2 - 0.329p + 115.1$

*fan labels (a)–(g) are different fan models, designated in Table 4
§where Q is air flow rate and p is the shed static pressure (Pa)

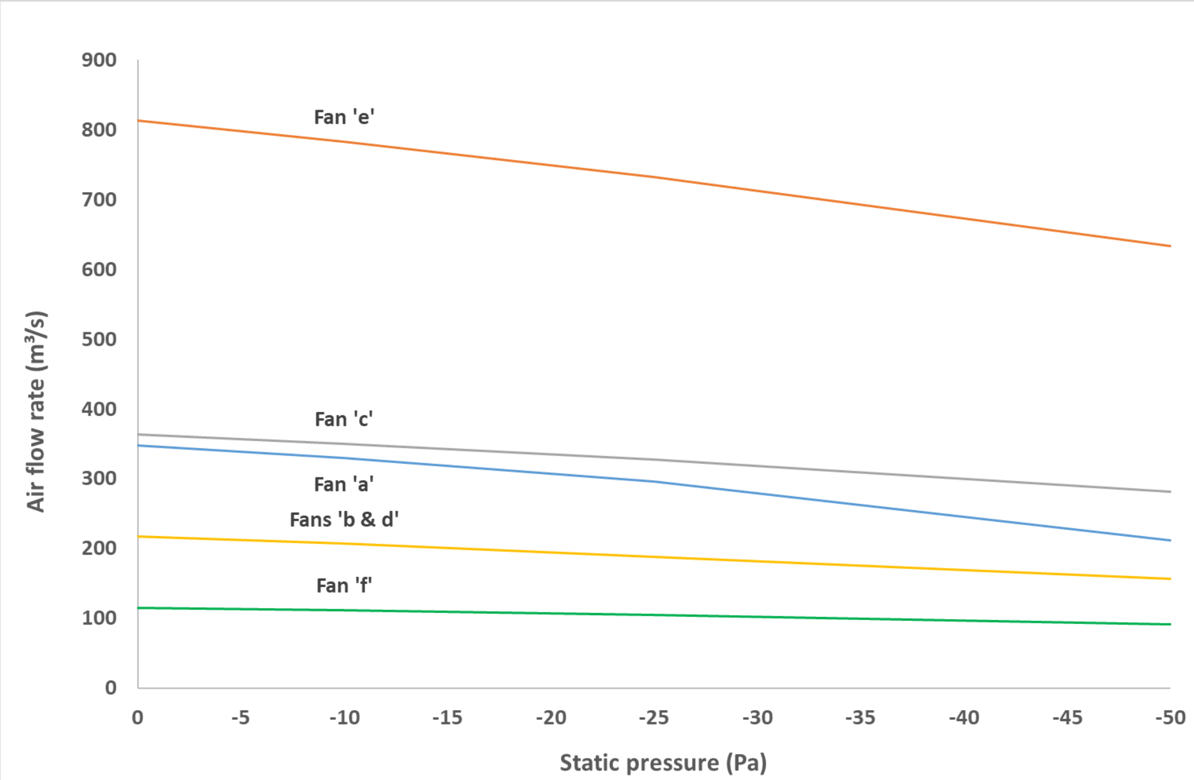

Figure 11. Air flow rate of fans, showing decreasing flow rate as static pressure in the shed becomes more negative

4.3.3.2 Measuring OER in naturally ventilated sheds

Measuring OER from naturally ventilated sheds is a far more complex and challenging task compared to mechanically ventilated sheds. In naturally ventilated sheds, the side walls of the shed are opened using hinged flaps or curtains to allow the wind to blow through. Sheds may also have a roof ridge vent that operates in a similar manner. Roof ridge vents support convective air movement in the shed when there is low wind speed. The amount of wall/roof opening depends on temperature, and is controlled either by an electronic temperature controller that uses winches to open and close the opening, or is manually opened and closed by the farmer based on their experience and interpretation of the weather conditions and pig thermal comfort. The target temperature for grower/finisher pigs is typically 17–24 °C and depends on the pig age, shed flooring design and other influencing factors. When the shed temperature is below the target temperature, the shed openings will be partly closed to retain heat in the shed, resulting in some degree of control of the ventilation rate through the shed. Conversely, when the temperature is above the target temperature, the shed will be fully opened to maximise heat transfer out of the shed. Once the shed is fully open, ventilation rate is completely controlled by the wind, resulting in rapidly fluctuating and highly variable ventilation rates that have no direct relationship to ambient conditions. Measuring the highly dynamic ventilation rate in naturally ventilated sheds is the greatest challenge associated with measuring odour emissions (Ogink *et al.*, 2013).

There are multiple approaches to measuring ventilation rates in naturally ventilated animal houses that have been the subject of research, development and reviews (Table 6). There are no universally agreed methods for measuring the ventilation rate in naturally ventilated sheds, but tracer gases (including CO_2, which is considered a natural tracer) are generally considered superior, especially in buildings that have poorly defined openings/vents. The challenges associated with tracer gas methods include:

- the requirement for accurate gas analysers to measure the incoming and outgoing gas concentration in every opening of the shed
- estimating the respiration (for CO_2 balance) of the animals and manure in the shed, which varies with animal species, feed intake, animal activity and quantity of manure in the shed.

The tracer gas methods are more suited to long term studies where the investment in the equipment and time required to install the gas measurement system is commensurate with the potential benefits. In this project, where short-term measurements were required during brief visits at multiple farms, it was decided to measure the ventilation rate in naturally ventilated sheds by directly measuring the air flow though the wall openings.

Table 6. Methods available for measuring ventilation rates in naturally ventilated animal houses

Ventilation estimation method	References	Potential error* (%)
Carbon dioxide (CO_2) balance	(Blanes and Pedersen, 2005; Calvet *et al.*, 2010; Kiwan *et al.*, 2013; Ogink *et al.*, 2013; Pedersen *et al.*, 1998; Pedersen *et al.*, 2008; Phillips *et al.*, 2001; Samer *et al.*, 2012)	15–40
Heat balance	(Blanes and Pedersen, 2005; Heber *et al.*, 2001; Pedersen *et al.*, 1998)	30–100
Moisture balance	(Blanes and Pedersen, 2005; Pedersen *et al.*, 1998; Samer *et al.*, 2012)	5–40
Tracer gas methods	(Demmers *et al.*, 2001; Kiwan *et al.*, 2013; Ogink *et al.*, 2013; Phillips *et al.*, 2001; Samer *et al.*, 2012)	10–15
Measuring differential pressure across vents	(Demmers *et al.*, 2001; Ogink *et al.*, 2013)	>50
Direct airflow measurement through vents/openings	(Blanes and Pedersen, 2005; Ogink *et al.*, 2013; Phillips *et al.*, 2001)	25

*Calvet *et al.* (2013)

To measure the air flow through the open wall vents, an air speed and direction measurement system was positioned in the middle of the curtain opening, adjacent to where the odour sample was collected. The air speed measurement system was comprised of:

- an ultrasonic anemometer (Windsonic[1]; Gill Instruments Ltd, Hampshire UK),
- a combined temperature and relative humidity sensor (Vaisala model HMP110-B15A1C3B0[2]; Vaisala Corporation, Helsinki, Finland)
- a data logger (HOBO UX120-006M; Onset Computer Corporation, Bourne, MA, USA)
- a height-adjustable tripod stand.

The height adjustable tripod stand was used to position the anemometer in the middle of the opening on the side wall of the shed, and its direction was aligned with the walls of the shed. The stand was usually positioned on the outside of the shed to prevent interference by the pigs. The data logger was configured to collect all data at 1 s intervals during the odour sampling period. At the end of each sampling day, the data was downloaded for later processing to calculate the ventilation rate.

At the time of odour sampling, the dimensions of the shed openings were measured with a measuring tape and recorded. These enabled the cross-sectional area of all openings on the shed to be calculated.

Most of the sheds (with the exception of the deep litter eco-shelters) had only two side wall openings. Depending on the ambient wind direction at the time of collecting the odour sample, one opening was designated as the inlet side, and the other was the outlet side. The odour sample was collected on the outlet side in a position approximately central to the opening on the shed (centre of the shed width, and middle of the opening from top to bottom). For the eco-shelters, air was observed to be exiting through two sides of the building. For these, the odour sample was collected from the dominant outlet side of the shed, but ventilation rate was calculated out of all relevant side openings of the shed depending on the wind direction. Data from the anemometer was used to calculate the horizontal wind component that was perpendicular to the openings on the shed (air direction leaving the shed). The air direction was multiplied by the cross-sectional area of the relevant openings every second, and these air volumes were averaged on a 1 s time interval over the odour collection period to calculate the average ventilation rate, Q ($m^3 s^{-1}$), which was necessary for the calculation of OER (Equation 3). Prior to calculating OER, the ventilation rate was adjusted to standard conditions (0 °C, 101.3 kPa) as required by AS/NZS 4323.3-2001 (Equation 2).

Roof ridge vents were present on the sheds at Farms B, C and E (Figure 6, Figure 7 and Figure 10). At farms B & C, the ridge vent was closed during odour sampling (during cool weather they were already closed by the control systems, otherwise, they were manually closed by farm staff during odour measurements). At Farm E, the roof ridge vent was fixed in an open position. For this ridge roof vent, the area of the opening was estimated, and added to the area of the side wall opening. For safety and instrumental reasons, it was not feasible to measure the air exchange rate through the roof vent on this shed.

At the time of odour sample collection, the ambient temperature, ambient relative humidity, shed temperature, vent opening widths, vent opening gap, air velocity exiting the vent, herd details and time since last effluent/manure flush/removal were recorded.

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[1] Windsonic - option 3 (analogue outputs), 0-30 m s^{-1}, 2% wind speed accuracy, 2° direction accuracy;
[2] Vaisala – 2% RH accuracy, 0.2 °C temperature accuracy

4.3.3.3 Calculation of OER for piggery sheds

OER was calculated by multiplying the odour concentration by the ventilation rate. The emission rate was then normalised by dividing the OER by the number of SPU in the shed (Equation 3).

$$OER = CQ/SPU \qquad \text{Equation 3}$$

Where:

OER = Odour emission rate (ou s^{-1} per SPU) at 0°C and 101.3 kPa

C = Odour concentration as measured by olfactometry (ou)

Q = Shed ventilation rate (m^3 s^{-1}) at 0°C and 101.3 kPa

SPU = The number of SPU in the shed/room where OER was measured

4.4 Calculation of OER using VEF maker

The software program APL *Variable Emissions File (VEF) Maker* (Pacific Air and Environment, 2004), which is commonly referred to as *'VEF Maker'*, is the recommended way to calculate odour emission rates from piggery sources when using odour dispersion modelling (Tucker, 2018). The values calculated by VEF Maker are intended to calculate realistic and consistent OER for modelling purposes and are not intended to replicate the full range and dynamic variation of OER in real-world situations. The software program uses formulas specified in Nicholas *et al.* (2003) to enable estimation of OER from various configurations of sheds and ponds under a variety of weather conditions.

In this project, which is focussed on OER and odour modelling, the OER for each odour source were compared to OER calculated using VEF maker.

For shed odour sources, input parameters used to calculate OER using VEF Maker were as described by Nicholas *et al.* (2003). Ambient temperature at the time of sampling was used to determine the base OER, with multiplier factors used for the frequency of effluent flushing in the shed (allocated an effluent removal factor of either 1.0 or 1.7) or pull-plug system (assumed to be recharged with >49 mm, and allocated a factor of 1.0). Sheds that were naturally ventilated were allocated a ventilation factor of 1.0 and the mechanically ventilated sheds were given a factor of 1.0 unless the temperature was >25 °C, in which case they were given a factor of 1.5. All sheds had 'clean or moderately dirty' pens, and so were given a cleanliness factor of 1.0. Deep litter sheds were given a base OER depending on the frequency of litter removal and the ambient temperature. All deep litter sheds were naturally ventilated and had standard bedding supply rate and stocking rate, and were therefore allocated a ventilation factor of 1.0, and cleanliness factor of 1.0.

Pond OER was calculated using the seasonal formulae, with assumed VS loading rates of:

- 10 for solids settling ponds and primary SEPS (based on design VS loading rates for SEPS in the NEGIP (Tucker, 2018)
- 1 for primary anaerobic ponds
- 1 for secondary ponds and offline ponds/SEPS

Secondary ponds, offline/drying SEPS and ponds, and dry SEPS and ponds were multiplied by a value of 1/6, as prescribed by Nicholas *et al.* (2003).

The emission rate multiplying factor relating to wind speed and stability class was set at 0.3 for all area source OER because they were measured using the flux chamber, and comparisons between VEF maker and measured OER need to be on the basis of conditions within the flux chamber (described further below) and not ambient conditions. **Determining an emission factor for the conditions within a flux chamber is well outside the intended purpose of this factor in VEF Maker (which was developed using OER measurements from wind tunnels) and therefore, despite comparisons being made between measured area source OER and OER calculated with VEF Maker in the remainder of this report, it may not be an appropriate use of the VEF Maker calculations**. However, to enable comparison between calculated and measured OER values, the multiplying value of 0.3 for the factor relating to wind speed and stability class was considered appropriate because, by definition, the flux chamber has no defined wind speed (described by Nicholas *et al.* (2003) as "Wind speed category 1 (0–0.6 m s^{-1})". This selection is supported by air speed measurements inside flux chambers expected to be 0.05–0.12 m s^{-1} based on previous measurements with higher sweep rates (Hudson, 2009). Additionally, sweep air rate of 5 L min^{-1} (as used in this project) has been demonstrated to equate to 10 m wind speeds of 0.51 m s^{-1} (Prata *et al.*, 2018). In addition to low wind speed, the flux chamber does not allow for vertical mixing, and therefore was allocated with a stability class "F". Altering the selection of the wind-speed category and stability class, to represent the conditions in the flux chamber, will have a significant effect on the OER calculated using the formulas in VEF Maker—it will have a MUCH greater effect than the choice of VS loading rate or season.

4.5 Methods for dispersion modelling and separation distance investigation

A desktop investigation was performed to compare Level 1, Level 1.5 and Level 2 assessments (Table 1) as described in the NEGIP (Tucker, 2018). The hypothesis of the modelling exercise was that *'if VEF Maker overestimates emission rates, or if the odour criterion is too stringent, odour modelling will result in larger odour contours than separation distance formula methods'*. This hypothesis was formulated based on recent odour modelling experiences by Australian piggeries where odour modelling has produced larger separation distances. In reality, the separation distance calculations should be more conservative, with Level 1 assessments calculating larger odour separation distances than site-specific modelling (Tucker, 2018).

The purpose of this exercise was to calculate separation distances and perform odour modelling on multiple piggery sites, all using the same methodologies, to improve understanding about the effects of different farm features, odour criteria and modelling inputs on calculated odour separation distances.

The detailed methodology of the odour assessment investigation is described in **Appendix A**. In summary:

- Six typical Australian piggeries located in Queensland (Qld), New South Wales (NSW), South Australia (SA), Victoria (Vic) and Western Australia (WA), with a variety of shed and effluent designs and features, were used as the basis of generic modelling case study sites. While the farms were considered as generic sites, and treated like a green-field modelling exercise, details about the farm, herd size, production, sheds and the effluent/manure system were obtained to maximise the relevance of the modelling exercise for 'typical' piggeries.
- Separation distances were calculated using the Level 1 (separation distance formula) and Level 1.5 (separation distance formula with wind frequency factor) methods as described in the NEGIP. Wind frequency factors were determined using the meteorological data that was

used in the odour dispersion modelling (described below). The separation distances calculated using these methods were plotted around each piggery.

- Odour dispersion modelling (Level 2 assessment) was performed with CALPUFF. Important inputs for modelling include meteorology, terrain and odour emissions. Meteorological files for a representative year were developed at each piggery site using observed data (if it existed) or generated using TAPM. The meteorological data and terrain data were processed using CALMET in preparation for the CALPUFF dispersion modelling. Odour emission rates for the piggery sheds and ponds were calculated using VEF Maker. Odour contours based on the odour impact criteria of each Australian State, as well as the criteria defined in the NEGIP (rural dwelling[1]—3 ou, 98th percentile, 1 hour average) were plotted around each piggery.
- Odour contours from Level 1, Level 1.5 and Level 2 were compared for each piggery site.

[1] A ***rural dwelling*** on agricultural land is occupied by people who genuinely need to live there to support the agricultural use of that land (e.g. to supervise stock or crop). This is different from a ***rural residential development***, which refers to dwellings that are not primarily associated with agriculture. (https://www.planning.vic.gov.au/__data/assets/pdf_file/0026/97172/PPN37-Rural-Residential-Development_June-2015.pdf)

5. Results

5.1 Literature review

(Reproduced from the September 2018 milestone report for APL project 2017/2237, by Grant Brown)

The most significant review into OER from Australian piggeries was commissioned by the Pig Research and Development Corporation (PRDC) in 2000 (Watts, 2000) and provides a comprehensive review into emission rates and major emissions sources from piggeries. This review cites that a major problem with piggery odour research, at the time of publication, is the measurement of odour itself. The review highlighted that there were very few laboratories in Australia that were capable of performing olfactometry to measure odour concentration and, more importantly, there was no Australian Standard in place for odour concentration measurement. However, following the introduction of *AS/NZS 4323.3-2001 — Determination of odour concentration by dynamic olfactometry* (Standards Australia/Standards New Zealand, 2001), there are now laboratories in Australia capable of conducting olfactometry to this standard, which largely resolved this issue.

Watts (2000) also found that an issue with measuring odours from piggeries is the sampling techniques used to collect odour samples. The review points out that it is difficult to measure OER accurately from naturally ventilated sheds and areas sources such as ponds. This issue remains today with no agreement Australia-wide on how odour samples should be collected, or how ventilation rates should be measured, especially in naturally ventilated sheds.

In their review, Watts (2000) highlighted that most of the research at the time of the publication was focussed on odour emissions from either naturally ventilated sheds, or 'conventional' sheds. The conventional style shed referred to a design that is common in North America and Europe, which are enclosed and mechanically ventilated during cold weather. Conventional sheds also feature static manure pits that are only cleared in the spring months. The North American/European shed style is not common in Australia with the majority of piggeries using flushing sheds where the manure is removed on a daily to weekly basis. This meant that most of the research on odour emissions at the time was not relevant to Australian piggeries. However, the review by Watts (2000) concluded the following about the major factors influencing odour emissions from pig sheds:

- Temperature
    - Increasing air temperature increases odour emissions from sheds, with emissions always greater in summer than in winter (2–4 times greater)
    - Odour emissions are highest when internal shed temperatures are above 25–30 °C
- Humidity
    - Data indicated that increasing humidity within a shed increases OER
- Waste removal system
    - Deep pit litter systems (such as those commonly used in North America and Europe) tend to have higher odour than flushing sheds
    - Regular flushing of sheds decreases odour emissions
- Shed cleanliness
    - Cleaner sheds emit less odour
    - Increased flushing and hosing with improved general cleanliness was found to reduce odour emissions
- Shed age
    - Older sheds emit more odour than newer sheds. The reasons for this are not entirely clear
- Animal type and stocking density

- o Despite the fact that farrowing and weaner sheds are designed and managed differently to grower/finisher sheds, the data does not show any clear differences between stocking density or animal type
- Diet composition
    - o No evidence at the time of publication that diets have any influence on odour emissions; however, more recent international studies have shown that the pig's diet significantly affects the emission of odorants from manure (Le *et al.*, 2005; Trabue *et al.*, 2019a, b).
- Ventilation rate
    - o Ventilation rate does not have a strong effect on gross odour emissions. Increasing ventilation rate decreases internal odour concentrations, but gross emission rates remain the same. This is true for mechanically ventilated sheds and naturally ventilated sheds
    - o No published data comparing daytime and night-time emissions

Watts (2000) also reviewed the research surrounding 'deep litter' shelter piggeries with respect to OER. The only research data available at the time suggested that deep litter sheds are highly variable in their OER and tend to increase towards the end of the grow-out cycle as manure accumulates. The review suggests that the main factors influencing odour emissions from deep litter sheds include:

- ventilation rate
- air temperature
- time of occupation.

They concluded that, overall, OER from deep litter sheds were lower than from conventional sheds.

Following a review of piggery OER values reported in literature, Nicholas *et al.* (2003); Watts (2000) recommended baseline OER values that could be applied to piggery odour sources Table 7.

Table 7. Recommended OER values reported by

Odour source	**Recommended OER by** Nicholas *et al.* (2003); Watts (2000)
Shed – Effluent flushing system	• 2.5 ou s^{-1} per SPU - when temp is <10 °C • 5.0 ou s^{-1} per SPU - when temp is 10–25 °C. • 7.5 ou s^{-1} per SPU - when temp is > 25 °C
Shed – deep litter	<u>Single batch litter up to 7 weeks</u> • 1.25 ou s^{-1} per SPU - when temp is <10 °C • 2.5 ou s^{-1} per SPU - when temp is 10–25 °C. • 3.75 ou s^{-1} per SPU - when temp is >25 °C <u>Single batch bedding after 7 weeks</u> • 2.0 ou s^{-1} per SPU - when temp is <10 °C • 4.0 ou s^{-1} per SPU - when temp is 10–25 °C. • 6.0 ou s^{-1} per SPU - when temp is >25 °C
Anaerobic treatment ponds	• 9.0 ou $m^{-2}s^{-1}$ – Summer • 18.5 ou $m^{-2}s^{-1}$ – Winter • 13.75 ou $m^{-2}s^{-1}$ – Spring and Autumn

At the time of the review, Watts (2000) expressed that, despite their importance, there was very little work conducted on OER from treatment ponds, with the only data available coming from Schulz and Lim (1993) and (Smith *et al.*, 1999) which suggested that ponds are the major source of odour emissions and contribute about 75% of total farm odour emissions. The review suggested that emission rates from ponds vary with pond type i.e. primary/secondary, whether the pond was anaerobic or aerobic and the wind speed across the pond. They also suggested that emissions from ponds are highly variable and dependent on the following factors:

- pond loading rate
- pond age
- microbial population
- sludge accumulation
- pond chemistry
- pond temperature
- and other, as yet unidentified, factors.

In 2003, an update of odour research for the pork industry was commissioned by Australian Pork Limited (Nicholas *et al.*, 2003) and built upon the work by Watts (2000). This update again emphasised the importance of effluent treatment ponds as a major source of odour emissions from Australian piggeries. They suggested that pond loading rate has a significant effect on OER, with pond chemistry also being a factor but placing less emphasis on it as a contributor due to insufficient evidence at the time. Nicholas *et al.* (2003) also suggested that pond OER are strongly influenced by pond volatile solids loading rate. They concluded that pond odour emissions may be decreased by designing ponds with lower loading rates and greater depth but stated that increased sludge accumulation over time will increase the loading rate and therefore odour emissions. The review also stated that there is a lack of odour emissions rate data for secondary ponds and highlighted this as an area needing further investigation.

Watts (2000) suggested that the OER from 'pink-ponds' (i.e. ponds that support purple-sulphur bacteria) were less than those from black, bubbling anaerobic ponds, but at the time of their review, there was no quantitative OER data available. A subsequent study commissioned by APL (McGahan *et al.*, 2001) found that this was not the case and there was no relationship between the quantity of purple sulphur bacteria and OER.

A study commissioned by Australian Pork Limited (Hudson *et al.*, 2004) looked at the effect of pond loading rate and the spatial variability of odour emissions from effluent ponds. This study found that increasing pond VS loading rate did not result in an equal increase in OER, and other factors such as season had a greater influence on OER. They also concluded that pond odour emissions can be highly spatially variable and recommended at least 4 samples be taken to have an accurate representation of pond odour emissions. The study also showed temporal variability in pond odour samples with the time of day and season (winter/summer) being significant factors in determining OER. They also concluded that OER from ponds are likely to be reduced if pond surface area is reduced, permeable pond covers are put in place, and solids separation devices are employed.

In a subsequent study, Hudson *et al.* (2007) investigated the odour emissions from effluent treatment ponds with permeable pond covers. The study showed that polypropylene and shade cloth covers could reduce emission rates by 50% compared to an uncovered pond. Hudson *et al.* (2007) noted that the efficacy of permeable pond covers is probably a lot higher as the nature of the odour released from a covered pond is much less offensive, but the process of dynamic olfactometry only tests for the presence/absence of odour, not the offensiveness or character. International studies on the effect of impermeable pond covers at reducing pond odour emissions showed a much greater effect. A study commissioned by the United States Department of Agriculture (Stenglein *et al.*, 2011) showed impermeable pond covers can reduce odour, hydrogen sulphide (H_2S), and ammonia emissions by 95%. A review by (Nicolai *et al.*, 2004) looked at the effect of floating plastic covers on effluent ponds in the Mid-Western United States and reported this kind of pond cover could reduce odour emissions by 60 to 78% and reduced H_2S by 90%. To date, no additional data on OER from covered anaerobic ponds in Australia is available.

A study by Skerman *et al.* (2008) investigated the odour reduction benefits of using HLA ponds, with VS loading rates greater than 600 g VS m^3 day^{-1}, as the principal effluent treatment system. This study produced similar results to Hudson *et al.* (2004) finding that greatly increasing loading rates did not greatly increase OER compared with conventional anaerobic ponds that were designed using the Rational Design Standard (as described in the NEGIP (Tucker, 2018)). Skerman *et al.* (2008) also found that HLA ponds develop a thick crust on the surface of the pond. Ponds that develop a thick crust were found to have significantly lower OER than conventional treatment ponds. Skerman (2013) then investigated odour emissions from SEPS, at a piggery in Queensland. Their investigation found the OER from SEPS (per square metre) to be within the range of conventional anaerobic ponds and HLA ponds, but concluded that overall odour emissions from SEPS are likely to be lower than conventional ponds due to smaller surface area, and low OER from drying SEPS.

5.1.1 Identified gaps in the current data

A major component of this literature review was to identify gaps in the literature that the sampling phase of this project should prioritise to help fill. A common knowledge gap mentioned in several publications (Hudson *et al.*, 2004; Nicholas *et al.*, 2003; Skerman *et al.*, 2008) is the absence of data on secondary pond emissions. In an update of the Watts (2000) review, Nicholas *et al.* (2003) highlighted that data from secondary pond emissions is either not applicable to Australian piggeries or not done to the current olfactometry standard AS/NZS 4323.3-2001 (Standards Australia/Standards New Zealand, 2001) and recommended that emissions from secondary ponds, following covered and uncovered ponds, be an area of future focus.

Data collected prior to 2000, Dalton *et al.* (1997) suggested that odour emissions from piggery sheds were also a major contributor (14–30%) to overall OER. However, most of these estimates were based on naturally ventilated shed systems, and little data is available about the potential effects of modern mechanically ventilated piggery sheds on OER. The current trend of many pork production facilities in Australia is transitioning away from naturally ventilated sheds towards mechanically ventilated sheds. Further investigation into the effects on OER from mechanically ventilated sheds is needed.

The continual modernisation of the Australian pork industry means shed effluent management systems are constantly changing and improving. Some piggeries are now shifting to a ‘pull-plug’ system of effluent management to reduce water use. While sheds are still hosed quite often (daily/weekly) in this system, the effluent pits may sometimes only be emptied every six weeks, which could have an effect on OER. At the time of the review by Watts (2000), these systems were not common and mainly limited to South Australia. As such, little data exists on the effects of this system on OER.

Miscellaneous sources of piggery farm odours also warrant further investigation. These sources may include areas used for sludge drying and processing, mortality composting, storage and processing of digestate from a CAP or digesters, storage of imported by-products used for co-digestion, biogas flares and storage for co-digester systems as well as biogas systems. Little to no research has been conducted on the OER from these sources, while their overall contribution to piggery farm odour is likely to be minimal, they should be considered.

The literature review indicated that the following areas are lacking in OER data and should be updated during the sampling phase of this project;

- secondary ponds (following covered and uncovered primary ponds);
- effluent systems that have a CAP
- mechanically ventilated sheds
- pull-plug sheds
- miscellaneous sources — sludge drying, mortality composting, digestate storage.

5.2 Consultation with industry and stakeholders

(Reproduced from the April 2019 milestone report for APL project 2017/2237, by Grant Brown)

5.2.1 Discussions with pork industry/producers

The purpose of the consultation phase was to meet with pork industry representatives and producers with the aim of identifying current and future industry trends. Meetings with pork producers were held to ensure the odour sampling campaign covers the predominant environmental management practices and will be representative of future industry developments. These meetings highlighted several industry trends and management practices that will be included in the odour sampling phase. It was suggested that odour sampling on secondary ponds, following a CAP, be a priority as there is little odour emission data from these sources. Further sampling of SEPS was also raised as a potential source of odour with little OER data.

5.2.2 Discussions with State regulatory authorities

5.2.2.1 Queensland

Consultation with the Department of Agriculture and Fisheries' Intensive Livestock Environmental Regulation Unit was completed in December 2018. This unit is responsible for environmental regulation of licenced piggeries in Queensland. The regulatory unit explained they will largely defer to the NEGIP for direction on piggeries in Queensland. They are not concerned with the sampling devices used during the project, only that the same device/s be used consistently throughout the sampling campaign. Discussions revealed there was some concern around the OER from mechanically ventilated sheds as they have anecdotally experienced more intense odour impact from some mechanically ventilated sites, compared to some naturally ventilated ones. HLA ponds were also a potential odour source that the Queensland authorities would like to have more OER data on. Overall, the Queensland regulatory authorities are in agreement with the current project objectives and direction.

5.2.2.2 South Australia

Consultation with the Environment Protection Authority of South Australia (EPA SA) was completed in March 2019. The EPA SA stated that they believe flux-chamber odour measurement devices will yield more representative OER data, but were interested in the German Standard VDI 3880:2011 (VDI, 2011) for odour measurement. However, they will defer to the Australian/New Zealand Standard (AS/NZS 4323.4:2009) for odour sample collection, which employs the use of a flux-chamber.

The South Australian authorities also suggested some samples be taken in South Australia, but this may not be feasible. However, if some samples are taken in climates that reflect conditions in South Australia, the authorities conveyed this would be acceptable. The samples collected in Victoria and New South Wales may be similar to conditions in South Australia.

5.2.2.3 Victoria

Representatives from Agriculture Victoria were consulted about the project's proposed aims and odour sampling methodology. The discussion group were supportive of the project objectives and were in agreement with the initial project motivations that odour modelling for piggery sites often over-estimates the reality of actual odour impacts. Victorian authorities were particularly interested with emissions from piggeries that have covered ponds and encouraged odour sampling from these facilities. Odour sampling from piggeries using deep litter management, which is more prevalent in southern states, was also recommended during this discussion group.

Additionally, Victorian authorities offered to assist with finding potential pork production sites, which fit the criteria for the Victorian odour sample collection phase of the project.

5.2.2.4 New South Wales

Discussions with the New South Wales Environment Protection Authority (NSW EPA) produced similar outcomes to discussions in other states. The NSW EPA explained that most of the odour complaints they receive come from older piggeries, during hotter months, but the majority of piggeries are well managed and don't cause odour nuisance. NSW authorities suggested biogas capture on piggeries in NSW is becoming more popular and odour emissions data from piggeries with biogas facilities may prove helpful.

The NSW EPA stated that it is critical that some of the odour sampling be conducted in NSW due to concerns that samples taken elsewhere may not accurately reflect conditions in their State. Based on this feedback, the project methodology was expanded to include odour sampling in NSW.

5.2.3 Implications of consultation phase

Based on the discussions with the State regulatory authorities, the odour sampling phase of the project was conducted using a flux chamber for odour sample collection from area sources. The various states mostly defer to the Australian Standards and the NEGIP for odour sampling methodology and odour buffer assessment. Table 8 summarises the preferred sample collection method for each State.

Table 8. Preferred method of area source sampling by State regulators

State	Flux Chamber	Wind Tunnel	Comments
Queensland	Yes		Defer to Australian Standard (Flux chamber)
South Australia	Yes	No	Interested in DVI (German Standard)
Victoria	Yes	No	
New South Wales	Yes		Defer to Australian Standard (Flux chamber)

Consultation with the regulatory authorities in each State confirmed that they were largely on-board with the project goals and methodology. No alterations to project objectives or schedules were recommended based on the discussions with the various regulatory authorities. Industry and regulator consultation identified the following areas as priorities for the odour sampling phase:

- secondary effluent ponds
- SEPS and HLA ponds
- mechanically and naturally ventilated sheds
- flushing and pull-plug sheds
- deep litter sheds
- biogas facilities

5.3 OER – data summary

5.3.1 OER by farm – Sheds

The OER measured from the sheds at different farms in QLD (Farm A), NSW (Farms B, C and D) and VIC (Farm E) are represented in Figure 12.

At Farm A, the OER per SPU (OER) was measured from weaner and grower/finisher sheds with either pull-plug or flushing effluent systems. The results showed that the average OER was generally higher from pull-plug sheds compared to flushing sheds (Figure 12). There were no obvious differences between the weaner and grower/finisher sheds having pull-plug effluent system (Figure 12). In the sheds with flushing effluent system, however, the average OER was slightly higher from the weaner sheds compared to grower/finisher sheds (Figure 12).

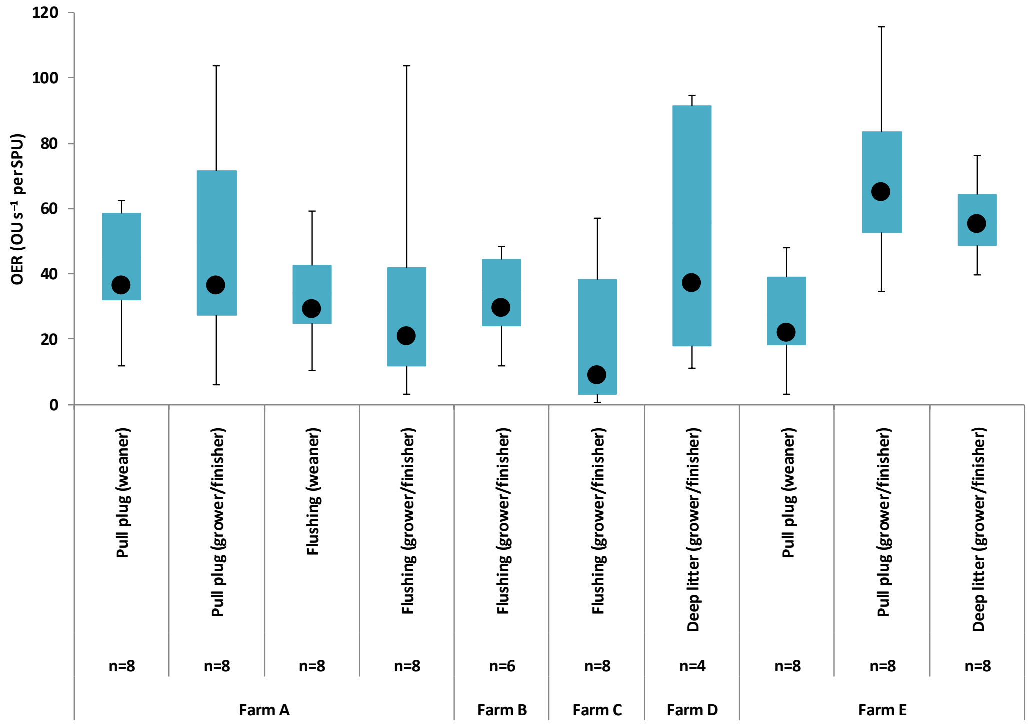

Figure 12. Odour emission rates (OER) per standard pig unit (SPU) measured from sheds at the studied farms in QLD (Farm A), NSW (Farms B, C and D) and VIC (Farm E)[1]

At Farms B and C, the OER was measured from grower/finisher sheds with effluent flushing systems. The average OER measured from these sheds at Farm B were generally similar to or higher than those measured at Farm C and Farm A (Figure 12).

At Farm D, the OER was measured from deep litter sheds hosting grower/finisher pigs. Despite the higher variations, the average OER measured from the deep litter sheds at Farm D was lower than the deep litter sheds at Farm E (Figure 12).

The average OER from the pull plug grower/finisher sheds were higher at Farm E (naturally ventilated) than those measured from pull-plug grower/finisher shed at Farm A (mechanically ventilated). The pull-plug weaner shed, however, had a lower average OER compared with the similar sheds at Farm A (Figure 12).

The ventilation rates measured at Farms A to E are shown in Figure 13. The two grower/finisher sheds at Farm E were naturally ventilated. During both odour sampling events at Farm E, strong winds perpendicular to the shed contributed to high ventilation rates (Figure 13). The maximum ventilation rates measured at these sheds were much greater than the maximum ventilation rate in the mechanically ventilated grower/finisher sheds at Farm A, which had higher SPU occupancy. We suggest that the high OER measured at Farm E was more likely attributed to the strong winds at the time of sampling than shed design or management factors.

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

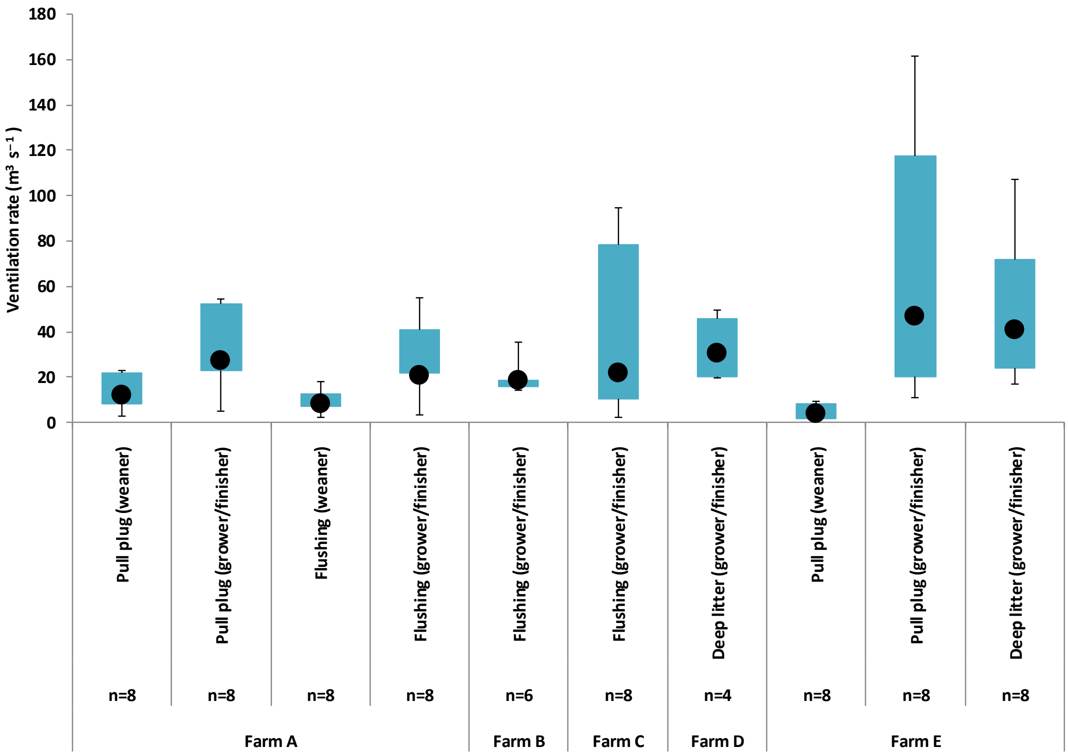

Figure 13. Ventilation rates measured from the sheds at the studied farms in QLD (Farm A), NSW (Farms B, C and D) and VIC (Farm E)[1]

5.3.2 OER by farm – Ponds

In this study, Farms A and E had anaerobic pond systems. While both farms had primary ponds, Farm A had solid settling and secondary ponds and Farm E had an offline drying pond, which had liquid effluent that was surrounded by dried sludge (dry material).

The average OER per square meter measured form the primary pond at Farm A was higher than those measured from the primary pond at Farm E (Figure 14).

At Farm A, the average OER measured from the primary ponds were slightly higher than the OER measured from the solid settling and secondary ponds (Figure 14). At Farm E, the primary ponds had a slightly higher average OER than the drying ponds, and the drying pond (dry material) had the lowest average OER at this farm (Figure 14).

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[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans.

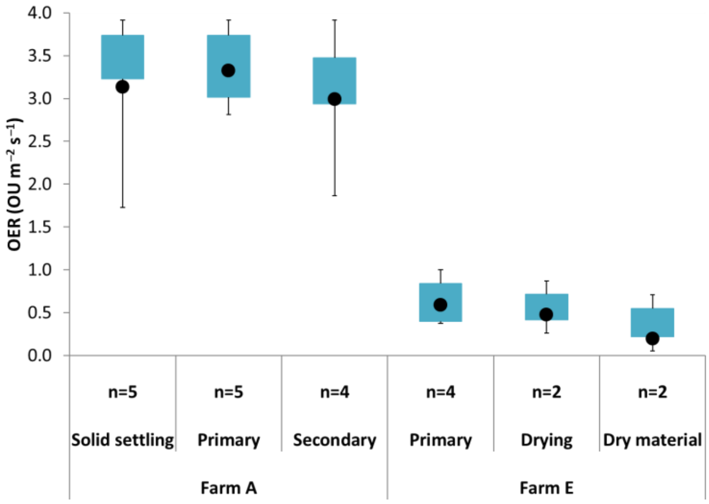

Figure 14. Odour emission rates (OER) measured from ponds at Farms A and E[1]

5.3.3 OER by farm – SEPS

The OER was measured from SEPS at Farms B, C and D. The average OER measured from the active SEPS and secondary holding pond (which takes effluent from the tail-end of the active SEPS) at Farm B were less than at Farm C, and these were both less than the SEPS sources at Farm D (Farm B < Farm C < Farm D; Figure *15*). The secondary holding ponds after SEPS had higher average OER than the active SEPS at Farms B and C (Figure *15*), and were higher than the OER from the secondary holding pond at Farm A, which takes effluent from an anaerobic pond system (Figure 14).

The average OER measured from the drying and dried SEPS were within the same range at Farms B and C (Figure *15*), and was comparable to the offline drying primary anaerobic pond at Farm E (Figure 14).

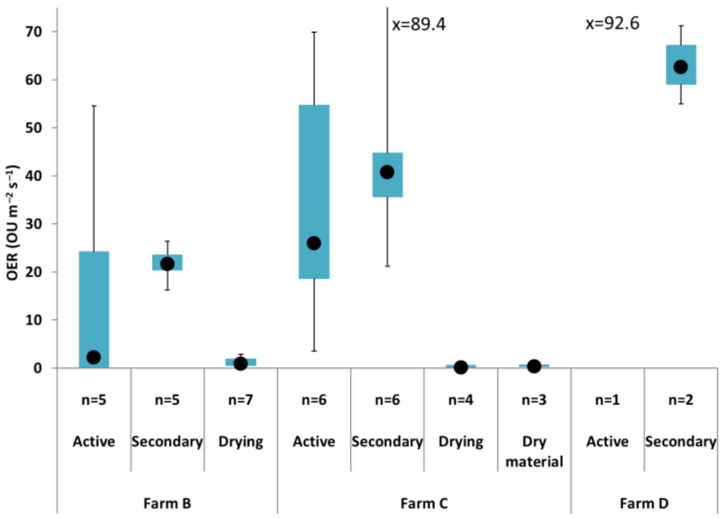

Figure 15. Odour emission rates (OER) measured from sedimentation and evaporation pond systems (SEPS) at Farms B, C and D. The x values (Farms D and C) show the OER of a single measurement that could not be fitted in the scale of this graph[7]

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

5.3.4 *OER by farm – Compost piles*

The OER from the compost piles were measured at Farms A, C and E. The compost piles at Farms A and C were mortality compost piles that were covered with pond solids or straw/sawdust, respectively. The OER from the mortality composting piles were measured from locations where mortalities had been placed 3–7 days earlier. The compost piles at Farm E were eco-shelter litter compost piles. The variations in OER measured from the compost piles are reported in section 5.7, Figure 27.

5.3.5 *Unpublished OER data from Third-Party sources*

To complement the OER measurements made during this project, OER data was acquired from several piggeries, who had commissioned their own odour studies between 2006 and 2018. In total, there were 80 OER values provided from sources including farrowing sheds, effluent ponds, SEPS and manure compost/stockpiles (Table 9). These piggery-commissioned studies typically focussed on one aspect of their production system and therefore did not necessarily include OER data from all major farm odour sources.

OER reports from the Third-Party piggeries did not consistently provide detail about the odour source, farming practices odour sampling details (flushing rates, time of day, ambient conditions etc.) and therefore could not be directly compared with the OER data measured during this project. Third-Party OER data from effluent ponds, SEPS and compost (or manure/pond solids) were included if they were measured with a flux chamber using the methods described in AS/NZS 4323.4:2009. Shed OER data was included where the shed odour concentration and ventilation rate were measured. All Third-Party odour concentrations were measured at olfactometry laboratories that complied with AS/NZS 4323.3-2001.

Table 9. OER data summary from Third-Party sources

Odour source	**Season**	**Data count (*n*)**	**Area source OER**[∞] **(ou m^{-2} s^{-1})**	**Shed OER**[∞] **(ou s^{-1} per SPU)**
Farrowing shed	Summer Winter	8 4		121.5 (93.3–147.8) 35.5 (21.2–84.9)
SEPS - Active	Summer Winter	19 21	2.8 (0.24–51.5) 1.4 (0.26–33.7)	
SEPS – drying phase (combined liquid and solids surfaces)	Summer Winter	9 5	1.83 (0.04–2.6) 1.05 (0.22–7.1)	
SEPS – secondary holding pond	Winter	2	0.39 (0.39–0.39)	
Pond – solids settling	Summer	4	0.10 (0.04–0.40)	
Compost (stockpile SEPS solids)	Summer Winter	3 5	0.37 (0.34-0.40) 0.14 (0.06–0.32)	

[∞]data displayed—'geometric mean (minimum–maximum)'

5.4 Analysis of OER – sheds

In the following sections, the OER per SPU data from all of the farms were combined to enable general comparisons between the different types of sheds, ventilation systems and effluent systems.

5.4.1 Shed effluent systems

OER per SPU measured from deep litter (straw) sheds suggested that they were generally higher than effluent (flushing and pull-plug) sheds (Figure 16). It was also observed that the average OER measured from the pull-plug sheds were slightly higher than those measured from the flushing sheds (Figure 17).

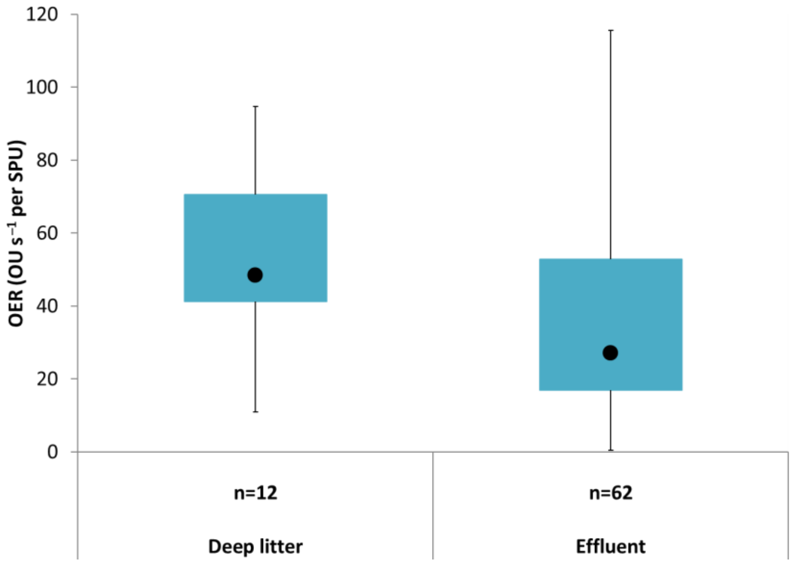

Figure 16. Odour emission rate (OER) per standard pig unit (SPU) measured from deep litter (straw) and effluent (flushing and pull-plug) sheds[1]

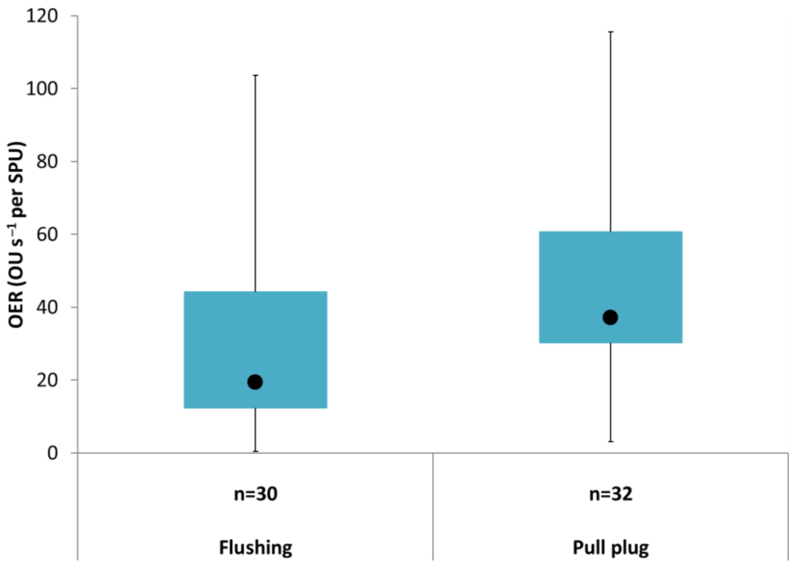

Figure 17. Odour emission rate (OER) per standard pig unit (SPU) measured from flushing and pull-plug sheds[8]

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

The effect of flushing on OER was investigated at Farm A. Comparing the OER before and after flushing at Farm A showed that flushing generally reduced the OER in both the pull-plug and flushing sheds (Figure 18). "Before flush" odour sampling was conducted within 3 to 31 days (average 22.5 ±12.10) since the last flush in pull-plug sheds, and 3 to 8 days (average 4.75 ± 2.18) since the last flush in the flushing sheds. The "after flush" OER was measured one day after flushing the sheds. The data included both winter and summer OER.

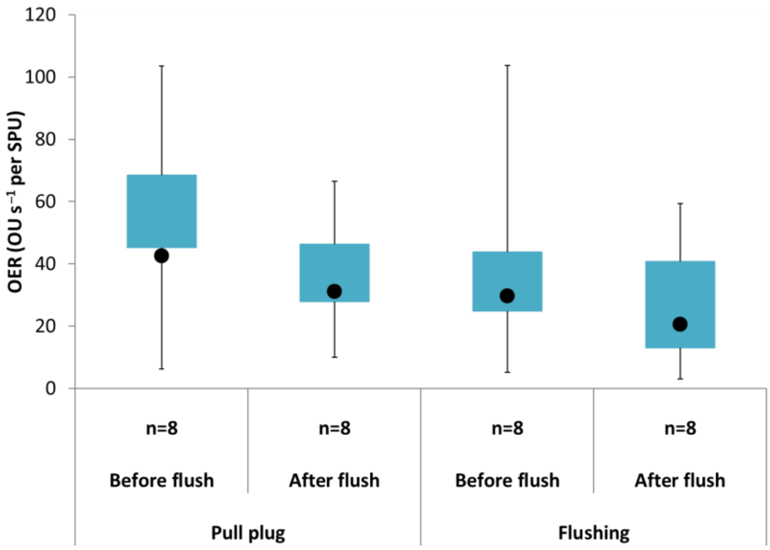

Figure 18. Odour emission rate (OER) per standard pig unit (SPU) in pull-plug and flushing sheds measured before and after flushing at Farm A[1]

5.4.2 Shed ventilation system

Naturally ventilated sheds had similar, but slightly higher average OER compared with the mechanically ventilated sheds (Figure 19). The data combined sheds with pull-plug, flushing and straw (deep litter) effluent systems in summer and winter.

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

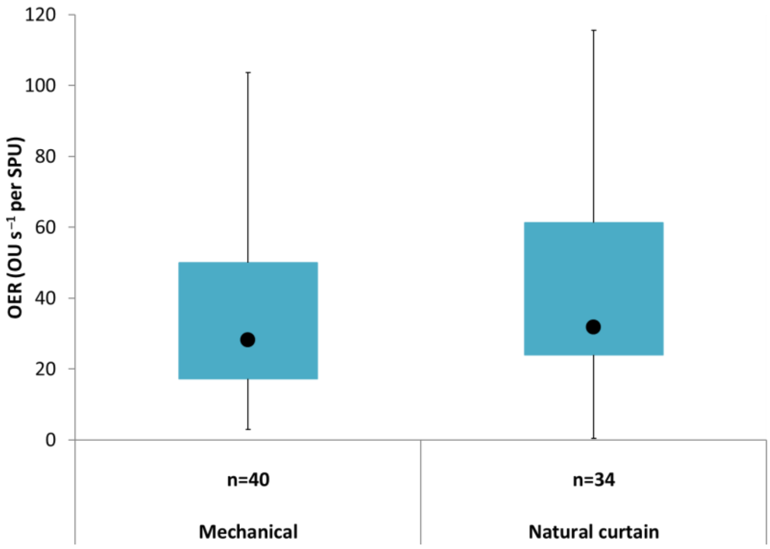

Figure 19. Odour emission rate (OER) per standard pig unit (SPU) measured from mechanically and naturally ventilated sheds[1]

At Farm A, odour sampling was undertaken in the early morning (to represent minimum ventilation conditions) and then repeated in mid-to-late morning after ventilation rate had substantially increased due to increasing ambient temperature. The OER measurements at Farm A showed that the average shed OER was lower in the early morning compared with those in the mid-to-late morning (Figure 20). Data from weaner and grower/finisher sheds with pull-plug and effluent flushing systems, from both summer and winter, were combined for this comparison.

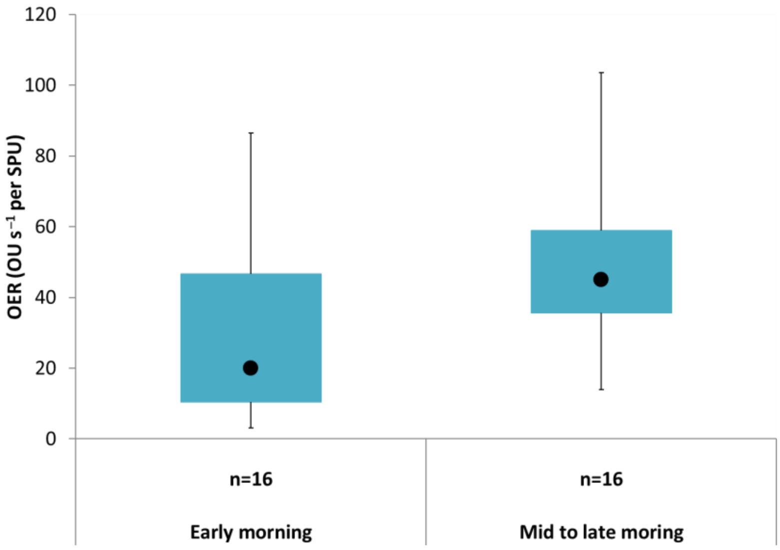

Figure 20. Odour emission rate (OER) per standard pig unit (SPU) measured in the early morning and mid-to-late morning at Farm A[10]

Principal component analysis (PCA) was used to investigate relationships and influencing factors between OER per SPU, shed ventilation rate as well as shed and ambient temperature and relative humidity (Figure 21). The first two factors of the PCA (ventilation rate and ambient temperature) could explain 76% of the variations.

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[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

The PCA results showed that OER per SPU was generally correlated with the ventilation rate and ambient temperature as they were grouped on the upper left side of the graph (Figure 21). The correlations between OER, ventilation rate and ambient temperature were significant ($P < 0.05$).
The OER per SPU was not correlated with the ambient and shed humidity as they are at right angles to each other on the PCA graph (Figure 21).

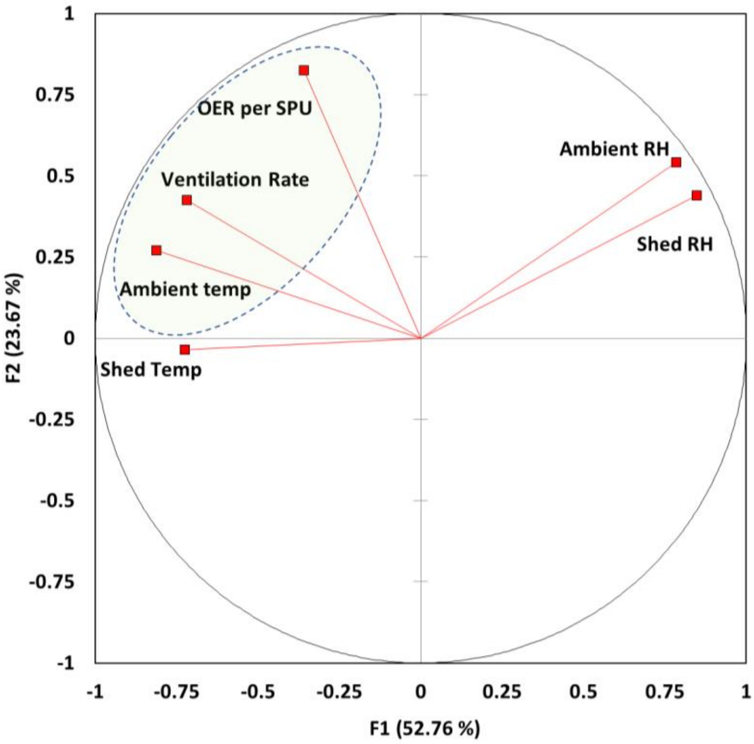

Figure 21. Principal component analysis (PCA) showing the relationships among the odour emission rate (OER) per standard pig unit (SPU) and shed ventilation rate, shed and ambient temperature (Temp) and humidity (RH)

Regression models were then developed to identify the relationships between the OER per SPU and the ventilation rate separately for mechanically and naturally ventilated sheds hosting either weaner or grower/finisher pigs.

Ventilation rate could explain 90% of the variations (adjusted $R^2 = 0.90$) in OER per SPU in the weaner sheds that had mechanical ventilation systems. Ventilation rate could also explain 87% of the variations in OER per SPU in the grower/finisher sheds with mechanical ventilation system.

In the naturally ventilated sheds (grower/finisher), the sheds' OER per SPU responded differently to the ventilation rate at different ambient temperature classes. At the ambient temperatures < 20 °C, ventilation rate explained 91% of the variations in the OER per SPU (Figure 22). The relationship was weaker at higher temperatures (> 20 °C) where 67% of the variations in OER per SPU could be explained by the ventilation rate (Figure 22).

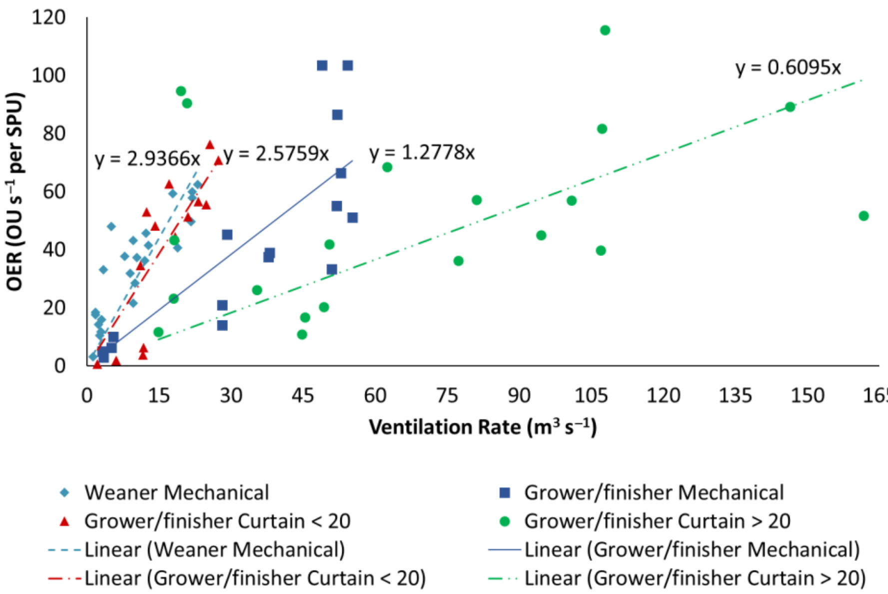

Figure 22. Relationships between ventilation rate and odour emission rate (OER) per standard pig unit (SPU) in weaner and grower/ finisher sheds with mechanical and natural ventilation systems[1]

5.4.3 *Pig class*

The average OER per SPU measured from the grower/finisher and weaner sheds were similar in this study. (Figure 23). The grower/finisher data combined the mechanically and naturally ventilated pull-plug, flushing and straw (deep litter) sheds, and weaner data combined the mechanically ventilated pull-plug and flushing sheds collected in summer and winter campaigns.

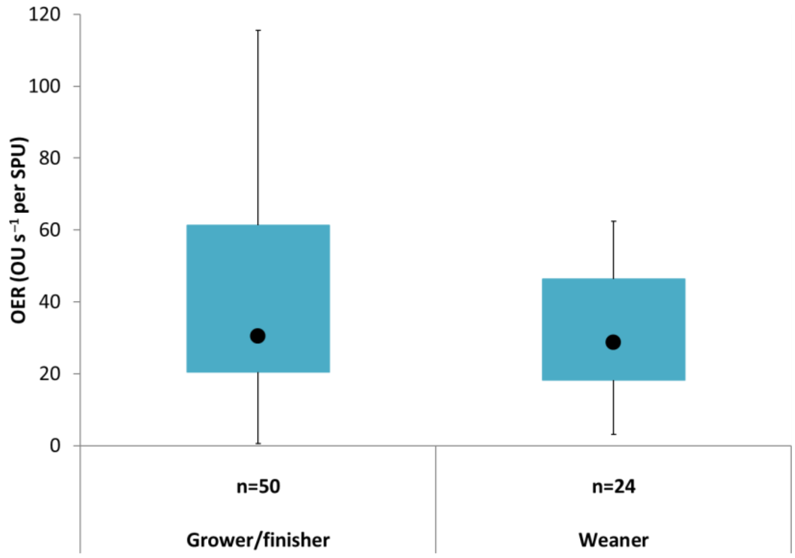

Figure 23. Odour emission rate (OER) per standard pig unit (SPU) measured from grower/finisher and weaner sheds[2]

[1] Notation '< 20' and '> 20' are related to the ambient temperature (°C)

[2] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

5.4.4 Seasonal variations

Our general observation indicated that the sheds' average OER per SPU was lower in winter compared to summer (Figure 24).

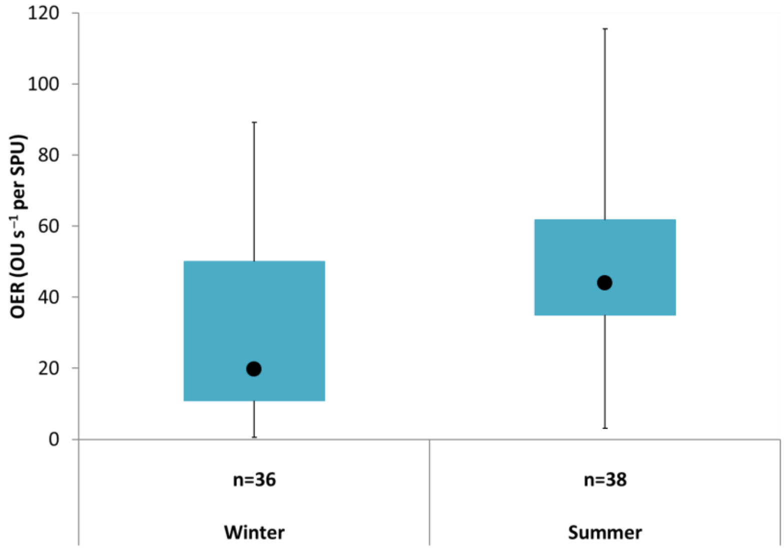

Figure 24. Odour emission rate (OER) per standard pig unit (SPU) measured from sheds in winter and summer[1]

5.5 OER – Ponds

5.5.1 Pond type

Pond OER was similar from primary and secondary anaerobic ponds, but these were less than was measured from solids settling ponds. The lowest OER was measured from dry/crusted surfaces in ponds that were drained and allowed to dry (Figure 25).

Summary of OER for ponds: solid settling > primary ≈ secondary > dry material.

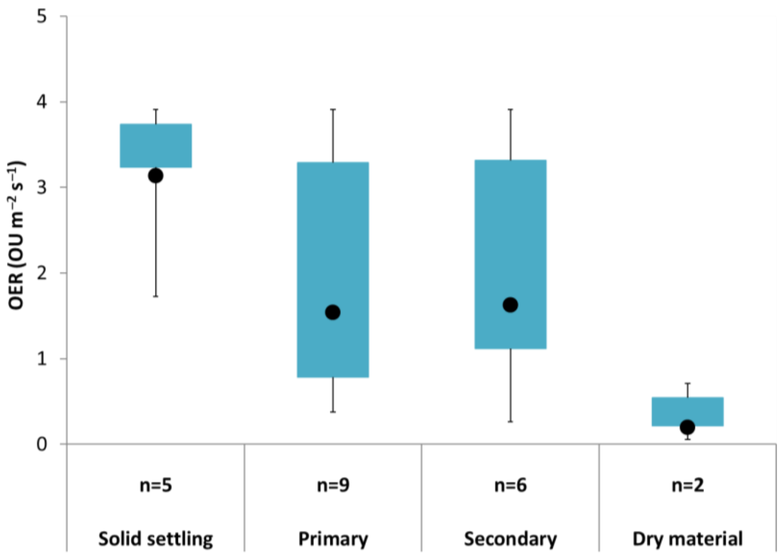

Figure 25. Odour emission rate (OER) from different types of ponds[13]

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

5.6 OER – SEPS

The OER measured from the active and secondary SEPS were higher than those measured from drying and dried (dry material) SEPS (Figure 26). The average OER from the secondary SEPS were the greatest, followed by active SEPS. The offline drying SEPS had the lowest OER, with very little difference between liquid and dried/crusted surfaces.

Summary of OER from SEPS: secondary ≈ active > drying ≈ dried (dry material).

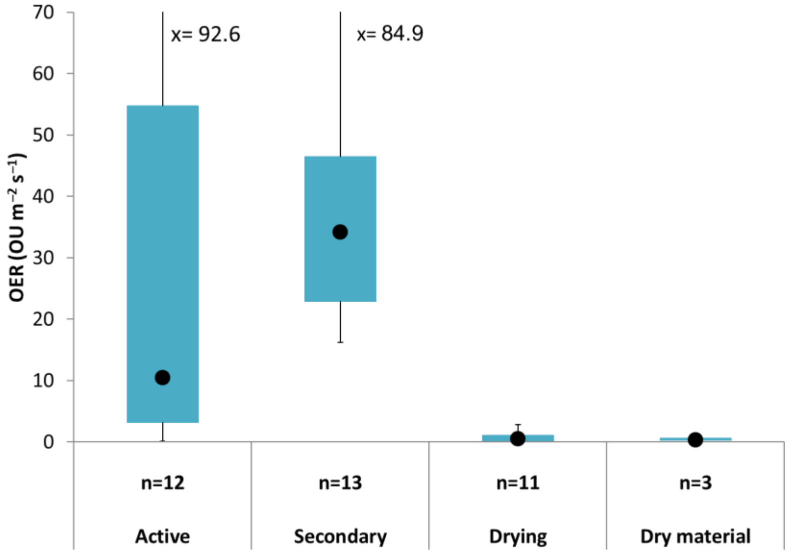

Figure 26. Odour emission rates (OER) measured from different types of sedimentation and evaporation pond systems (SEPS). The x-values show OER of a single measurement that could not be fitted in the scale of this graph[1]

5.7 OER – Compost piles

The results showed that the average OER from the mortality composting windrows that were covered with pond solids were higher than those from the mortality composing that were covered with straw/sawdust (Figure 27). The OER measured from the eco-shelter litter composts were in the same range as mortality composting covered with straw/sawdust (Figure 27). For this comparison, OER data were combined from the summer and winter sampling campaigns.

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

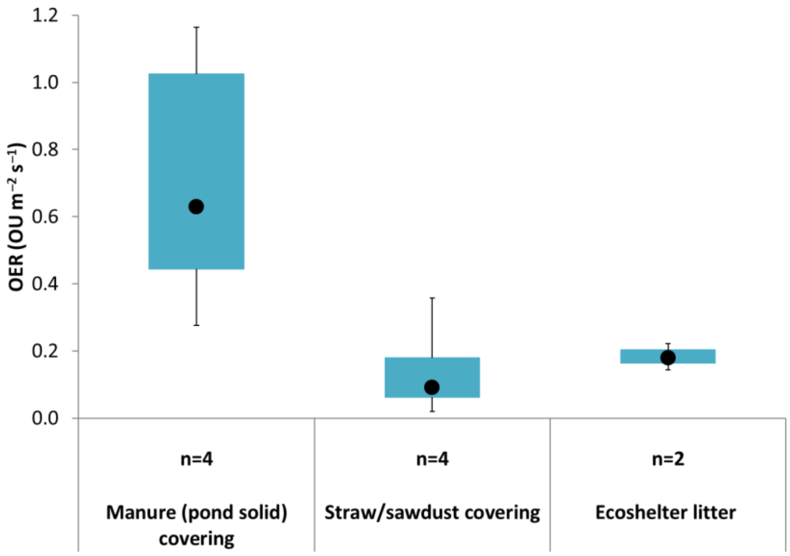

Figure 27. Odour emission rate (OER) from mortality compost covered with pond solid manure or straw/sawdust and eco-shelter litter compost[1]

Our observations indicated that the average OER from composts were generally higher in summer and lower in winter (Figure 28). The data combined the OER from all compost types.

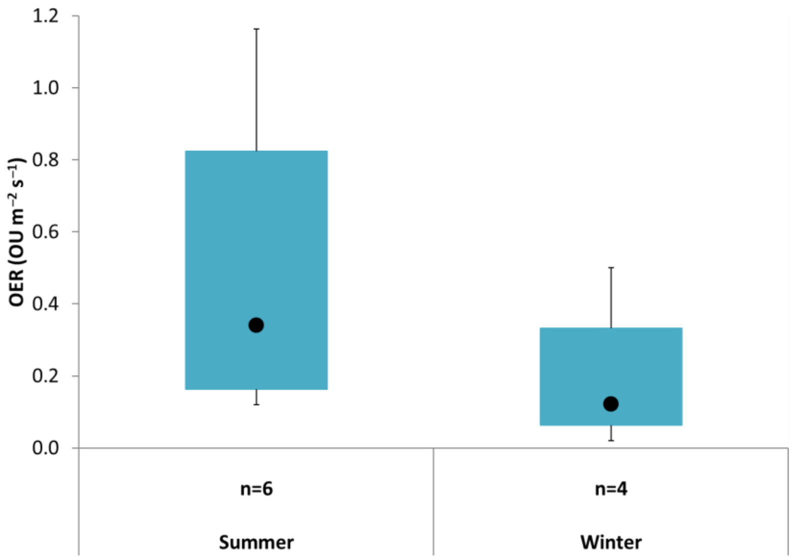

Figure 28. Odour emission rate (OER) from composts in winter and summer[16]

5.8 OER data from Third-Party sources

5.8.1 Sheds

Average OER from Third-Party shed measurements were generally higher than the OER measured by DAF (Figure 29). DAF's data included the mechanically and naturally ventilated sheds with deep litter

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

or effluent flushing systems, while the Third-Party data only included OER from mechanically ventilated sheds with effluent flushing systems.

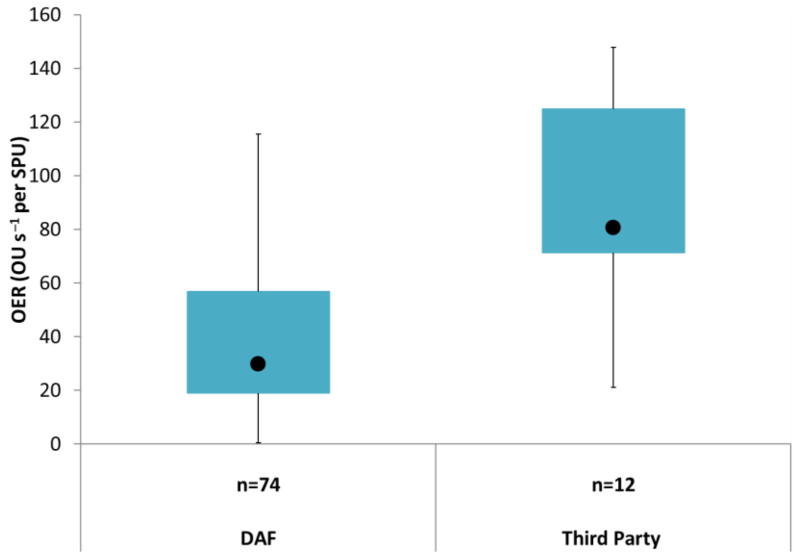

Figure 29. Odour emission rates (OER) per standard pig unit (SPU) measured from sheds by DAF and a Third-party[1]

5.8.2 SEPS

The results showed that average OER from the active SEPS measured by the Third-Party were generally lower than those measured by DAF (Figure 30). Relatively similar OER values were measured by the Third-Party and DAF from the offline SEPS (Figure 31).

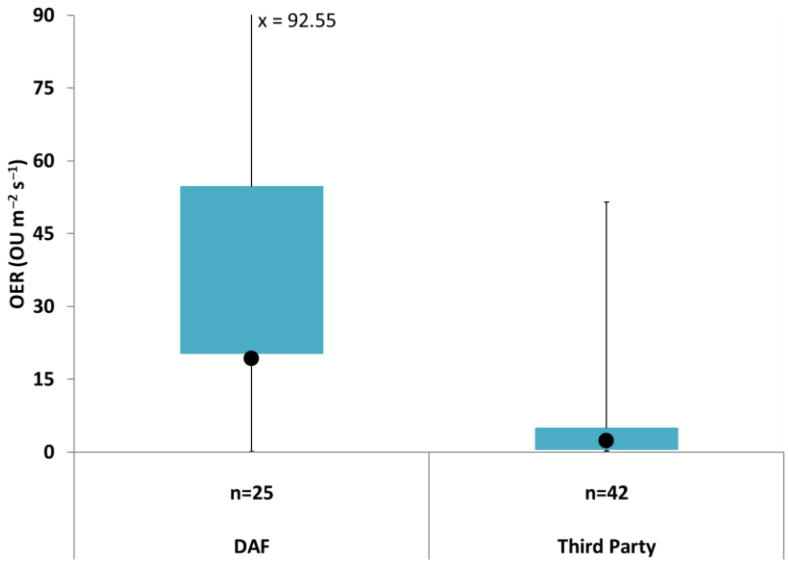

Figure 30. Odour emission rates (OER) measured from active sedimentation and evaporation pond systems (SEPS) by DAF and a Third-Party. The x values (Farms D and C) show the OER of a single measurement that could not be fitted in the scale of this graph[16]

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

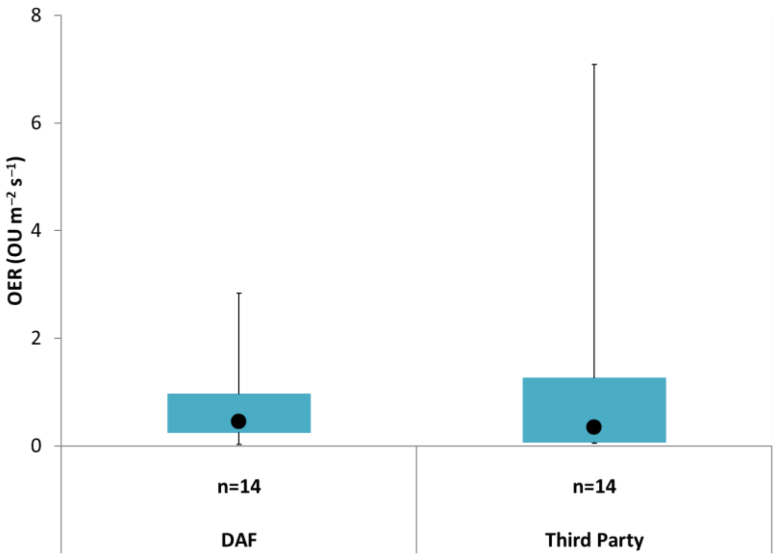

Figure 31. Odour emission rates (OER) measured from offline sedimentation and evaporation pond systems (SEPS) by DAF and a Third-Party[1]

5.8.3 Composts

OER from the compost piles measured by the Third-Party were similar to DAF's results (Figure 32). DAF's data included mortality composting, covered with pond solid manure or straw/sawdust, and eco-shelter litter composting. The Third-Party data included SEPS solid manure composting/stockpiling.

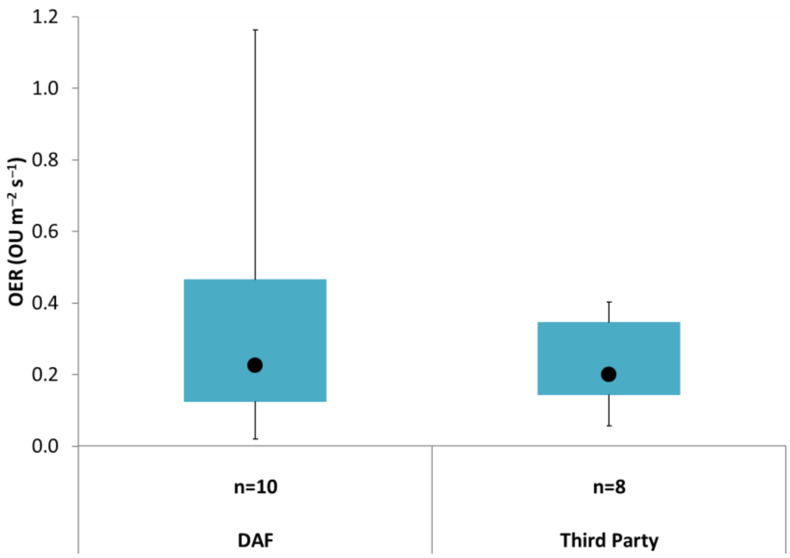

Figure 32. Odour emission rate (OER) from compost piles measured by DAF and a Third-Party[17]

[1] The boxes represent 25th and 75th percentiles, whiskers represent maximums and minimums and the close circles represent the geomeans. OU stands for odour unit.

5.9 Comparison of measured OER to calculated OER using VEF Maker

The equations used in VEF Maker originate from the report by Nicholas *et al.* (2003) and were used to calculate an OER for the specific conditions that existed during each of the OER measurements (Table 10). OER values calculated for area sources using VEF Maker are sensitive to the selection of wind speed and stability class parameters.

Table 10. Comparison of OER measured in this project with OER calculated using VEF Maker

Source	Type	Measured OER*	Measured OER (min-max)	VEF Maker[∞] OER (min-max)
Shed (OU s^{-1} per SPU)	Grower/finisher	30.4	0.53–115.6	2.5–8.5
	Weaner	28.7	3.1–62.4	2.5–11.3
	Mechanical	28.2	3.0–103.6	2.5–11.3
	Natural	31.9	0.5–115.6	2.5–7.5
	Deep litter	48.5	11.0–94.7	2.5–6.0
	Effluent	27.2	0.5–115.6	2.5–11.3
	Flushing	19.4	0.5–103.6	4.3–8.5
	Pull-plug	37.1	3.1–115.6	2.5–11.3
Pond (OU m^{-2} s^{-1})	Solid settling	3.13	1.7–3.9	2.3–5.4
	Primary	1.5	0.4–3.9	2.2–5.4
	Secondary	1.6	0.3–3.9	0.4–0.9
	Dry material	0.2	0.05–0.7	0.4–0.4
SEPS (OU m^{-2} s^{-1})	Active	10.4	0.1–92.6	2.3–5.4
	Secondary	34.1	16.2–89.5	0.4–0.9
	Drying	0.5	0.03–2.8	0.4–0.9
	Dry material	0.4	0.2–0.6	0.4–0.9

*Geomean
∞Pacific Air and Environment (2004)

As expected, the VEF Maker calculations did not produce OER covering the full range of OER measured during this project. For primary ponds, the VEF calculations produced higher OER than the measured values, whereas peak OER measured at the secondary ponds were greater than the calculated values. VEF Maker calculated lower OER for SEPS compared to measured OER, although further research is required to determine why OER from these SEPS were greater than previously measured (Skerman, 2013). Regarding shed OER, VEF Maker frequently calculated higher OER during periods of lowest OER; however, peak measured OER was greater than those calculated by VEF Maker.

5.10 Results from odour dispersion modelling study

Detailed results from the separation distance calculation and odour modelling exercise for each of the six example piggeries are presented in **Appendix A**. The odour modelling exercise produced plots of calculated separation distances and odour contours (Figure 33 is an example of one of these plots), and wind-roses (example provided in Figure 34, which summarised the directions of dominant winds for each site).

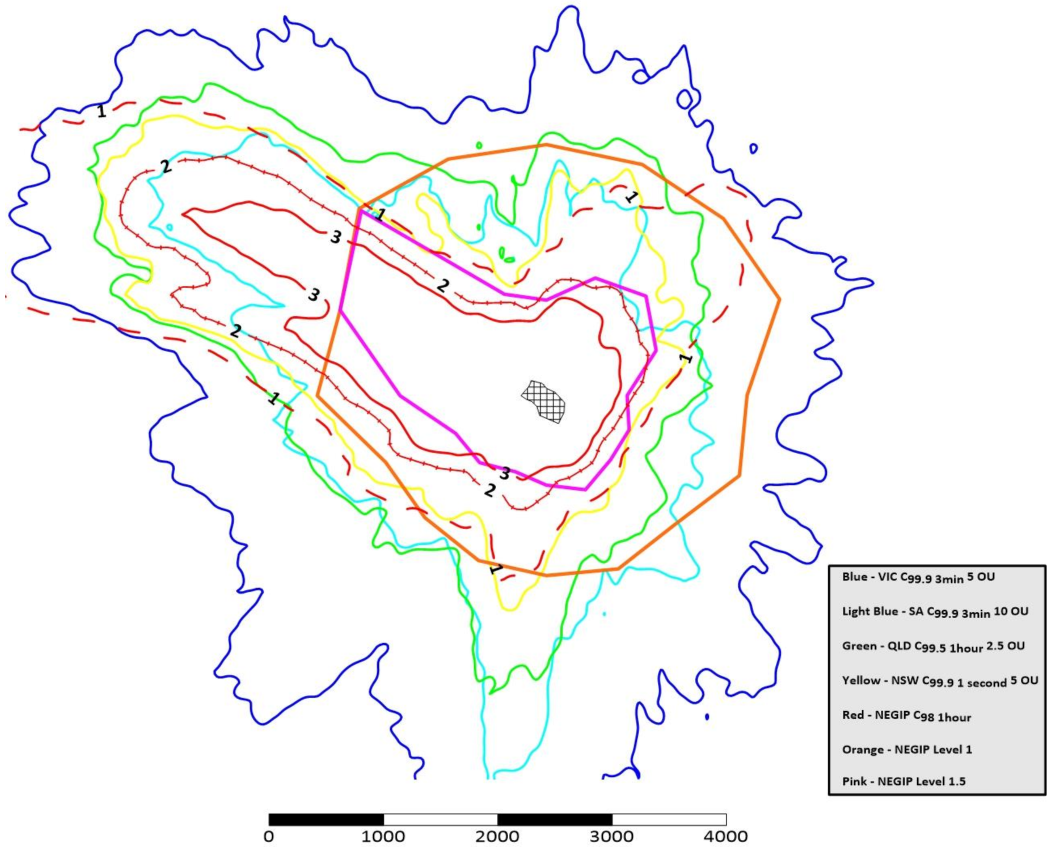

Figure 33. Example of odour modelling results - odour contours and separation distances around the generic piggery site (black hatched area)

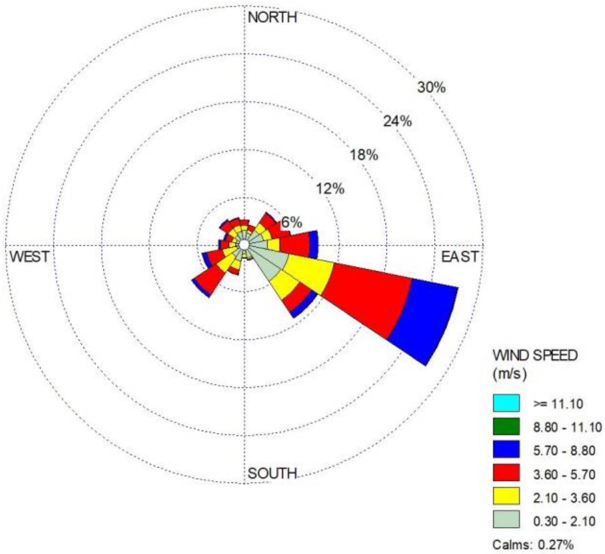

Figure 34. Wind rose showing ESE dominant wind direction for the generic piggery in Figure 33

6. Discussion

6.1 OER from sheds

OER was successfully measured from sheds at five farms with a variety of effluent management and ventilation configurations, as prioritised from the industry and stakeholder consultation processes.

Mechanically ventilated sheds were much simpler to measure odour emissions from, compared to naturally ventilated sheds, due to a consistent odour emission point and controlled ventilation that can be estimated with a combination of on-farm measurements (fan RPM and shed static pressure) and fan test data. Naturally ventilated sheds, on the other hand, are a persistent challenge for odour measurement, especially due to difficulties associated with measuring natural ventilation rates (Ogink *et al.*, 2013) and the errors and uncertainty that are known to exist regardless of the method used (Calvet *et al.*, 2013). We suggest that that the OER from mechanically ventilated sheds is also likely to be more closely related to the ventilation needs of the pigs, for temperature control, rather than being related to the wind conditions at the time, which may have no relationship to the pig production environment.

The range of OER per SPU measured in this project (0.5–115.6 ou s^{-1} per SPU) demonstrated a similar range to the OER per SPU reported by Nicholas *et al.* (2003) (0.3–192 ou s^{-1} per SPU, including Australian OER data 1.3–45.5 ou s^{-1} per SPU), which was the most recent review of OER by the Australian pork industry.

Shed OER measured in this project tended to be lower than OER reported in Third-Party data; however, The Third-Party data was all measured from farrowing sheds compared to weaner and grower/finisher shed in this project. Differences in ventilation rates, shed design and stocking density may have contributed to the observed differences in OER.

Average OER indicate that OER per SPU generally tended to be higher:

- at higher temperature (contributing to higher OER in summer)
- in grower/finisher sheds (compared to weaner sheds)
- in pull-plug sheds (compared to effluent flushing and deep litter sheds, which were similar to each other).

Caution must be exercised in assigning too much significance to these general trends, because some of the comparisons are made across multiple farms, and different sampling days, where individual farm characteristics (e.g. diet, shed design) or weather conditions (e.g. wind speed or direction) may have influenced the measured OER.

In a similar manner to the recommendation by Skerman *et al.* (2019) that pond grab-sample measurements of OER should only be considered a "snap-shot of progressively changing conditions [of] non-steady state systems", caution should be applied to the odour grab-samples that we measured at piggeries in this project. At each shed in this study, there are constant changes in manure quantity, effluent quantity, pig activity, ventilation and other factors that are known to affect emission rates.

6.2 OER from ponds and SEPS

OER was successfully measured from anaerobic effluent treatment ponds at two farms, and from SEPS at three farms, with a focus on effluent systems incorporating a CAP for biogas recovery, as prioritised from the industry and stakeholder consultation processes. All sampling was performed using a flux chamber, as requested by the State regulatory authorities. One unintended consequence of using the flux chamber, is that the OER measurements made in this project are not comparable to those reported by Nicholas *et al.* (2003), which were based on measurements with wind tunnels.

The OER measured from solids settling and primary anaerobic ponds (0.4-3.9 ou m^{-2} s^{-1}) were similar to those reported by Hudson *et al.* (2009) (0.02-3.9 ou m^{-2} s^{-1}). OER measured from active SEPS (0.14-92.6 ou m^{-2} s^{-1}), were generally higher than those reported by Skerman (2013) or Hayes *et al.* (2008) for active SEPS (0.24-33.7 ou m^{-2} s^{-1}). Third-Party OER data for active SEPS (0.2-51.5 ou m^{-2} s^{-1}) were also lower, but more similar to the OER measured in this project. Effluent draining into secondary ponds from these primary ponds or active SEPs recorded similar OER values to the primary pond/SEPS (1.9-3.9 ou m^{-2} s^{-1} after the primary pond and 16.2-89.4 ou m^{-2} s^{-1} following the active SEPS). However, once these ponds were taken offline (drained of effluent and left to dry), the OER was substantially lower (0.03-2.8 ou m^{-2} s^{-1}) regardless of whether the surface was liquid effluent or a dry/drying surface of manure/sludge solids. OER for drying SEPS was similar to, or less than, those published by Hayes *et al.* (2008) or supplied as Third-Party data to the project by Australian piggeries (0.04-7.1 ou m^{-2} s^{-1}).

During this project, a strong emphasis was placed on measuring OER from farms that had a CAP for biogas collection. At these farms, the CAP was located before a pre-existing pond system or SEPS. Anecdotally, it was suggested that the CAP should reduce the VS loading into the existing pond systems and reduce the required volume for these “now secondary” ponds. The expectation of reduced VS potentially influenced the management of pond sludge in the existing effluent system. Additionally, it was observed that the HLA solids settling pond and active SEPS, following the CAP, did not develop a dry surface crust as described in NEGIP (Tucker, 2018). It is suggested that the effluent and sludge exiting the CAP may have different properties than solids being collected directly from the piggery sheds, and this may require different treatment or management strategies to minimise odour emissions.

Finally, it must be remembered that “ponds are non-steady state systems and so undergo progressive change between desludging events, making interpretation of grab sampling data difficult….sampling of specific ponds over a usual project period of 2-3 years, only gives a snap-shot of progressively changing conditions” (Skerman *et al.*, 2019). Therefore, additional odour measurements are required in a focussed study that also considers the pond design, operation, loading, chemistry and microbiology, to compare with the OER values reported in this project.

6.3 OER from compost

OER was measured from mortality composting or manure composting windrows or piles that were covered with either sawdust or straw, manure from deep litter sheds, or solids that were removed from the effluent pond system.

OER values measured from compost windrows in this project (0.28-1.16 ou m^{-2} s^{-1} for mortality composting windrows using pond solids for covering; 0.02-0.36 ou m^{-2} s^{-1} for mortality composting using a sawdust/straw mixture for covering; and 0.14-0.22 ou m^{-2} s^{-1} for deep litter compost) are in good agreement with OER from manure and mortality composting operations in other intensive animal industries. OER from spent hen composting operations in the egg industry ranged from 0.4-1.1 ou m^{-2} s^{-1} for windrows manure covering and 0.15-0.5 ou m^{-2} s^{-1} for windrows with sawdust covering (McGahan, 2014). The OER values measured in this project were also similar to the Third-Party OER data.

The OER values from the mortality composting piles were measured from locations where mortalities had been placed 3–7 days earlier. Based on OER measurements from mortality composting windrows in other animal industries (McGahan, 2014), maximum OER is expected to reduce following this early phase of the composting operation, and therefore long-term, steady-state odour emission would be expected to be less.

OER measurements from compost windrows and piles were much lower than pond sources, and generally have a relatively small surface area, which suggests OER from well managed compost would likely be a minor contributor to overall farm odour emission.

6.4 OER compared to VEF maker calculations

VEF Maker calculations of OER were much less variable than OER measured during this project. This was expected.

The use of VEF Maker to calculate emission rates for comparison with OER measured from area sources (ponds and SEPS) may not be appropriate due to the poorly definable air speed and emission characteristics within a flux chamber. Despite this, the following comparisons were made (although it should be remembered that changing the wind velocity and atmospheric stability class factor will have a significant influence on any calculated OER from area sources):

- For ponds, VEF Maker calculated OER values were very close to the values measured in this project, although VEF Maker tended to over-predict OER for primary anaerobic effluent ponds.
- For SEPS, VEF Maker often over-predicted the minimum measured OER, although at high OER, the VEF Maker calculations tended to under-predict the emission rate. However, as discussed above, OER from SEPS were higher than expected, based on previously reported values. Further investigation of OER from SEPS using flux chambers, including the possible effect of the biogas CAP, is required before any consideration is given to changing the VEF Maker formulas.

For sheds, VEF Maker tended to calculate higher values of OER at times of when OER was measured to be low, but under-predicted the highest measured OER. As discussed above, shed OER measured in this project showed similar range of variability to the data that was used to develop the VEF Maker formula for shed odour emissions. There is therefore no justification to consider changing the formulation in the VEF maker calculations.

6.5 Comparison of NEGIP separation distances and odour modelling

Full discussion of the desktop investigation into odour assessment methods is provided in **Appendix A**.

Plots of the separation distances and odour contours (example shown in Figure 33) demonstrate the insensitivity of the Level 1 separation distance calculations (orange line in Figure 34) to the effects of dominant winds at the site (Figure 33). The Level 1.5 assessments (pink line in Figure 33) produced separation distances that were more closely aligned with expected effects of dominant wind directions.

The Level 2 odour modelling assessment produced a range of separation distances depending on the odour criterion used. In general, the NEGIP rural dwelling criterion produced the smallest odour contour followed by the NSW (yellow line in Figure 33), SA (light blue line in Figure 33) and Qld (green line in Figure 33) criteria (which were all similar), with the Vic (dark blue line) odour criterion producing the largest odour contours.

Increasing size of odour contours from modelling
NEGIP (3 ou rural dwelling) < NSW ≈ SA ≈ Qld < Vic

An important outcome was that the NEGIP Level 1 and 1.5 odour assessments frequently calculated separation distances that were considerably smaller than odour modelling when state based criteria are used. When the NEGIP impact criteria, at 98^{th} percentile at 1, 2 and 3 ou, are used, the S factor and modelling buffers are similar. This confirmed the hypothesis of the investigation and raises questions about the potential reasons why odour modelling produces larger separation distances for the scenarios that were modelled.

In theory, the odour criteria that are specified by each State are based on research about odour exposure thresholds where it is assumed that a receptor will experience odour nuisance, and presumably make odour complaints after repeated impacts. The different odour criteria used in each State clearly have a large influence on the required separation distances. With regard to the example farms used in the modelling exercise, we were advised that they have received few, if any, odour complaints after many years of operation. Despite this, some of these farms may not pass an odour impact assessment if they were re-assessed using the current odour modelling methodology. This suggests that the odour contours that were generated using modelling and the State-based criteria may be too large due to either the odour emission estimations using VEF Maker being excessive, or the State-based odour criteria being potentially incompatible with the modelling of piggeries in rural areas, or a combination of both.

Regarding odour emission estimations, experiences from odour assessments from area sources in other industries have raised questions about using odour emission rates that were measured using wind-tunnel sampling methods (refer to citations in the Discussion section in Appendix A). This is due to wind conditions inside the wind tunnel not correlating well with the low wind speed, stable conditions that are more often than not, the conditions when odour impacts occur, and are the conditions reported by odour modelling at the 98–99.9^{th} percentiles. VEF Maker formulas for pond area source odour emissions were based on wind tunnel odour emission rate measurement, which increases the potential for odour modelling to over-predict odour impacts from piggeries with ponds. The odour emission rates measured with flux chamber methods were in reasonable agreement with VEF maker calculations, especially for anaerobic ponds. Therefore, without additional data that contradicts the OER calculations in VEF maker, it is not considered appropriate to revise the method.

Regarding the influence of the odour criteria, it is firstly necessary to understand that the State-based criteria and the three odour criteria in the NEGIP (for rural dwellings—3 ou, rural residential receptors—2 ou, and town receptors—1 ou) are all distinctly different to each other and have different objectives. Most of the State-based odour criteria do not make any allowance for different types of receptors, who may have different expectations regarding odour from agricultural production (i.e. a piggery). For this reason, the State-based odour criteria are potentially overly conservative, and the criteria in the NEGIP may be more appropriate for piggeries. The NEGIP rural dwelling criterion (3 ou) produced odour contours that were mostly similar to, or shorter than, the calculated separation distances. Using the criteria for rural residential (2 ou) or town receptors (1 ou) would produce larger odour contours, and may be more appropriate for modelling some piggery situations, depending on the piggery location and receptor characteristics.

A combined consideration of emission rate estimations and odour criteria is required, as both need to be 'calibrated' with the other. The ultimate measure of success for any combination of emission estimation method and odour criterion is minimal odour impacts or complaints by the surrounding community. Future odour assessment investigations should be combined with an assessment of odour surveys or verified odour complaints to confirm the appropriateness of odour contours and separation distances calculated by the various odour assessment methods. Unfortunately, it can be significantly challenging to obtain accurate and unbiased odour complaint or survey data.

7. Implications and Recommendations

OER measured from pig sheds had a similar range to those reported previously, which indicates that current housing designs, husbandry, ventilation and feeding strategies result in similar OER per SPU as they did prior to the 2003 review conducted by the Australian pork industry (Nicholas *et al.*, 2003).

OER from ponds and SEPS were highly variable. In this project, a strong focus was placed on measuring OER from ponds and SEPS that follow a CAP that is used for biogas collection. The OER measured from solids settling ponds, primary anaerobic ponds, active SEPS and secondary ponds, especially those following a CAP, are potentially higher than previously measured, but this comparison is based on very limited published data and Third-Party OER data.

OER from compost piles and windrows were substantially and consistently lower than the effluent system ponds or SEPS. Mortality composting and deep litter manure composting and storage piles represent minor odour sources for the overall farming operation. Lowest odorant emissions were measured from compost piles with straw/sawdust covering; however, compost made from dry manure or effluent pond solids also had very low OER.

VEF Maker has been the recommended way to estimate odour emission rates for at least the last 10–16 years (Nicholas *et al.*, 2003; Tucker, 2010). OER for sheds measured in this project are similar to the values that were used to develop the VEF Maker formulas, but unfortunately, there is limited data previously reported for pond and SEPS OER that were measured with a flux chamber, which makes it impossible to compare to the pond OER data that was used as the basis for the VEF Maker formulas. The pond and SEPS OER calculated in this project using VEF maker relied on assumptions that the wind speed and atmospheric stability factors selected were appropriate for the conditions that exist in a flux chamber. These assumptions may not be correct, and it may not be valid to compare OER measured with a flux chamber with OER values calculated using VEF Maker.

The investigation of odour assessment methods described in the NEGIP have demonstrated that current odour modelling approaches (using VEF Maker for estimating emissions and CALPUFF modelling) produce similar separation distances to the Level 1 and 1.5 separation distance calculation methods in the NEGIP when the odour criteria listed in the NEGIP are used. When State-based odour criteria are used, the odour contours produced by modelling are considerably larger than calculated separation distances (using NEGIP Level 1 and 1.5 methods). This outcome is counter-intuitive, because separation distance formula methods should be conservative and, in general, calculate larger separation distances than site-specific odour modelling. The implication for the pork industry, based on outcomes from the odour assessment investigation, is that if prospective new or expanding piggeries are required to do odour modelling and use the relevant State-based odour criteria, they are likely to need bigger separation distances than they would using the separation distance calculations, and this may affect the prospects of their development being approved.

We recommend the following:

- The industry should not invest further in measuring OER from piggery sheds unless it is to evaluate a specific practice change that is expected to significantly affect OER. In this case, a focussed study, with replicated measurements should be designed to reduce variability that exists between sheds and farms.
- The industry should continue to estimate shed OER data for odour dispersion modelling using the VEF maker (or formulas published in Nicholas *et al.* (2003)), because those

techniques to estimate shed OER were based on similar variability in the range of OER per SPU.

- Additional OER measurements should be focussed on ponds and SEPS systems, at farms with and without a CAP, including hybrid CAP systems that have stirring and/or heating. These studies must assess the loading rates, volatile solids (VS) reduction (with specific focus on degradable and non-degradable VS), nitrogen (N) reduction, hydraulic retention times, effluent and sludge chemistry, microbiology and sludge accumulation in both the CAP and effluent ponds. In future, OER studies on farms with a CAP should be conducted at farms where the entire effluent system was designed specifically to accommodate the CAP, rather than it being retrofitted.
- A CAP is typically designed to maximise biogas yield, and may not be optimised for odour reduction. The industry should survey farms with a CAP to identify effluent system features and management strategies that have been found to minimise OER.
- Secondary ponds had OER that was similar to the primary anaerobic pond and active SEPS. This was not expected, but this project is the first occasion when OER has been measured from secondary ponds using a flux chamber.
- Manure and mortality composting piles and windrows are a minor source of odour emissions, and therefore the industry should continue to practice composting using the methods described in the NEGIP (Tucker, 2018). No further OER research is required for manure or mortality composting piles or windrows.
- VEF Maker formulas and parameterisation should not be changed based on the grab-sample OER values measured in this project. This is because the measurements made in this project are a “snap-shot in time” for highly dynamic odour sources, which are affected by a multitude of known and unknown factors, and were only measured at a limited number of piggeries.
- A carefully considered investigation comparing validated odour complaints, or odour survey records, with the odour assessment methods (described in the NEGIP) should be undertaken to resolve which of the methods produces odour contours or separation distances that are likely to mitigate odour nuisance. This project has demonstrated that there are substantial differences in the outcomes of the different levels of odour assessment, but their relationship to odour impacts and complaints requires specific investigation.

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Appendix A. Odour dispersion modelling report

Report

APL 2017/2237 Piggery Odour Validation Study
Comparison of S Factor and Modelling

Department of Agriculture and Fisheries

Job: 18-149

Date: 3 September 2020

Astute Environmental Consulting

TABLE OF CONTENTS

Project Title	Comparison of S Factor and Modelling
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Client	Department of Agriculture and Fisheries
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1 INTRODUCTION

The Australian pig industry has two main methods for defining buffers for piggeries, these are referred to as the “S Factor Method” and the other is dispersion modelling.

The S Factor method uses an empirical formula which determines buffer distances based on the number of pigs, the farm management, local terrain and land use. It is generally accepted that such methods (also known as Level 1 or Tier 1 assessments) are conservative. Anecdotal evidence including a lack of complaints for new piggeries approved on the basis of S Factor methods shows that the S Factor method is adequate for preventing odour nuisance for new piggeries.

The S Factor methods were derived based on odour modelling. For example, the original Queensland S Factor method was based on the methodology detailed in McGahan et al. (2000) which used odour emission rate data based on odour measurements performed in line with NVN 2820:1995/A1:1996 Air quality - Sensory odour measurement using an olfactometer (NVN, 1996). The modelling combined with complaint histories was used to formulate the final equation, which was detailed in DPI (2001).

Around 2000, APL Project 1628 began with a view to updating odour emission rate data for piggeries, in particular pond odour emissions. The results were detailed in APL (2004). The data along with other emission rate data for sheds was summarised prior to the finalisation of the project in Nicholas et al. (2003).

Based on Nicholas et al. (2003), the software VEF Maker was derived to simplify emission estimations from piggeries. The software allows a user to estimate shed emissions for mechanically or naturally ventilated sheds (deep litter or flushing sheds) and also pond emissions, including primary, secondary and tertiary ponds.

Available statistics show that in the last 10 to 15 years, the national pig herd has not grown significantly, therefore, the number of new large farms has been limited and most new farms are being assessed using the S Factor method.

The S Factor method, as noted above, is assumed to be conservative, however limited modelling of existing farms approved using the S Factor method indicated that odour modelling is more conservative, rather than being less conservative compared to the S Factor method.

The aim of this project was to compare the Australian Pork Limited “VEF Maker” software and dispersion modelling, to the widely used S Factor method detailed in the National Environmental Guidelines for Indoor Piggeries (Third Edition) (Tucker, 2018).

It is noted that the piggeries examined in this project were assessed on the basis of being typical farms, not because they had been subject to odour complaints or, to the best of our knowledge, ongoing odour issues.

2 METHODOLOGY

The methodology adopted here is consistent with that required in most states for modelling a new piggery. Whilst there are some differences state to state, the methodology meets the majority of state-based requirements.

The process for modelling a piggery is as follows:

- Select a representative year;
- Obtain information about the farm;
- Estimate emissions using standard methods based on existing or proposed design and management;
- Model meteorology for the area using standard methods;
- Model dispersion using CALPUFF; and
- Compare results to relevant odour criterion.

Further details on the methodology used are provided below.

2.1 Farm Selection

For the project, six piggeries were modelled. These included a single farm from Queensland, New South Wales, South Australia and Western Australia, and two from Victoria. The piggeries were selected on the basis of being typical of current farms, and located in rural areas. The farms consisted of a variety of shed types and effluent handling methods.

Information on each site was provided by the farm operator.

The layout of each piggery and sheds were then modelled using standard methods with a standard meteorological dataset, to enable a comparison between the S Factor method and the model results.

The farms selected are summarised in Table 2-1.

Table 2-1: Farm Shed Types and Effluent Systems

Farm	SPU	Region	Shed Types	Effluent Treatment
A	~11,500	Southern Queensland	Flushing only (naturally ventilated)	Pond System no solids pre treatment
B	~9,800	Southern NSW	Flushing and deep litter (naturally ventilated)	Pond System including Sedimentation Evaporation Pond system (SEP) no solids pre treatment
C	~10,000	Western Victoria	Flushing and deep litter (naturally ventilated)	No primary pond, Covered Anaerobic Pond (CAP), and effluent irrigated
D	~9,500	NSW/Victoria border region	Flushing and deep litter (naturally ventilated)	Primary/Secondary system no solids pre treatment
E	~11,000	South Eastern South Australia	Flushing and deep litter (naturally ventilated)	Primary/Secondary system with solids removal.
F	~8,800	South Western West Australia	Flushing only (mechanical and naturally ventilated)	Primary/Secondary system with solids removal.

2.2 Assessment Criteria

For this project the modelled results were compared to the odour criteria currently in use in Australian states, as well as the odour criterion in the National Environmental Guidelines for Piggeries (Third Edition) (Tucker, 2018)[a].

The criteria assessed are detailed below in Table 2-2. As noted elsewhere (e.g. Galvin et al. (2007)), the Victorian and South Australian criteria are most stringent. This is because they use the 99.9th percentile (9th highest predicted value) and a 3 minute average (1.82 times higher than the 1 hour average). Victoria uses modelling along with a risk assessment process rather than just using a model based criterion.

Table 2-2: State Based and NEGIP Odour Criteria

State	Concentration	Averaging Time	Percentile	Comment
Queensland	2.5 ou	1 hour	99.5th	Ground Level sources (DEHP, 2013)
New South Wales	2-7 ou (population dependant)	1 second	99th	Rural area, 5 ou typically applies (NSW EPA, 2016)
Victoria	5 ou (risk criterion)	3 minute	99.9th	Risk based method, but for this work we did not perform the risk assessment (State of Victoria, 2001; EPA Victoria, 2017)
South Australia	2-10 ou (population dependant) 10 ou (single residence)	3 minute	99.9th	Single rural residence 10 ou (EPA SA, 2016)
Tasmania	2 ou	1 hour	99.5	Similar to Queensland, but marginally more stringent. (EPA Tasmania, 2004)
NEGIP	3 ou	1 hour	98th	See PAE (2003) 3 ou is for a rural residence, 2 ou is applied to rural residential receptors and 1 ou for a town receptor

2.3 Representative year

For each site, we selected a representative meteorological year. This is important for dispersion modelling as typically only a single year of data is modelled in an assessment.

Critical meteorological factors for air quality assessments include wind speed, temperature and relative humidity. These need to be assessed against long term data to determine which year is most similar to the average conditions rather than simply selecting a modelling year at random. However, for sites where local data (especially on-site data) is available and of a suitable quality, the selection of a representative year is not as critical if a year of on-site data is available.

[a] "the NEGIP"

We selected the modelling year based on data from the closest weather station location (either Bureau of Meteorology or State Government station). Multiple years of data were analysed for wind speed, humidity and temperature, and the modelling year was then selected based on the analysis.

The years modelled are summarised in Table 2-3.

Table 2-3: Representative Years of Meteorology by Site

Site	Year Modelled
A	2008
B	2012
C	2018
D	2015
E	2016
F	2016

2.4 Meteorological Modelling

When modelling a site, meteorological data is required to run CALPUFF. The methodology used was based on in the requirements in the *Generic Guidance and Optimum Model Settings for the CALPUFF modelling system for inclusion into the Approved Methods* (OEH, 2011).

Where possible, we have endeavoured to include observed data into the modelling, but where no good quality data was available, we have relied on the prognostic model The Air Pollution Model (TAPM).

2.4.1 TAPM

TAPM (version 4), is a three-dimensional meteorological and air pollution model developed by CSIRO. TAPM is a prognostic model which uses synoptic scale data to predict hourly meteorology in the area modelled. Details about TAPM can be found in the TAPM user manual (Hurley, 2008a) and details of the model development and underlying equations can be found in Hurley (2008b). Details of validation studies performed for TAPM are also available and include Hurley et. al. (2008c).

TAPM v4 predicts meteorological data including wind speed and direction in an area using a series of fluid dynamics and scalar transport equations (Hurley, 2008b) by use of both prognostic meteorological and air pollution (dispersion) components. The benefit of using TAPM is that key meteorological aspects including the influence of terrain induced flows are predicted both locally and regionally.

TAPM can include observed wind speed and direction data from nearby weather stations. This is referred to as nudging. Further details on nudging can be found in Hurley (2008a).

TAPM typically has coarse default land use values in its database especially in the 300m domain. For each site we adjusted the land use in the innermost domain to be consistent with recent aerial photography for the area. An example is provided below in Figure 2-1. The TAPM setup is summarised in Table 2-4 below and is consistent with good practice and the requirements in NSW EPA (2016).

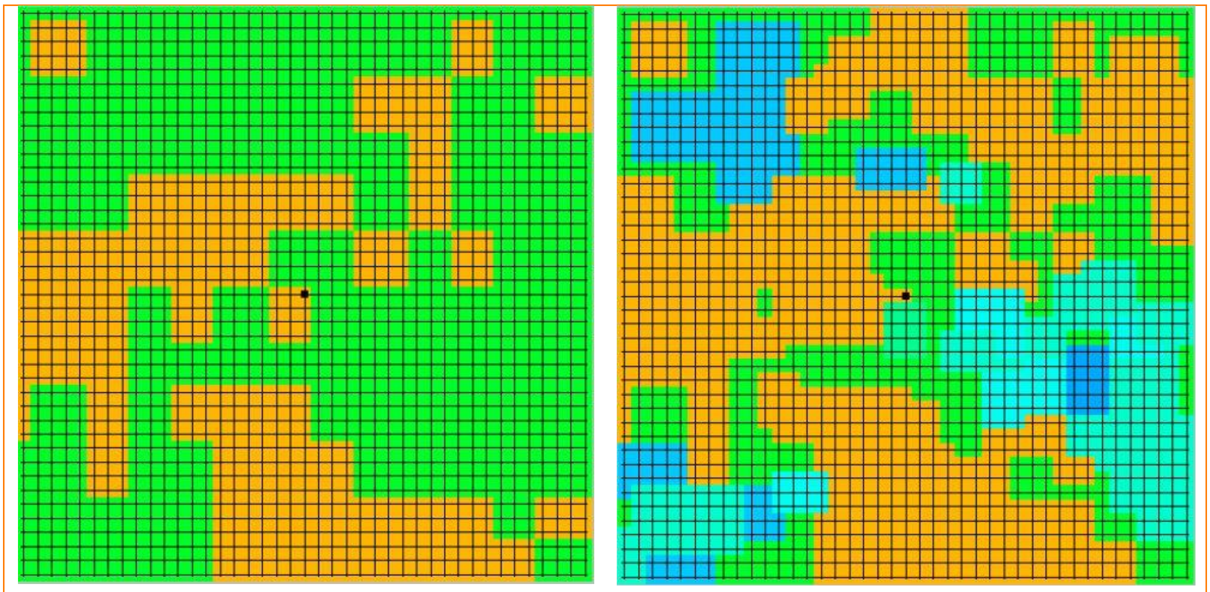


Figure 2-1: Default TAPM (left) and Adjusted Land Use (right) for the Site

For all sites, TAPM was run with a 25 x 25 x 25 grid, with spacings of 30 km, 10 km, 3 km, 1 km and 0.3 km. The run was centred as close as possible to each piggery and the grid used to drive CALMET was selected based on the terrain in the local area.

Sites A, D and E were run without nudging TAPM as there was not nearby sites with suitable quality data. Sites B, C and F included observed data from the area (closest station with observed data) with radius of influence selected based on the TAPM user manual.

2.4.2 CALMET

CALMET is the meteorological pre-processor to CALPUFF and generates wind fields which include slope flows, terrain effects, and can incorporate factors including terrain blocking. CALMET uses meteorological inputs in combination with land use and terrain information for the modelling domain to predict a three-dimensional meteorological grid (which includes wind speed, direction, air temperature, relative humidity, mixing height and other variables) for the area (domain) to be modelled in CALPUFF.

A 10 km x 10 km domain was modelled for each site with the centre of the domain being near the existing farm. A terrain resolution of 30 m was used throughout the domain and was initially taken from the Shuttle Radar Topography Mission (SRTM) dataset using CALPUFF view. This was then converted to a 100 m resolution for the model runs.

Land use was initially based on the Australia Pacific Global Land Cover Characterisation (GLCC) dataset at 1 km resolution. The land use was then manually edited at 100 m resolution based on a recent aerial photograph of the area using Google Earth Pro and CALPUFF View.

Key inputs used in CALMET are summarised below in Table 2-4.

Table 2-4: TAPM and CALMET Setup

Model	Parameter	Value
TAPM (v 4.0.5)	Number of grids (spacing)	30 km, 10 km, 3 km, 1 km, 0.3 km
	Number of grid points	41 x 41 x 25 (vertical)
	Year of analysis	Table 2-3
	Centre of analysis	Close as possible to the site
	Meteorological data assimilation	Yes, sites 2, 3 and 6 only
CALMET (v 6.334)	Meteorological grid domain	10 km x 10 km
	Meteorological grid resolution	0.10 km
	South-west corner of domain	Close as possible to the site
	Surface meteorological stations	NA
	Upper air meteorological data	NA
	3D Windfield	m3D from TAPM input as in initial guess field in CALMET Farms 1, 3, 4 – 0.3 km grid Farms 2, 5 and 6 – 1 km grid
	Year of analysis	See Table 2-3
	Terrad	Varied by site
	Method to compute cloud fields (MCLOUD)	4
	Compute kinematic effects (IKINE)	0
	Input to the diagnostic wind field model (IPROG)	14
	Threshold buoyancy flux (Threshl)	0.05 (See Rayner 2011)

2.5 S Factor Methodology

2.5.1 Level 1

The buffer methodology detailed in the NEGIP is used to determine buffer distances using an empirical formula. In simple terms, the size of the piggery in Standard Pig Units (SPU), a piggery effluent removal factor, an effluent treatment factor, a siting factor and a terrain weighting factor are used to predict the required buffer (distance from sensitive locations). Details of the development of the S Factor methodology including the use of the 98th percentile, 1, 2 and 3 ou contours can be found in Tonkin Consulting (2008a)

The separation distance (buffer) required is calculated using Equation 1 below where D is the distance in metres, N is the number of SPU, S1 is a design factor for effluent removal (S1R) and treatment (S1T), S2 is a siting and surface roughness factor and S3 is a terrain factor. Equation 1 can therefore be expressed as shown in Equation 2.

$$D = N^{0.55} \times S1 \times S2 \times S3 \qquad \text{Equation 1}$$

$$D = N^{0.55} \times S1R \times S1T \times S2R \times S2S \times S3 \qquad \text{Equation 2}$$

The factors which can be applied are summarised below as follows:

- Table 2-5: S1 Factors Effluent Removal and Treatment ;
- Table 2-6: S2 Factors– Receptor and Surface Roughness; and
- Table 2-7: S3 Factor - Terrain.

Details on how the factors should be selected and applied can be found in Appendix A, Section A5 of the NEGIP.

Table 2-5: S1 Factors Effluent Removal and Treatment

Effluent Removal System	S1R
Conventional shed – static pit, pull plug or flushing system	1.00
Deep litter system, pigs on single batch of bedding ≤7 weeks	0.63
Deep litter system, pigs on single batch of bedding > 7 weeks	1.00
Effluent Treatment	**S1T**
Pond with >40% separation of volatile solids before pond	0.80
Pond with 25 – 40% separation of volatile solids before pond	0.90
Pond with <25% separation of volatile solids before pond	1.00
Permeable pond cover	0.63
Impermeable pond cover	0.50
Deep litter system – spent bedding stockpiled / composted on-site	0.63
No manure treatment or storage on-site – effluent / bedding removed from site	0.50

Table 2-6: S2 Factors– Receptor and Surface Roughness

Receptor Type	S2R
Town	25
Rural Residential	15
Legal House	11.5
Surface Roughness Factor	**S2S**
Limited ground cover, grass	1.00
Crops	1.00
Undulating Terrain	0.93
Open Grassland (grass, scattered trees)	0.90
Woodlands (low density forest)	0.7
Open forest (canopy cover 30-70%)	0.6
Forest with significant mid and lower story vegetation	0.5

Table 2-7: S3 Factor - Terrain

Terrain	Downslope	Upslope
Narrow valley (>1% slope)	2.0	0.5
Gently sloping (1-2% slope)	1.2	1.0
Flat (0-1% slope)	1.0	1.0
Receptor downslope in different sub-catchment	1.0	-
Sloping (>2% slope)	1.5	0.7
Significant hills and valleys	0.7	0.7

2.5.2 Level 1.5

The level 1.5 factor adds a S4 factor to Equation 1 above as shown in Equation 3 below.

$$D = N^{0.55} \times S1R \quad \times S1T \quad \times S2R \quad \times S2S \quad \times S3 \times S4 \qquad \text{Equation 3}$$

The factor is a wind frequency factor, which calculates the frequency of winds from 22.5° increments from North (i.e. North, North-North-East, North-East and so on) for winds below 3 m/s. Further details on this method can be found in A5.9 of the NEGIP.

For each site modelled, the on-site meteorology was processed and the S4 factors were calculated for each of the 16 compass points for each site. In line with the NEGIP a 20% safety factor was added. For example if the winds from one direction resulted in a factor of 60% in the downwind direction, the final value would be 80% (60%+20%).

The results of the S4 factor calculations can be found in Section 4.1 below.

Further information on the development of the Level 1.5 methodology can be found in the report *Preliminary investigation of a method for adjusting Level 1 separation distances to wind direction frequencies for low wind speeds* (Tonkin Consulting, 2008b).

2.6 Emissions Estimation

Emissions for this project were based on the use of the VEF Maker Software. VEF Maker was prepared by Pacific Air & Environment based on the report, 2003 Update of Odour Research for the Pig Industry. APL Project 1889 (Nicholas, et al., 2003).

The background behind the selection of the values in VEF Maker can be found in Nicholas et al. (2003).

It is important to note two things regarding VEF Maker:

1. When selecting shed flushing options, the terminology in Nicholas et al. (2003) should be used, as the term “days per week” has been included in the VEF Maker software rather than simply “days”. For example, it should read Flushed > 6 days with no pit recharge (i.e. every 6th day or longer), rather than Flushed > 6 days per week with no pit recharge;

2. The effluent Removal definitions within the Help File of VEF Maker uses incorrect definitions for shed flushing. For correct definitions, see Nicholas et al. (2003)[b].

For farms with covered lagoons, it was assumed that the secondary ponds still behaved like secondary ponds in a conventional primary/secondary system (i.e. consistent with the NEGIP S Factor method factor 0.5 for covered ponds), and for farms that used sedimentation and evaporation pond systems (SEPS), it was assumed that they behaved like primary ponds. This was done to replicate standard modelling which may be performed by a consultant modelling a piggery.

All ponds were assumed to have a loading consistent with the rational design standard of Barth (1985) which is 100 grams of volatile solids (VS) per cubic metre per day. It is noted that the rational design standard has lower loading in colder areas, and higher loading in warmer areas. The loading rate was used as it is the default in VEF Maker, however, this is not a significant assumption, as APL Project 1628 showed that the effect of changing the loading rate (even doubling or tripling) on a pond does not significantly increase emissions as it has a non-linear effect.

Mortality composting was not included as the emissions from these windrows, when properly managed, are low and not offensive in nature compared to piggery pond and shed emissions.

2.6.1 Farm A

Farm A had five sheds all being naturally ventilated. Four of the sheds are flushed daily, with one shed being a pull plug system, and 1 room flushed per week. Therefore, all sheds were given an Effluent Factor (in VEF Maker) of 1 and the shed cleanliness was assumed to be “clean or moderately dirty”.

Effluent is treated in three ponds, a primary, secondary and tertiary/wet weather. Loading into the ponds was assumed to be 100 g VS/m^3/day, 30 g VS/m^3/day and 10 g VS/m^3/day respectively. It is noted that VEF maker assumes the tertiary pond to have nearly the same emission rate as the secondary pond.

An example emissions profile for Farm A is shown in Figure 2-2. The x axis shows the hour of year. Hour one is 1 January at 1 am and so on. As there are 8,760 hours in a non leap year, the middle of the year (i.e. winter) is hour ~4,380.

With regard to Figure 2-2 (and other figures below showing emissions), the pond emission rate is expressed as odour units per square metre per second. The total odour emission rate from the ponds is determined by multiplying the emission rate in the figure at a given point in time by the pond area and that data was used as an input into CALPUFF.

[b] The factors within VEF Maker are correct.

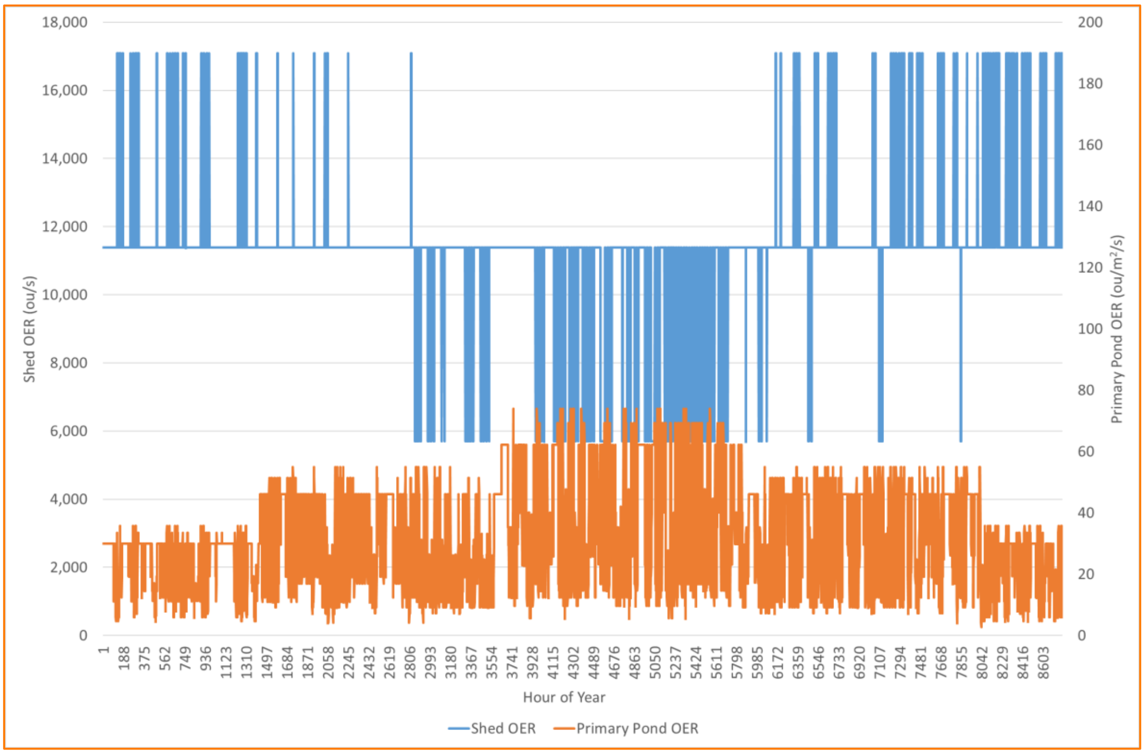


Figure 2-2: Example Emissions Profile – Farm A

2.6.2 Farm B

The farm makes use of a SEPS system. For the purposes of this work, the SEPS and wet weather ponds were treated in VEF Maker as follows:

- One as a primary (actively loaded);
- One as a secondary (not actively loaded); and
- The third as a secondary pond/supernatant pond from active SEP[c].

The loading into the ponds was left at 100 g VS/m^3/day. It is noted that VEF maker has an adjustment for loading built in as “Pond Type Factor” which is 1 for a primary pond, and 0.1667 for a secondary pond which gives emissions 1/6th of a primary pond. It also allows adjustment by volatile solids loading rate. For example, if 30 g VS/m^3/day is assumed to be entering the secondary pond, this reduces emissions by an additional 12%.

Sheds 1 to 8 were modelled as naturally ventilated deep litter systems with a litter change frequency of 4 weeks. The remaining five sheds were naturally ventilated pull plug sheds with pit recharge. Staggering of cleaning of the deep litter sheds was not selected.

Example emissions profiles are shown below in Figure 2-3.

[c] VEF maker assumes all ponds have offensive odour and that a secondary and wet weather/tertiary ponds have the same emission characteristics.

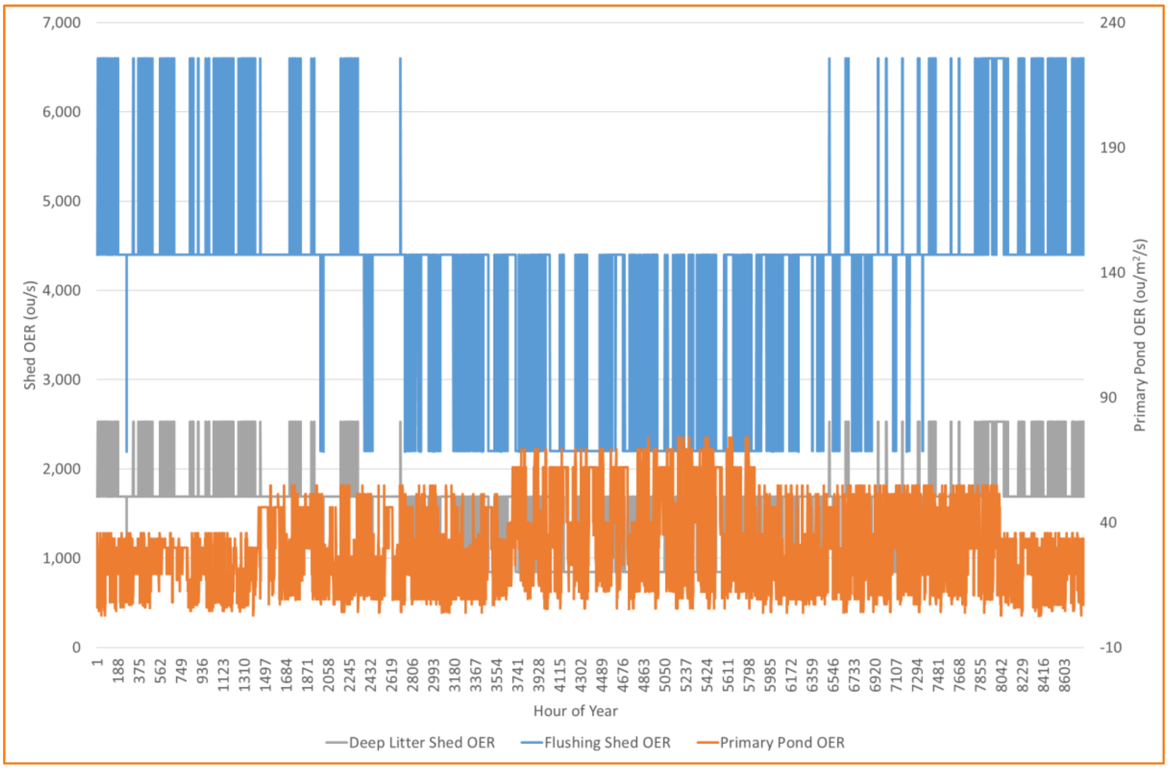


Figure 2-3: Example Emissions Profile – Farm B

2.6.3 Farm C

Farm C had a combination of flushing and deep litter sheds. The flushing sheds were modelled as pull plug with pit recharge and naturally ventilated. The deep litter sheds were modelled with a 12 week litter change frequency with natural ventilation. The site has a covered lagoon, and no treatment ponds. Example emission profiles are shown below in Figure 2-4.

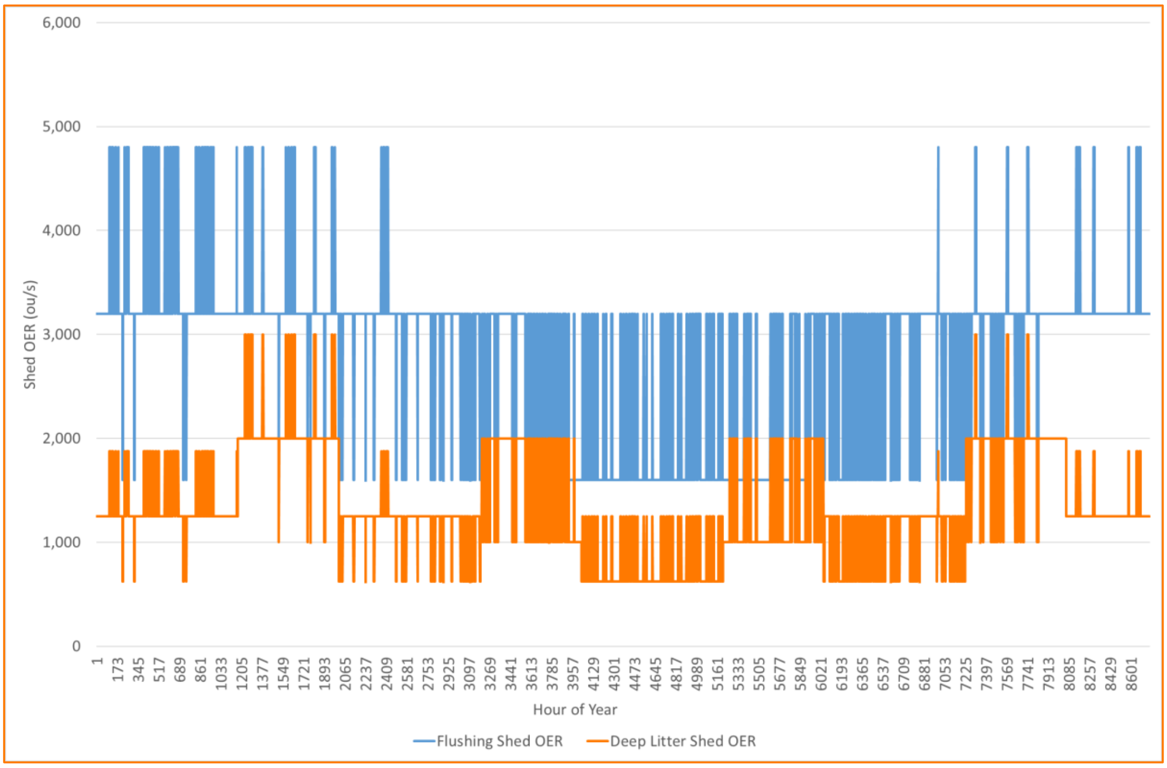


Figure 2-4: Example Emissions Profile – Farm C

2.6.4 Farm D

Farm D had a combination of flushing and deep litter sheds. The flushing sheds were modelled as pull plug with pit recharge and naturally ventilated. The deep litter sheds were modelled with a 5 week litter change frequency and natural ventilation.

The site has a standard effluent system where effluent from the sheds was pumped via a sump to the anaerobic ponds south the site. As such the results shown below are with and without the pond as a sensitivity test. Pond loading was assumed to be 100 g/VS/m^3/day for the loaded pond, and the second pond was assumed to behave like a secondary pond when not loaded.

Example emission profiles are shown below in Figure 2-5.

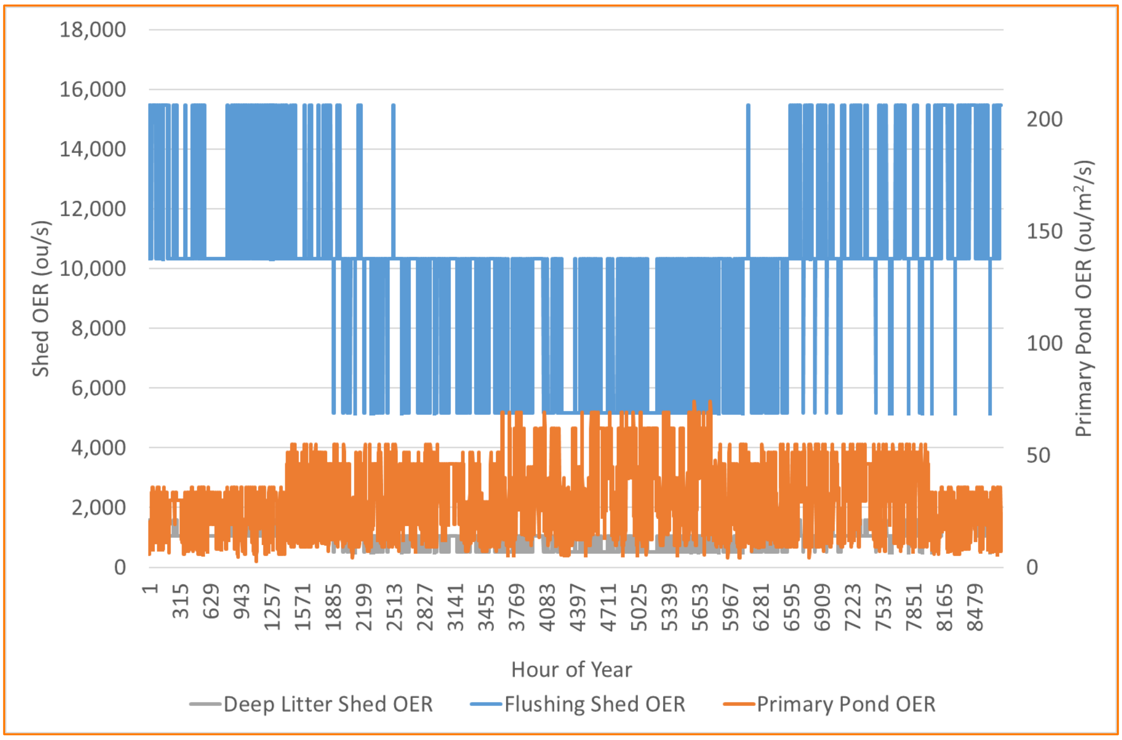


Figure 2-5: Example Emissions Profile – Farm D

2.6.5 Farm E

Farm E had a combination of flushing and deep litter sheds (12 week and 7 week litter change frequency). The flushing sheds were modelled as pull plug with pit recharge and naturally ventilated.

The site has a standard primary/secondary type effluent system with a solids separator. Pond loading was assumed to be 100 g/VS/m^3/day as based on APL (2004). As emissions do not change linearly with loading rate, the difference in emissions with solids separation is not considered to be significant for the purposes of this work.

Example emission profiles are shown below in Figure 2-6.

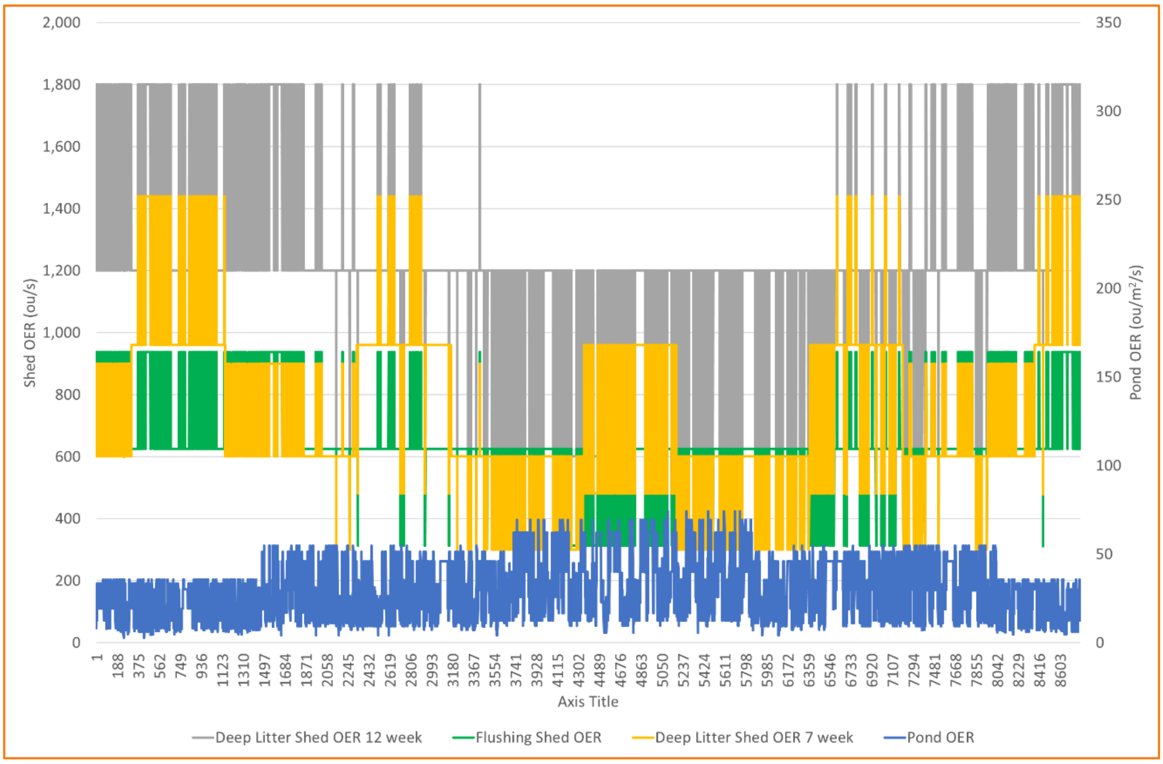


Figure 2-6: Example Emissions Profile – Farm E

2.6.6 Farm F

Farm F has flushing sheds which were modelled as pull plug with pit recharge and either mechanically or naturally ventilated. Mechanical ventilation adds 50% to predicted emissions when ambient temperatures are above 25°C.

The site has a standard primary/secondary type effluent system. Pond loading was assumed to be 100 g/VS/m³/day.

Example emission profiles are shown below in Figure 2-7.

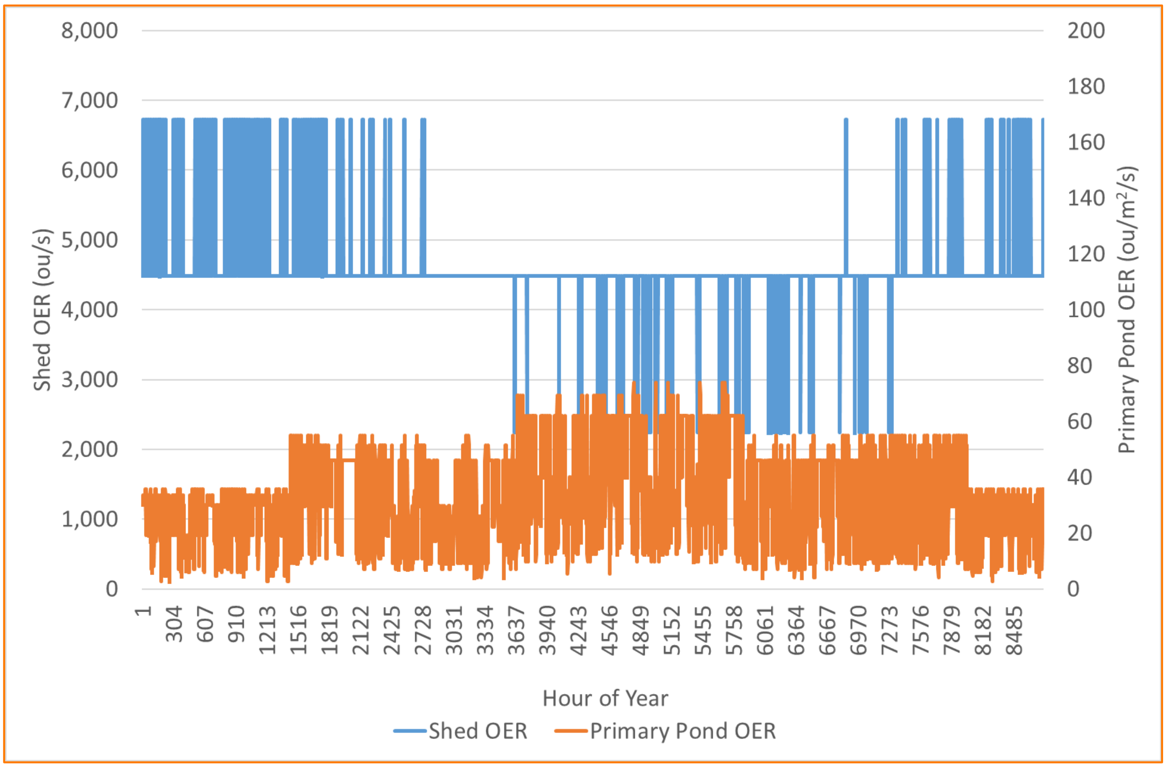


Figure 2-7: Example Emissions Profile – Farm F

2.7 CALPUFF

CALPUFF (Exponent, 2011) is a US EPA regulatory dispersion model and is a non-steady state puff dispersion model that simulates the effects of varying meteorological conditions on the emission of pollutants. The model contains algorithms for near source effects including building downwash, partial plume penetration as well as long range effects such as chemical transformation and pollutant removal. CALPUFF is widely recognised as being the best model for odour studies as it handles light wind conditions and terrain effects better than simpler steady state models such as AUSPLUME and AERMOD. As such it is often used as a regulatory model in all states and Territories of Australia.

CALPUFF simulates complex effects including vertical wind shear, coastal winds including recirculation and katabatic drift. The model employs dispersion equations based on a Gaussian distribution of puffs released within the model run, and it takes into account variable effects between emission sources.

Key inputs used in CALPUFF for the project are summarised below in Table 2-8.

Table 2-8: CALPUFF Setup

Model	Parameter	Value
CALPUFF (v 6.4.2)	Meteorological grid domain	10 km x 10 km
	Meteorological grid resolution	0.1 km
	South-west corner of domain	Close to each farm site in line with the domain size
	Method used to compute dispersion coefficients	2 - dispersion coefficients using micrometeorological variables
	Minimum turbulence velocity (Svmin)	0.2 m/s
	Minimum wind speed (m/s) allowed for non-calm conditions	0.1 m/s
	Volume source parameters (sheds)	
	Height of release (h)	1.5m
	Initial sigma Y	Shed length/4
	Initial sigma z	1.0m
	Constant or variable?	Hourly variable using an external file (Volemarb)
	Area source parameters (ponds)	
	Height of release (h)	0.5m
	Initial sigma z	0.5m
	Effective rise velocity	0 m/s
	Effective radius	0m
	Source temperature	Same as ambient
	Constant or variable?	Hourly variable using an external file (Baemarb)

3 METEOROLOGICAL DATA

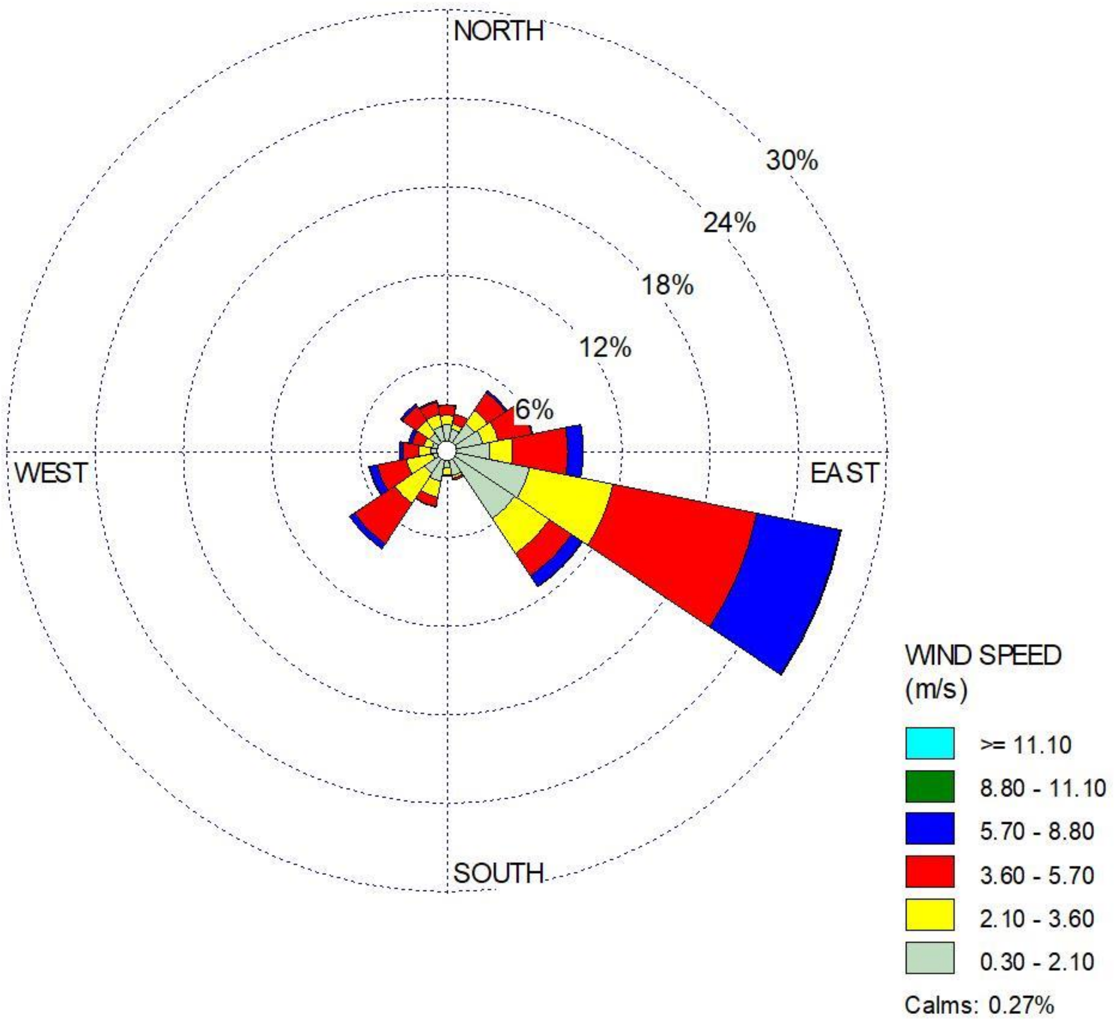
The principal meteorological parameters that influence plume dispersion are wind direction, wind speed, atmospheric stability (turbulence) and atmospheric mixing height (height of turbulent layer). Wind roses are shown below for each of the six locations modelled. Checks were made of other parameters including atmospheric stability and mixing height however these are not included in this report.

Wind roses are used to show the frequency of winds by direction and strength. The bars show the compass points (north, north-north-east, north-east etc) from which wind comes from. The length of each bar shows the frequency of winds from that direction and the different coloured sections within each bar show the wind speed categories and frequency of winds in those categories. In summary, wind roses are used to visually show winds over a period of time.

The wind roses below were created from data extracted from CALMET and are presented below as follows:

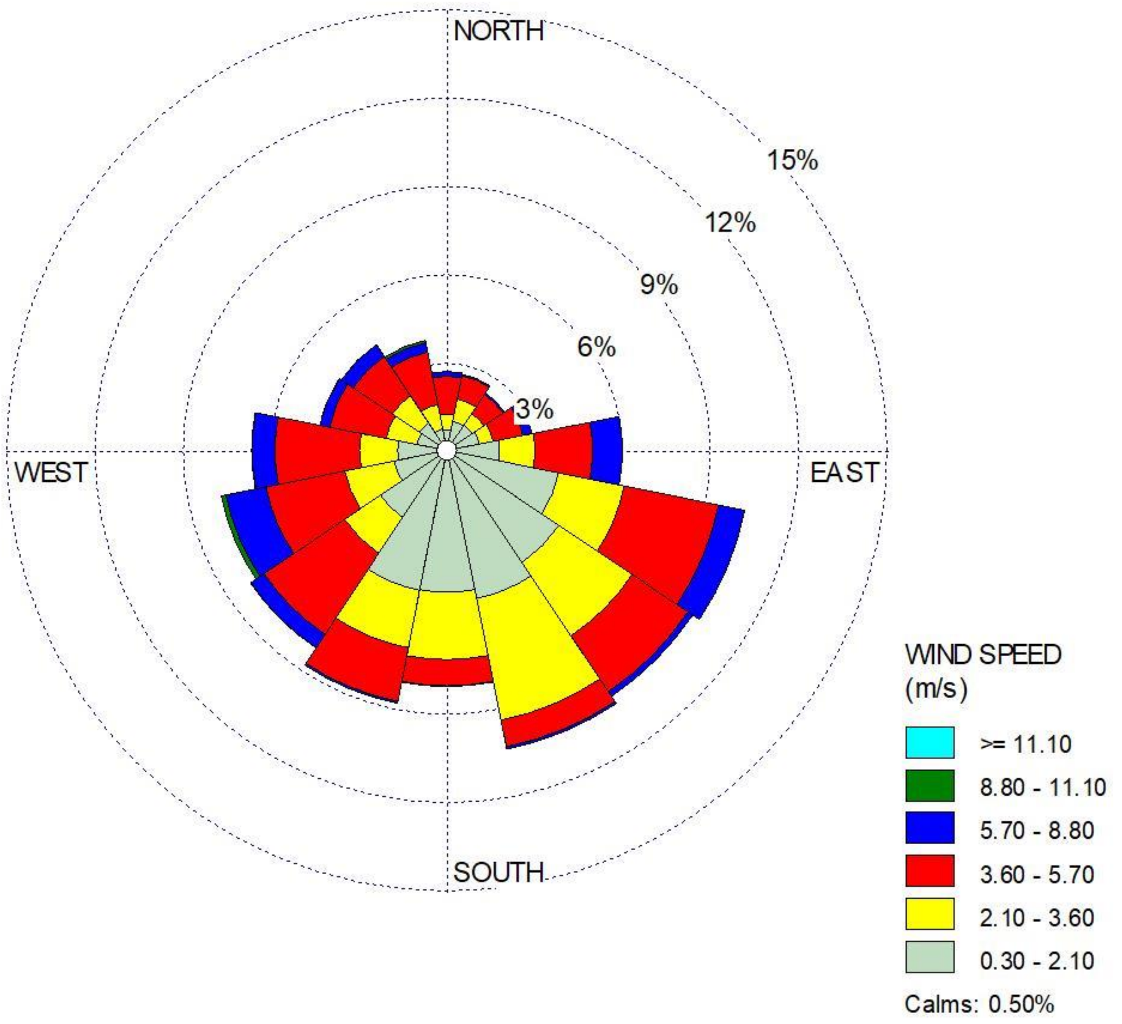
- Figure 3-1 – Farm A;
- Figure 3-2 – Farm B;
- Figure 3-3 – Farm C;
- Figure 3-4 – Farm D;
- Figure 3-5 – Farm E; and
- Figure 3-6 – Farm F.

Note when calculating the S4 factor, the shapes are reversed. The wind roses show the direction the wind is coming from; thus when reversed, the largest S4 factor buffer is on the opposite side to the direction the dominant winds are coming from. Also, concerning the S4 factor, it only includes winds under 3 m/s, so the shape may not always directly compare to the wind roses which contain the frequency of all wind speeds.



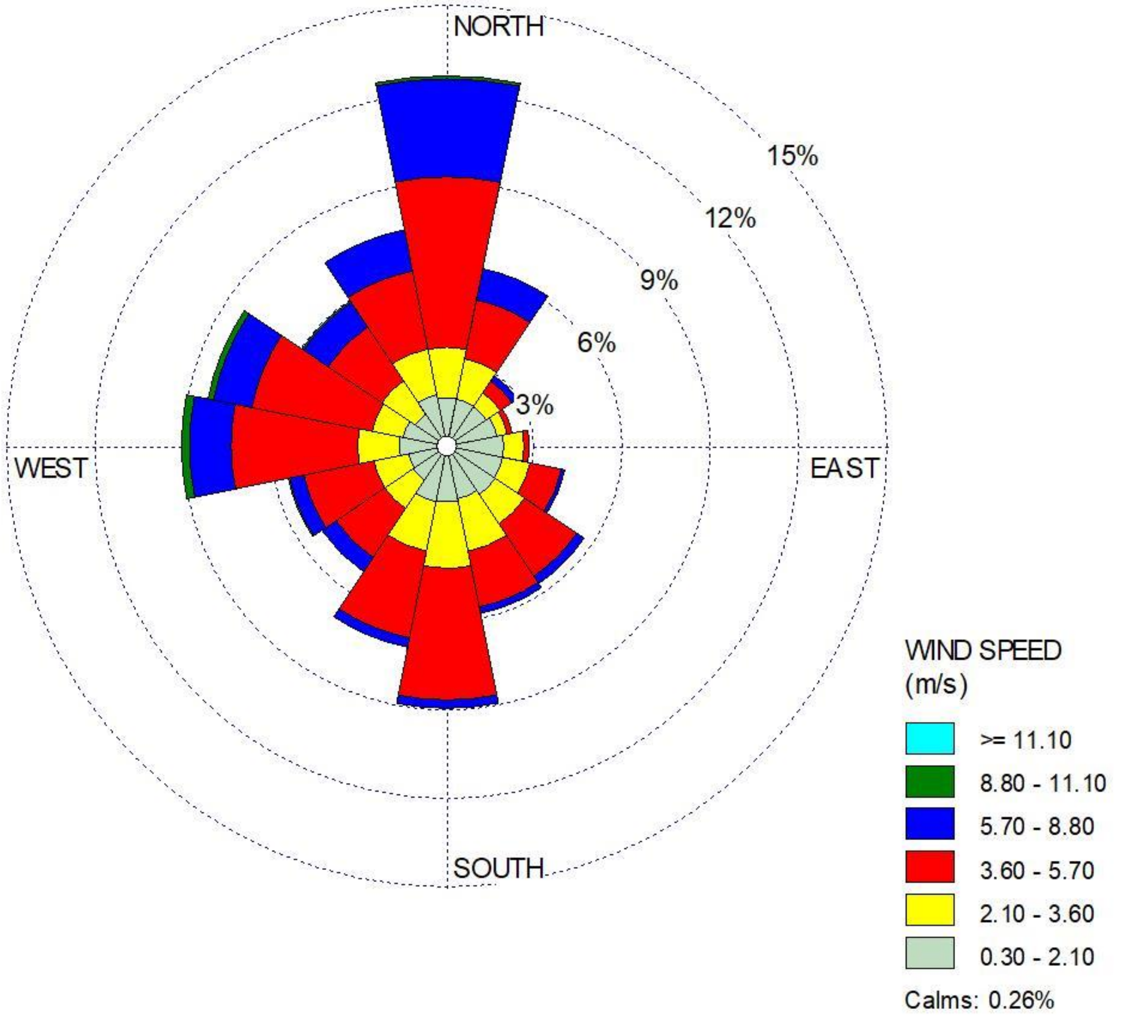
Location: Centre of domain	*Year:* 2008	*Data Source:* CALMET extract
Calm winds: 0.27 %	*Average wind speed:* 3.28 m/s	*Creator:* W. Shillito

Figure 3-1: Annual Wind Rose for Farm A



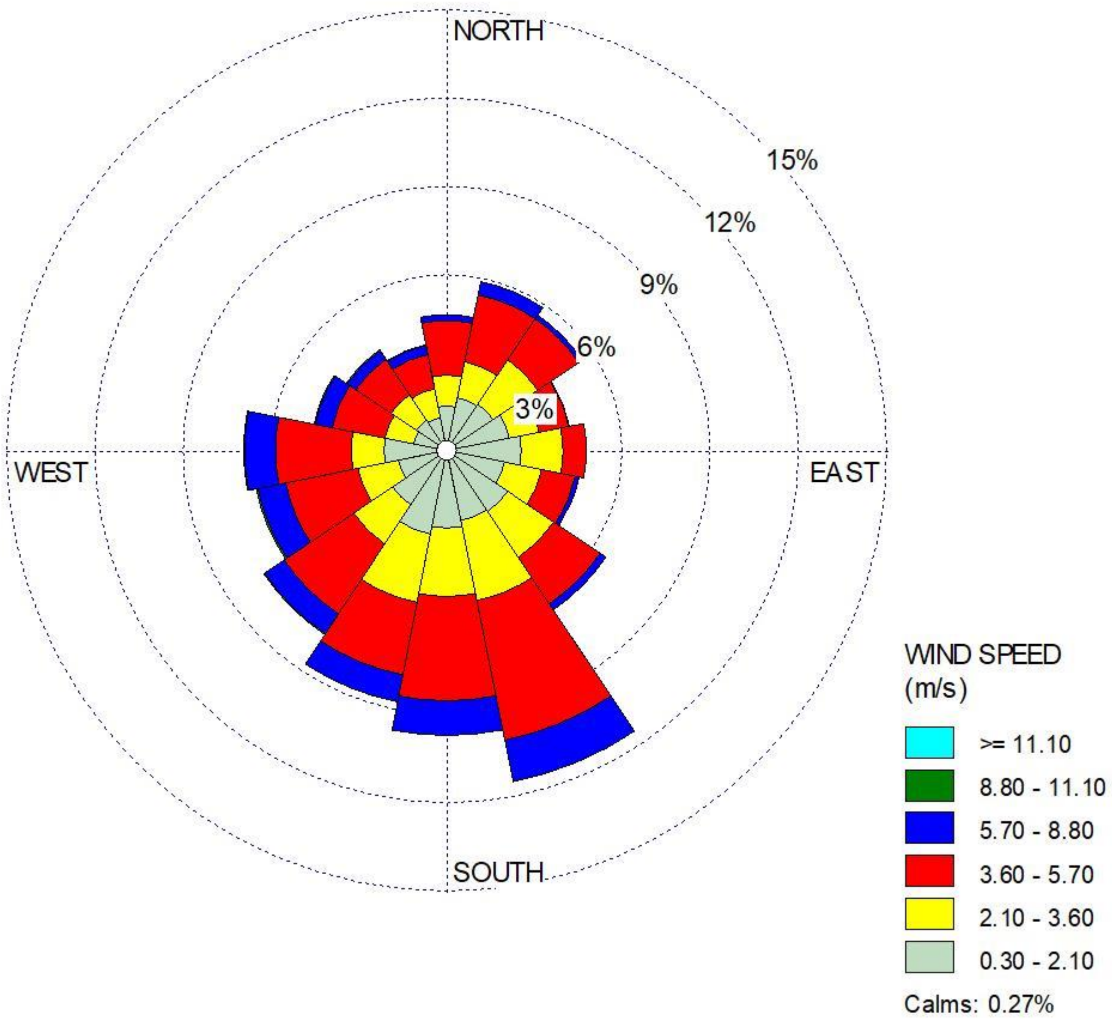
Location: Centre of domain	*Year:* 2012	*Data Source:* CALMET extract
Calm winds: 0.5%	*Average wind speed:* 3.1 m/s	*Creator:* W. Shillito

Figure 3-2: Annual Wind Rose for Farm B



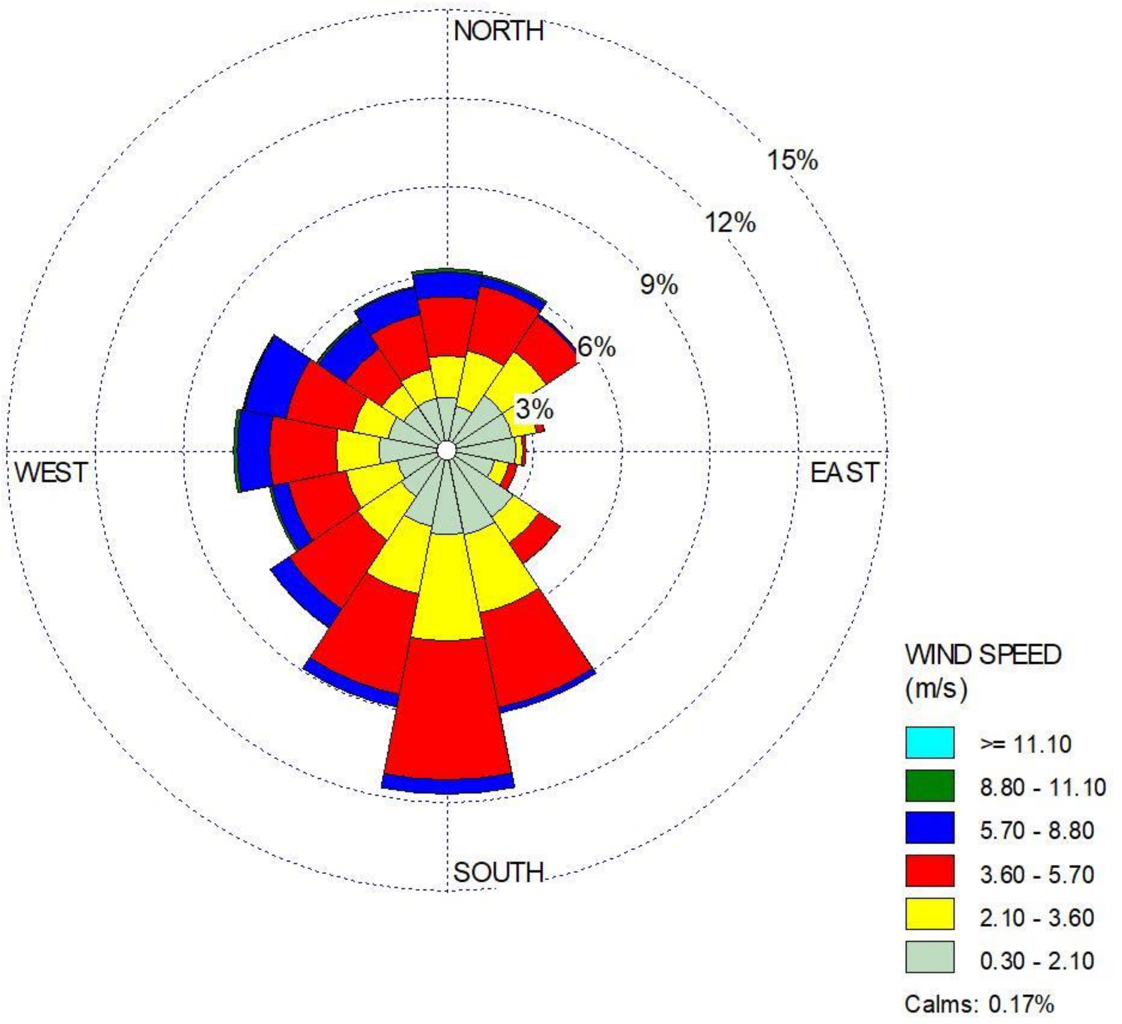
Location: Centre of domain	*Year:* 2018	*Data Source:* CALMET extract
Calm winds: 0.26 %	*Average wind speed:* 3.7 m/s	*Creator:* W. Shillito

Figure 3-3: Annual Wind Rose for Farm C



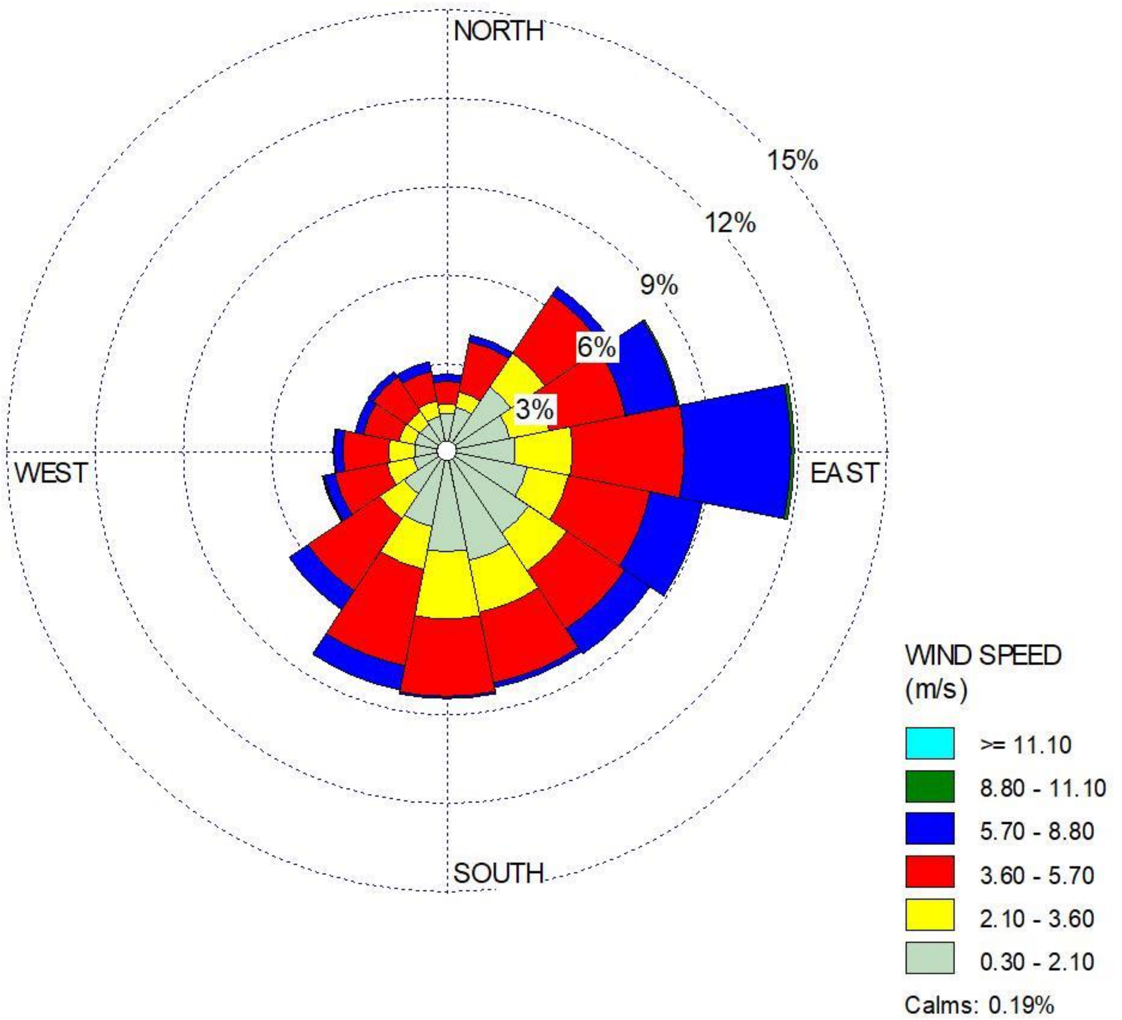
Location: Centre of domain	*Year:* 2015	*Data Source:* CALMET extract
Calm winds: 0.27 %	*Average wind speed:* 3.3 m/s	*Creator:* W. Shillito

Figure 3-4: Annual Wind Rose for Farm D



Location:	*Year:*	*Data Source:*
Centre of domain	2016	CALMET extract
Calm winds:	*Average wind speed:*	*Creator:*
0.17 %	3.3 m/s	W. Shillito

Figure 3-5: Annual Wind Rose for Farm E



Location: Centre of domain	*Year:* 2016	*Data Source:* CALMET extract
Calm winds: 0. 19 %	*Average wind speed:* 3.5 m/s	*Creator:* W. Shillito

Figure 3-6: Annual Wind Rose for Farm F

4 RESULTS

4.1 S Factor Calculations

4.1.1 Farm A

The farm has flushing sheds only (S1R) and has a primary/secondary/tertiary pond system with no additional effluent treatment (S1T). The site has a capacity of 11,500 SPU.

The assessment was based on rural residences only (S2R) and surface roughness values (S2S) in each of the 16 directions were selected based on land use within 2 km of the site which was derived using a recent aerial photograph.

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.2 km from the centre[d].

If terrain features relevant to odour dispersion were evident (e.g. a confining valley), the factor for that direction was derived based on information at hand. None were present for Farm A, as the area is generally flat.

A number of the sectors had open grassland with few trees, and some had woodlands (i.e. S2 factor of 11.5 x 0.9 or 11.5 x 0.7) thus the distances differed with direction for the Level 1 assessment.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used as detailed in the NEIGP.

The factors used for Farm A are detailed below in Table 4-1. The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

[d] The distance was arbitrarily selected based on the site location and terrain elements.

Table 4-1: Farm A – S Factor Values

Direction	S1	S2	S3	S4[e]	D (level 1)	D (level 1.5)
N	1 (1 x 1)	10.35	1.2	36.1%	2,135	771
NNE		10.35	1.2	49.5%	2,135	1,058
NE		10.35	1.2	55.0%	2,135	1,174
ENE		10.35	1.2	45.1%	2,135	963
E		8.05	1.2	36.7%	1,660	609
ESE		8.05	1.2	36.9%	1,660	613
SE		8.05	1	42.2%	1,384	583
SSE		8.05	1	45.7%	1,384	632
S		8.05	1	42.7%	1,384	591
SSW		8.05	1	39.1%	1,384	541
SW		8.05	1	50.8%	1,384	703
WSW		8.05	1	52.0%	1,384	720
W		10.35	1	59.2%	1,779	1,053
WNW		10.35	1	100.0%	1,779	1,779
NW		10.35	1.2	98.8%	2,135	2,108
NNW		10.35	1.2	39.9%	2,135	851

The calculated buffers are shown graphically in Section 4.2**.**

4.1.2 Farm B

The farm has a combination of flushing and deep litter sheds. There are 13 sheds on site, with eight being deep litter sheds with growers, and the final five being finisher sheds. The grower sheds have 675 SPU per shed, and the litter is changed every 4 weeks. The finisher sheds hold 880 SPU per shed and is flushed daily. Therefore 55% of the SPU are held in deep litter sheds, and 45% of the SPU are held in flushing sheds.

The farm makes use of SEPS. For the purposes of this work, the SEPS were treated as a conventional primary/secondary pond system with the active SEP being the primary pond, and the non-loaded SEP being a secondary pond.

As above, the assessment was based on rural residences only ($S2_R$) and surface roughness values ($S2_S$) in each of the 16 directions was selected based on land use within 1.2 km of the site which was derived using a recent aerial photograph. The land consisted of open grassland with few trees.

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.2 km[f] from the centre.

If terrain features relevant to odour dispersion were evident (e.g. a confining valley), the factor for that direction was derived based on information at hand. None were present for Farm B, as the area is generally flat.

[e] Rounded to one decimal place
[f] The distance was arbitrarily selected based on the site location and terrain elements.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used.

The factors used for Farm B are detailed below in Table 4-2. The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

Table 4-2: Farm B – S Factor Values

Direction	S1	S2	S3	S4[g]	D (level1)	D (level 1.5)
N	S1=0.5768 S1R=(5400/9800x0.63[h])+(4400/9800x1) = 0.796 S1T=(5400/9800x0.5)+(4400/9800x1) = 0.724	10.35	1.2	93.2%	1,123	1,046
NNE		10.35	1.2	95.5%	1,123	1,073
NE		10.35	1.2	60.9%	1,123	684
ENE		10.35	1	55.9%	936	523
E		10.35	1	50.5%	936	472
ESE		10.35	1.2	40.3%	1,123	453
SE		10.35	1.2	41.0%	1,123	460
SSE		10.35	1	35.6%	936	333
S		10.35	1	32.4%	936	303
SSW		10.35	1	37.2%	936	348
SW		10.35	1	35.4%	936	331
WSW		10.35	1	38.1%	936	356
W		10.35	1	51.0%	936	477
WNW		10.35	1	85.2%	936	798
NW		10.35	1.2	95.4%	1,123	1,071
NNW		10.35	1.2	100.0%	1,123	1,123

The calculated buffers are shown graphically along with the odour contours in Section 4.2 below.

4.1.3 Farm C

The farm has a combination of flushing and deep litter sheds. There are 15 sheds on site, with five flushing sheds (5,520 SPU) and the remaining 10 being deep litter sheds (4,500 SPU). The flushing sheds are pull plug and are flushed once a week with pit recharge. The deep litter sheds have litter that is changed every 12 weeks.

The site has a covered anaerobic pond (CAP) and no secondary pond. As no factor is allowed for this in the NEGIP, it has been treated as having a secondary pond on site (i.e. factor of 0.5).

As above, the assessment was based on rural residences only (S2R) and surface roughness values (S2S) in each of the 16 directions was selected based on land use within 1.5 km of the site[i] which was derived using a recent aerial photograph. The land consisted of grassland with few trees.

[g] Rounded to one decimal place
[h] Bedding removed from site
[i] The distance was arbitrarily selected based on the site location and terrain elements.

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.5 km from the centre. The area was found to be flat.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used.

The factors used for Farm C are detailed below in Table 4-3. The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

Table 4-3: Farm C – S Factor Values

Direction	S1	S2	S3	S4[j]	D (level1)	D (level 1.5)
N	S1=0.417 $S1_R$=(5,520/10,020x1)+(4,500/10,020x0.63) =1 $S1_T$=(5,520/10,020x0.5[k])+(4,500/10,020x0.5) = 0.5	10.35	1	100.0%	685	685
NNE		10.35	1	100.0%	685	685
NE		10.35	1	85.9%	685	588
ENE		10.35	1	92.1%	685	631
E		10.35	1	96.3%	685	659
ESE		10.35	1	90.0%	685	616
SE		10.35	1	89.7%	685	614
SSE		10.35	1	100.0%	685	685
S		10.35	1	100.0%	685	685
SSW		10.35	1	100.0%	685	685
SW		10.35	1	82.0%	685	562
WSW		10.35	1	82.7%	685	566
W		10.35	1	93.9%	685	643
WNW		10.35	1	98.7%	685	676
NW		10.35	1	100.0%	685	685
NNW		10.35	1	100.0%	685	685

The calculated buffers are shown graphically in Section 4.2.

4.1.4 Farm D

The farm has a combination of flushing and deep litter sheds. There are 11 sheds on site, with four flushing sheds (~6,600 SPU) and the remaining 7 being deep litter sheds (~2,900 SPU). The flushing sheds are pull plug and are flushed once a week with pit recharge. The deep litter sheds have litter that is changed every 5 weeks.

The site has an anaerobic pond and second pond that is offline/drying. The pond use is rotated so that at any one point in time one is actively loaded and the other is not. The ponds are located away from the sheds at a significant distance.

[j] Rounded to one decimal place

Two scenarios were run to test sensitivity of the assessment:

- The site without ponds (i.e. assuming covered ponds); and
- The site with ponds (no treatment).

As above, the assessment was based on rural residences only (S2R) and surface roughness values (S2S) in each of the 16 directions was selected based on land use within 1.5 km of the site which was derived using a recent aerial photograph. The land consisted of grassland with few trees.

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.5 km from the centre. The area was found to be flat.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used.

The factors used for Farm D are detailed below in Table 4-3 (without ponds) and Figure 4-5 (with ponds). The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

Table 4-4: Farm D – S Factor Values – Without Ponds

Direction	S1	S2	S3	S4[i]	D (Level 1)	D (level 1.5)
N	S1=0.443 $S1_R$=(6,648/9,588x1)+(2,940/9,588x0.63)=0.886 $S1_T$=(6,648/9,588x0.5)+(2,940/9,588x0.5)=0.5	11.5	1	99%	789	783
NNE		11.5	1	100%	789	789
NE		11.5	1	87%	789	690
ENE		11.5	1	76%	789	600
E		11.5	1	80%	789	630
ESE		11.5	1	60%	789	471
SE		11.5	1	60%	789	475
SSE		11.5	1	58%	789	460
S		11.5	1	66%	789	524
SSW		11.5	1	77%	789	607
SW		11.5	1	86%	789	681
WSW		11.5	1	82%	789	645
W		11.5	1	92%	789	725
WNW		11.5	1	83%	789	652
NW		11.5	1	98%	789	770
NNW		11.5	1	100%	789	789

[i] Rounded to one decimal place

Table 4-5: Farm D – S Factor Values – With Ponds

Direction	S1	S2	S3	S4[m]	D (Level 1)	D (level 1.5)
N	S1=0.751 $S1_R$=(6,648/9,588x1)+ (2,940/9,588x0.63) =0.886 $S1_T$=(6,648/9,588x1)+ (2,940/9,588x0.5) =0.847	11.5	1	99%	1,337	1,325
NNE		11.5	1	100%	1,337	1,337
NE		11.5	1	87%	1,337	1,169
ENE		11.5	1	76%	1,337	1,015
E		11.5	1	80%	1,337	1,068
ESE		11.5	1	60%	1,337	798
SE		11.5	1	60%	1,337	804
SSE		11.5	1	58%	1,337	779
S		11.5	1	66%	1,337	887
SSW		11.5	1	77%	1,337	1,028
SW		11.5	1	86%	1,337	1,153
WSW		11.5	1	82%	1,337	1,092
W		11.5	1	92%	1,337	1,227
WNW		11.5	1	83%	1,337	1,104
NW		11.5	1	98%	1,337	1,304
NNW		11.5	1	100%	1,337	1,337

The calculated buffers are shown graphically in Section 4.2 below.

4.1.5 Farm E

Farm E has a capacity of ~11,000 SPU spread throughout multiple sheds. Approximately 8% of pigs are housed in deep litter sheds with a 12-week litter change frequency, 71% in deep litter sheds with a 6-week change frequency and 21% in pull plug shedding with pit recharge which is flushed weekly.

Effluent treatment occurs in a primary/secondary pond system. There is a screw press prior to the pond. Typically screw press units remove 20-40% of VS loading (FSA Environmental, 2002) so it has been assumed there is greater than 25% removal.

As above, the assessment was based on rural residences only (S2R) and surface roughness values (S2S) in each of the 16 directions were selected based on land use within 1.5 km of the site which was derived using a recent aerial photograph. The land has limited grass cover.

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.5 km from the centre. The area was found to be flat.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used.

The factors used for Farm E are detailed below in Table 4-6. The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

[m] Rounded to one decimal place

Table 4-6: Farm E – S Factor Values

Direction	S1	S2	S3	S4[n]	D (level1)	D (level 1.5)
N	0.429	11.5	1	100%	839	839
NNE	$S1_R$=(960/11,344x1)+ (8050/11,344x0.63)+ (2334/11,344x1)+ =0.737 $S1_T$=(960/11,344x0.5)+ (8050/11,344x0.5)+ (2334/11,344x0.9)+ =0.582	11.5	1	99%	839	833
NE		11.5	1	75%	839	632
ENE		11.5	1	78%	839	651
E		11.5	1	79%	839	667
ESE		11.5	1	77%	839	642
SE		11.5	1	66%	839	550
SSE		11.5	1	66%	839	555
S		11.5	1	72%	839	604
SSW		11.5	1	73%	839	613
SW		11.5	1	82%	839	691
WSW		11.5	1	77%	839	642
W		11.5	1	66%	839	555
WNW		11.5	1	60%	839	504
NW		11.5	1	83%	839	695
NNW		11.5	1	100%	839	839

The calculated buffers are shown graphically in Section 4.2**.**

4.1.6 Farm F

Farm F has a capacity of ~8,800 SPU spread throughout multiple sheds. All sheds are pull plug and are flushed weekly. Approximately half of the sheds are mechanically ventilated. Effluent treatment occurs in a primary/second/tertiary system. There is a run down screen prior to the primary pond system. It is assumed that this system is at least 25% efficient.

As above, the assessment was based on rural residences only (S2R) and surface roughness values (S2S) in each of the 16 directions was selected based on land use within 1.5 km of the site which was derived using a recent aerial photograph. The land consisted of grassland with few trees, as well as some sections of woodland (~700m to 1 km deep).

Terrain weighting factor S3 was calculated based on the slope between the middle of the piggery and the terrain at each of the compass points 1.5 km from the centre. The area was found to be flat (<1%) with some receptor's directions being slightly above the height of the piggery.

The S4 factor was calculated based on the methodology detailed in the NEGIP based on the meteorological data summarised in Section 3 above. Note that a safety factor of 20% was used.

The factors used for Farm F are detailed below in Table 4-7. The descriptors for the factors were detailed above in Table 2-5 to Table 2-7.

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[n] Rounded to one decimal place

Table 4-7: Farm F – S Factor Values

Direction	S1	S2	S3	S4°	D (level 1)	D (level 1.5)
N	S1=1 (1x0.9)	10.35	1	100.0%	1,383	1,383
NNE		10.35	1	92.0%	1,383	1,272
NE		10.35	1	67.1%	1,383	928
ENE		8.05	1	58.0%	1,076	624
E		8.05	1	52.9%	1,076	569
ESE		8.05	1	49.8%	1,076	535
SE		11.5	1	47.8%	1,537	734
SSE		11.5	1	52.7%	1,537	809
S		11.5	1	48.7%	1,537	748
SSW		11.5	1	56.9%	1,537	874
SW		11.5	1	91.1%	1,537	1,400
WSW		11.5	1	81.3%	1,537	1,250
W		11.5	1	88.0%	1,537	1,352
WNW		11.5	1	96.7%	1,537	1,485
NW		11.5	1	100.0%	1,537	1,537
NNW		11.5	1	100.0%	1,537	1,537

The calculated buffers are shown graphically in Section 4.2.

4.2 Dispersion Modelling

The results of the dispersion modelling and S Factor Calculations are shown below as follows:

- Figure 4-1: Farm A - S Factor and Modelling Results;
- Figure 4-2: Farm B - S Factor and Modelling Results;
- Figure 4-3: Farm C - S Factor and Modelling Results;
- Figure 4-4: Farm D - S Factor and Modelling Results – Assumes Covered Primary;
- Figure 4-5: Farm D - S Factor and Modelling Results – With Ponds;
- Figure 4-6: Farm E - S Factor and Modelling Results; and
- Figure 4-7: Farm F - S Factor and Modelling Results.

Note that Level 1, Level 1.5 and Level 2 (modelling) methods are all included in the figures.

For each figure, the each coloured line represents either an odour criterion or the Level 1 or Level 1.5 buffer. These are shown as follows:

- Blue – Victoria $C_{99.9\ 3min}$ = 5 ou;
- Light Blue – South Australia $C_{99.9\ 3min}$ = 10 ou;
- Green – Queensland $C_{99.5\ 1hr}$ = 2.5 ou ;
- Yellow – New South Wales $C_{99\ 1sec}$ = 5 ou;
- Red – NEGIP $C_{98\ 1hr}$ = 3 ou;

° Rounded to one decimal place

- Orange – NEGIP Level 1 buffer; and
- Pink – NEGIP Level 1.5 buffer.

Note that the red contours that are used to show the NEGIP odour criteria show the three possible values ranging from the most stringent (1 ou) to that used for a rural residence (3 ou)[p].

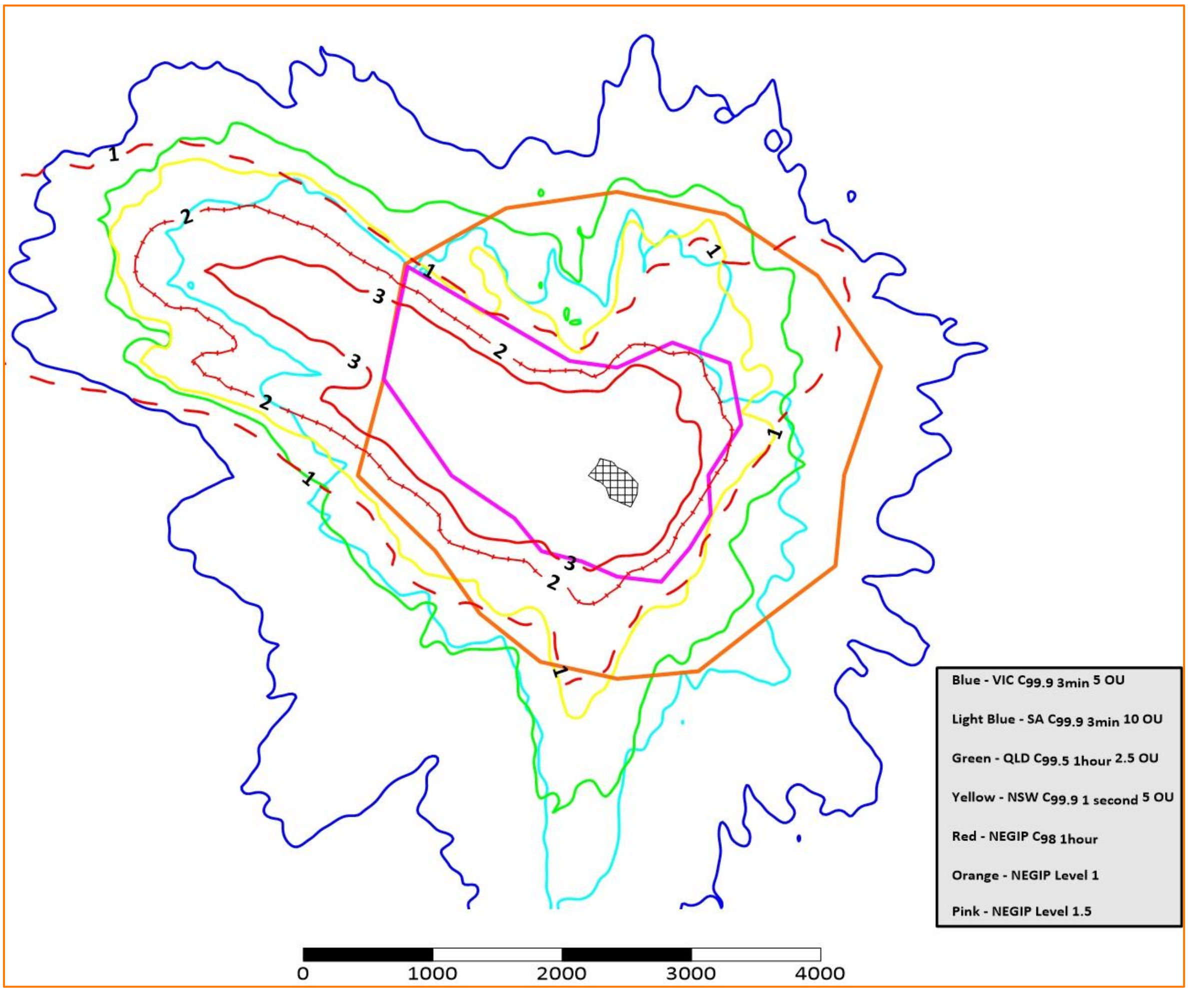

Figure 4-1: Farm A - S Factor and Modelling Results

[p] See Table 2-2.

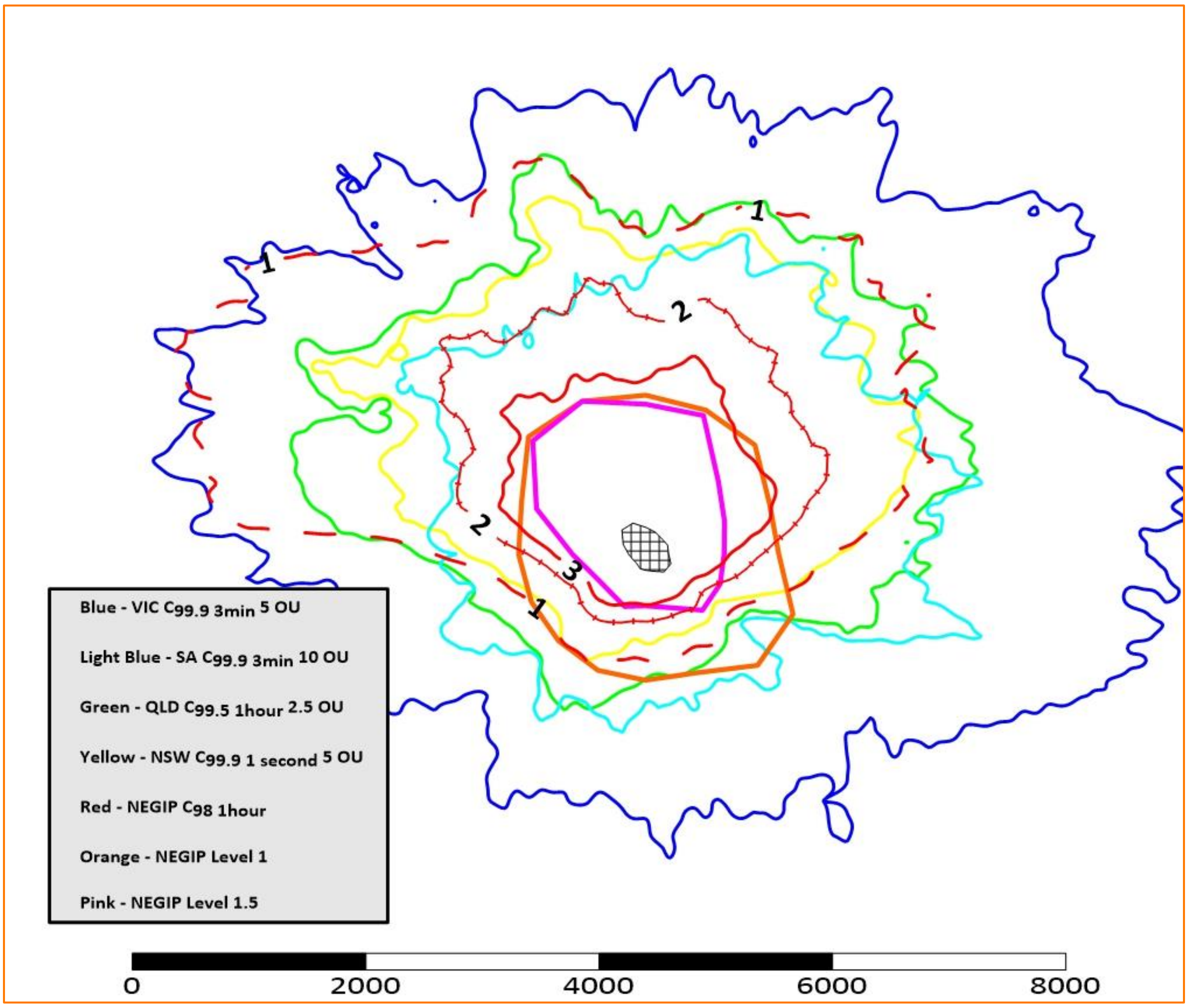

Figure 4-2: Farm B - S Factor and Modelling Results

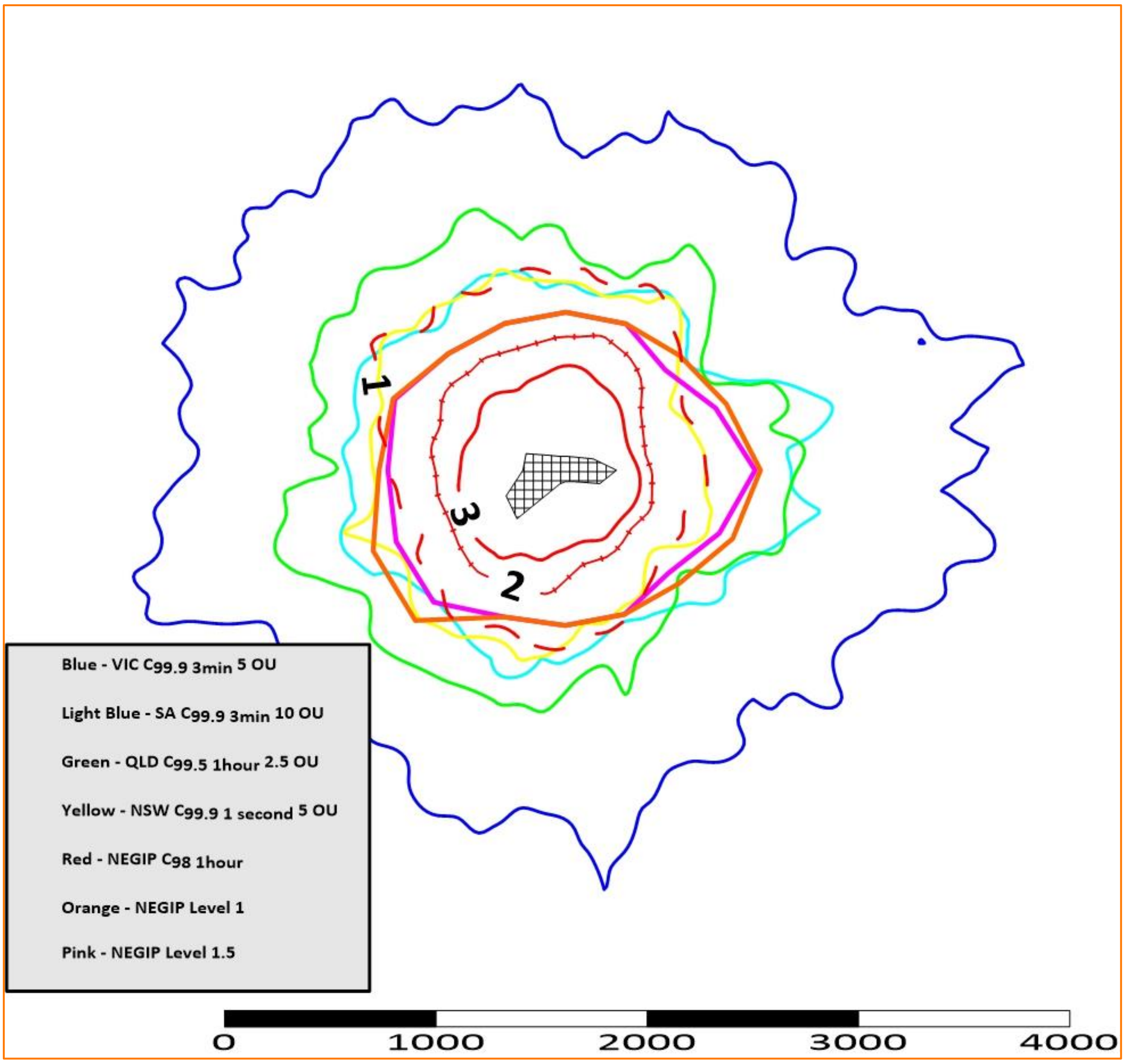

Figure 4-3: Farm C - S Factor and Modelling Results

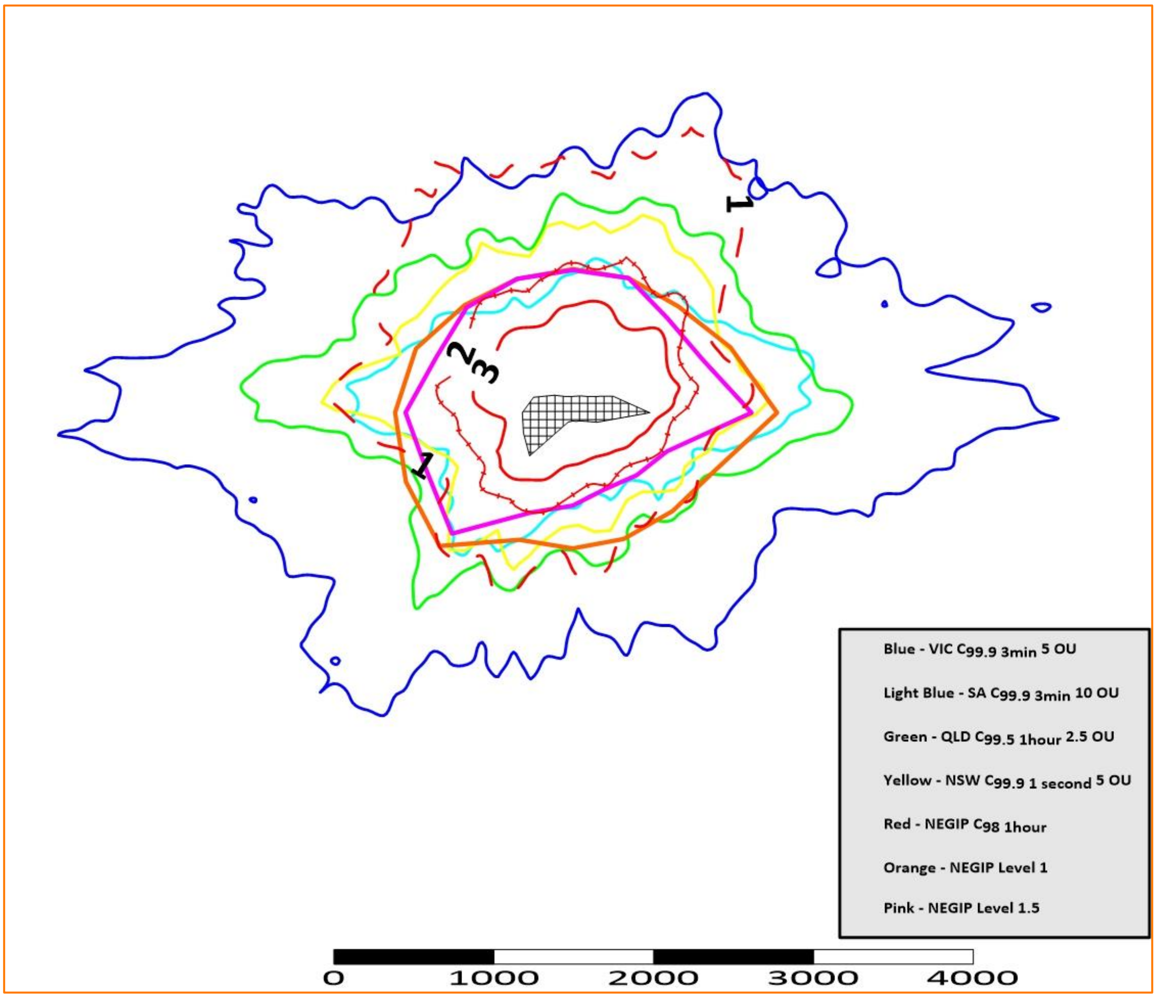

Figure 4-4: Farm D - S Factor and Modelling Results – Assumes Covered Primary[q]

[q] No ponds were modelled.

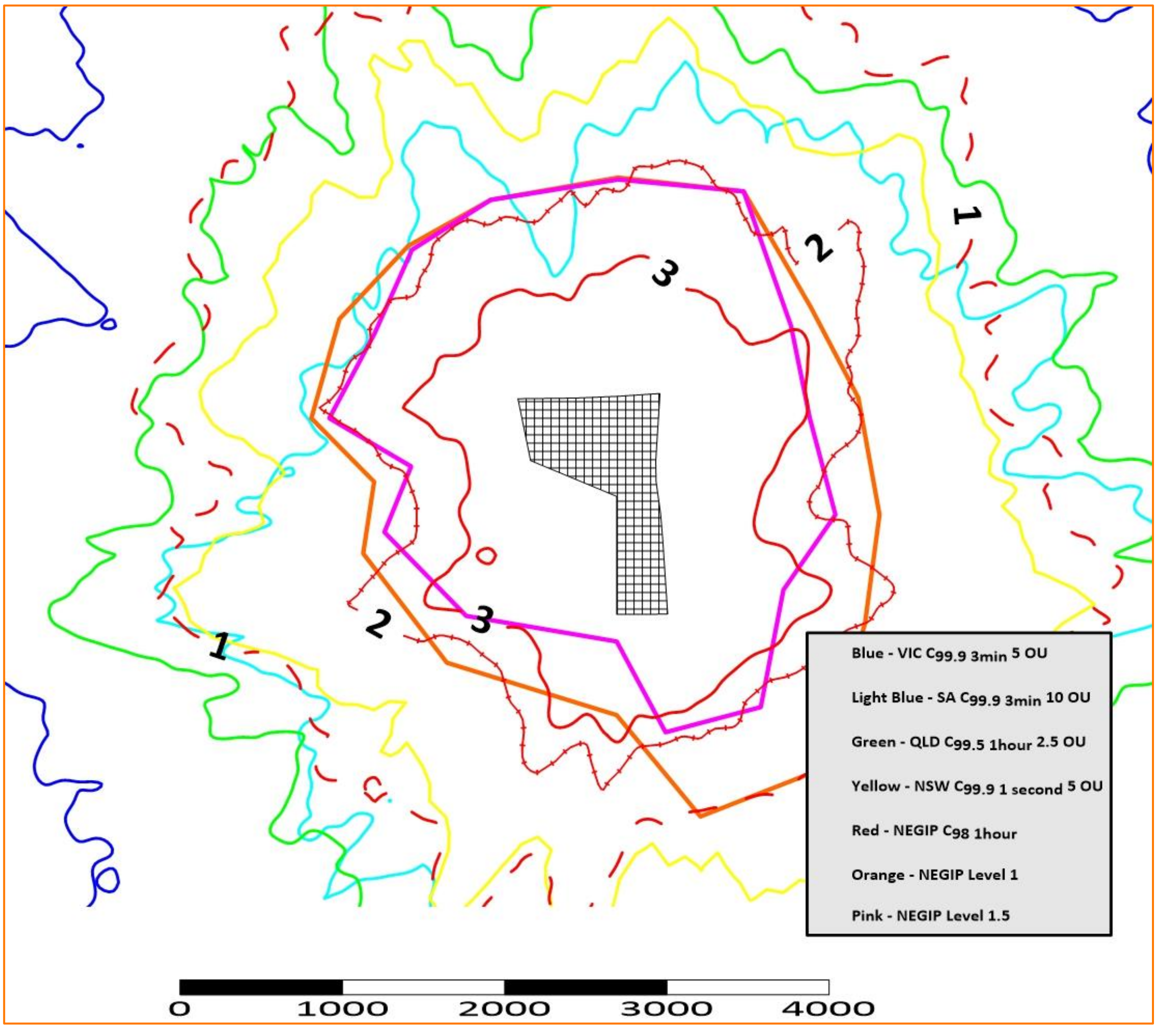

Figure 4-5: Farm D - S Factor and Modelling Results – With Ponds

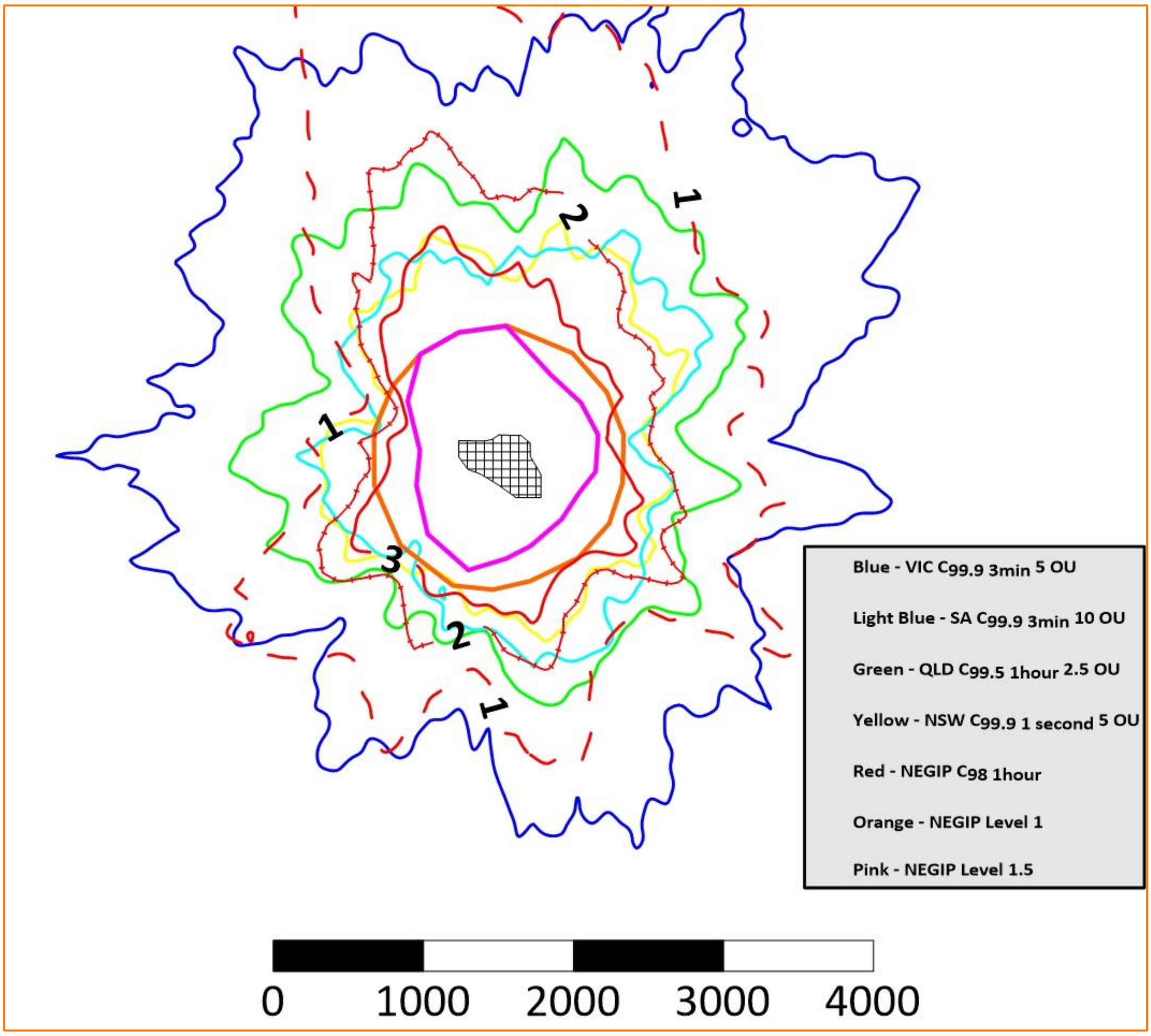

Figure 4-6: Farm E - S Factor and Modelling Results

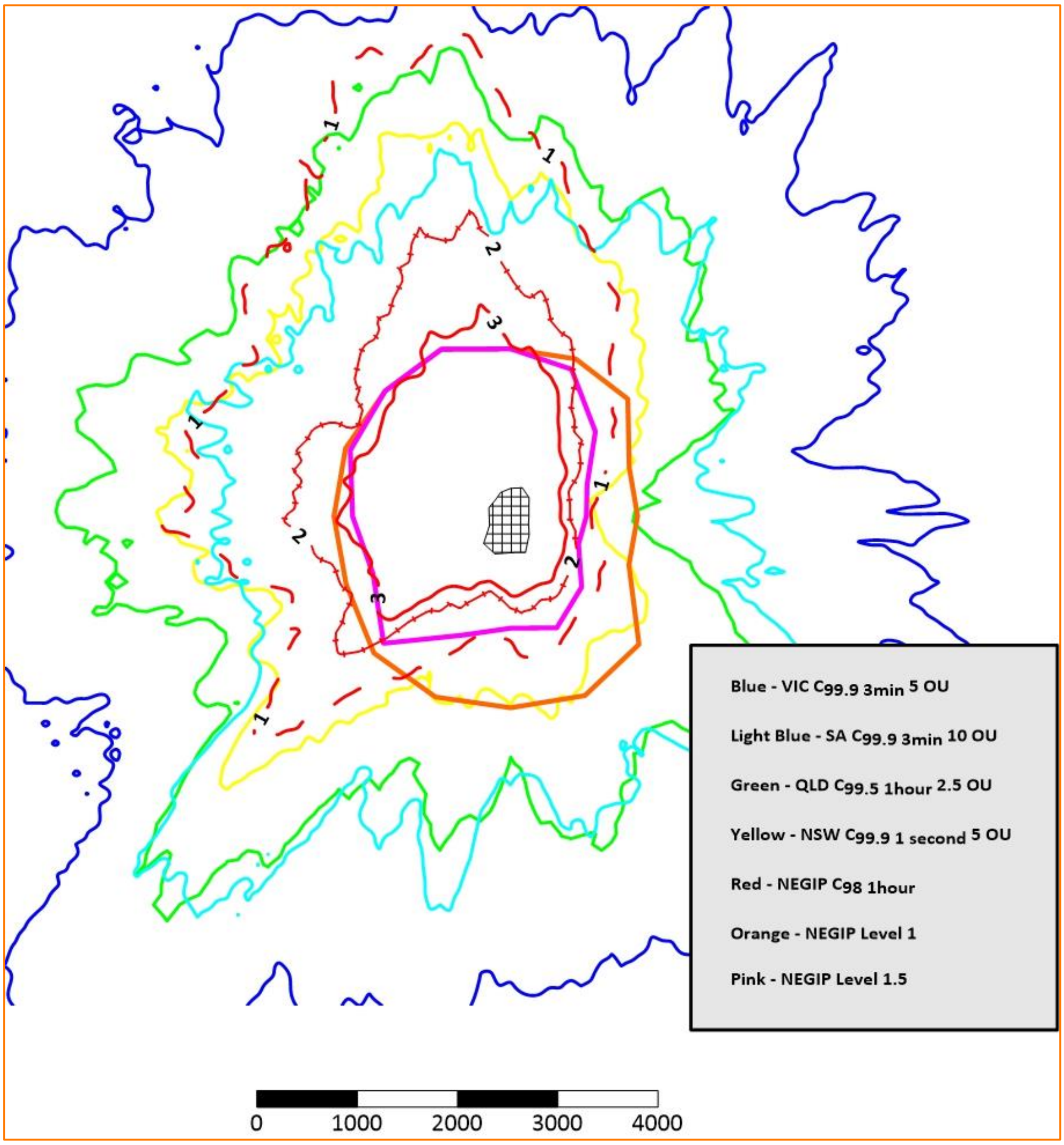

Figure 4-7: Farm F - S Factor and Modelling Results

5 DISCUSSION

Prior to discussing the results, it is relevant to consider the history of the S Factor methods, and underlying inputs into the modelling.

5.1 History of S Factors

Modelling has historically been used as the primary method for assessing potential odour impacts of piggeries. For example, the method of McGahan et al. (2000) was the basis of the original S Factor methodology used in Queensland (DPI, 2001). Using their methodology various piggery sizes were approved. Until the publication of contemporary odour criteria, those in McGahan et al. ranged up to 25 ou at the 99.5th percentile, 1 hour average concentration (NVN olfactometry). Given that the odour emission rate data were based on the NVN standard, the equivalent concentration in AS4323.3 odour units is in the order of ~8 ou (assuming a ~3:1 ratio between methods and allowing for guessing as opposed to certain and correct).

The modelling methodology and the S Factor approach were both used in Queensland up until the adoption of the NEGIP.

As part of this project, we compared the DPI (2001) S Factor method, the NSW Level 1 method in the Technical Notes (DEC NSW, 2006b) and the NEGIP method for a “worst case” piggery. That is, the largest value for a 10,000 SPU piggery on flat land, grass/crops (i.e. limited vegetation), single rural residence and the option for shed type which led to the largest buffer[r] (QLD – held for greater than 24 hours within building , NSW – Slatted floor and deep pit and NEGIP – conventional shed, static pit, pull plug or flushing system). The buffers were 1,632 m, 1,500 m and 2,377 m respectively based on the inputs above. As a result, the NEGIP would yield the largest buffer for a standard piggery.

The primary difference between the methods is the exponent in the NEGIP. The equation is $N^{exponent}$ and then the S factors are applied. For NSW and QLD, the exponent is 0.5, but for the NEGIP the exponent is 0.55. If the 0.5 exponent is used in the NEGIP equation, the buffer is 1,500m. Therefore, the NEGIP buffer (for the assumptions above) is bigger as the piggery size increases, as a result of the exponent value that is used.

Critically the NEGIP buffers for a standard piggery (flat terrain, single rural residence, cropland) are larger than those required under DPI (2001). In other words, the NEGIP Level 1 method is generally more conservative. The NEGIP Level 1 method also includes a factor of 0.5 for covered ponds. This doesn’t mean that emissions are halved, but that the primary ponds, which are assumed to generate 80% of emissions from a site are only reduced by 75% when covered: secondary ponds are still included.

We are not aware of any significant complaint history associated with any farm that has been approved on the basis of the S Factor method in the NEGIP. Therefore, considering that the NEIGP S Factor method produces larger buffers than the NSW and QLD S Factor methods, it is considered to be sufficiently conservative to avoid odour complaints.

[r] Generally a S Factor of 1, which is the largest for most S factor options i.e. flat = 1, crops only no trees = 2

Based on the information provided to us to date, we understand that none of the farms assessed in this report have a history of complaints. This is discussed in Section 5.4 below, especially with regard to the locations of nearby receptors.

5.2 Estimation of Emissions

As noted above, the emissions in this report were estimated using the VEF Maker software assuming that the software can be applied to standard piggeries. Consistent with earlier modelling of piggeries (Watts, 2000; Nicholas, et al., 2003), the shed emissions were based on earlier shed measurements, and the pond emissions were based on wind tunnel based data. As shown in the figures above (e.g. Figure 2-7) the shed emissions were expressed as odour units per second per source (ou/s), and the pond emissions were odour units per square metre per second (ou/m^2/s). At first glance, the shed emissions appear higher, but it should be recognised that the emission rate for the pond needs to be multiplied by the pond area. Therefore, for the piggeries that had a primary and secondary pond system, the dominant sources were the ponds. This was especially so if a large tertiary/wet weather pond was also present, and the pond emissions were assumed to be higher in winter (as opposed to the shed emissions which were lowest in winter).

The publication AS4323.4 (Standards Australia, 2009) (commonly known as the flux chamber standard) was released after the report *The effect of loading rate and spatial variability on pond odour emissions, Final report for Australian Pork Limited, Project 1628* (APL, 2004) was published. The data in the aforementioned report was collected using a wind tunnel.

As noted elsewhere, the flux chamber emissions tend to be lower than wind tunnel emissions. The reason for this associated with the conditions inside the flux chamber. Unlike a wind tunnel where a constant wind speed of 0.3 m/s is present (equivalent to between 0.4 to 3 m/s depending on stability class) at 10 metres above ground level, the conditions inside a flux chamber are often considered to be consistent with low wind speed stable conditions.

Whereas odour flux data obtained by Watts (2000), Nicholas et al. (2003) and others, and used in the VEF Maker algorithms, was based on wind tunnel data, more recent data including that obtained by The Odour Unit (2008) have been collected from piggeries using flux chambers.

It is our experience that until recently, VEF Maker had not been widely used for modelling piggeries, and most regulators relied on S Factor methods. Hence, the issues arising from using wind tunnel based flux data from piggery ponds had not been brought to light. Recent proposed piggery developments have highlighted the need for improved site-specific modelling, because the piggeries modelled often didn't reflect existing or proposed operations.

Meat and Livestock Australia (MLA) published its feedlot odour emission model project in 2015. It contained a number of chapters on sampling and analysis as well as modelling. Of relevance here is the report *Development of an odour emissions model for Australian Feedlots - Part F: Emissions estimation and model application* (Ormerod, et al., 2015). The original emissions estimation methodology used in the report was based on wind tunnel data from pond and pen systems.

In the first iteration of the model and its application at a number of feedlots with known complaint histories (including one that had recently been through a significant court appeal relating to a proposed expansion), it was found that odour concentrations at receptors were an order of magnitude or more above the current odour criterion and the critical odour contours were substantially larger than the buffers produced by the recognised S Factor method for the feedlot industry. The results in this report show a similar pattern.

The issue was addressed in Ormerod et al. (2015), which provided some analysis of the effects of sampling method (specifically flux chamber vs wind tunnel) on estimated emission rates as a result of differential aerodynamic forcing of odour fluxes. Concerning impacts from ground level sources (including ponds), they noted that “maximum downwind impacts occur under near-calm, stable conditions, which are far more closely represented by the flux chamber than the wind tunnel”. To account for this, Ormerod et al. (2015) noted that a scaling factor was required to adjust the wind tunnel results to a comparable flux chamber value. It is noted that unlike piggeries, which have both sheds and ponds (volume sources and area sources), feedlots only have area sources. The implications of this are discussed in Section 5.4 below.

Finally, the emission rates for the farms were based on an assumed pond loading rate. Some of the sites had solids removal, but as shown in Galvin et. al. (2002) removing 20% of solids is likely to change emissions in the order of 5%, and doubling the loading changes the emissions by only 20%.

5.3 Modelling methodology

The modelling methodology for this report used a standard setup, that is, TAPM/CALMET for meteorology and CALPUFF for the dispersion modelling component. Ponds were modelled as area sources, and sheds as volume sources.

As the setup and inputs for the meteorological modelling are standard, they are not discussed here. However, the results do show that for sites with a dominant wind direction (i.e. Site A), the lower percentiles can distort the plume shape in the dominant downwind direction.

One item requiring consideration is the use of non-buoyant volume sources for sheds. This ignores the effects of thermal buoyancy (i.e. enhanced plume buoyancy) but it is only likely to be significant in terms of model results if there are no ponds on site and the dominant source is sheds. It is also relevant that under calm conditions, the calculated plume growth from volume sources can be continuous, leading to a short-term overestimation of odour impacts. However, it is only relevant if there are no pond sources on site and there is a high frequency of calm events, which isn’t an issue for most piggeries.

We note that the modelling above didn’t focus on wet weather storages if multiple ponds were present. This is because the VEF Maker software treats all ponds as secondary ponds, which would lead to far larger odour contours than shown above, especially for Farm F.

Next is the assumption of conservation of mass. When modelling odour, it is assumed that there is no change in the total odour plume ‘mass’ over time as it disperses. For example, it assumes that there are no chemical transformations (e.g. oxidation) that might reduce the odour-forming potential of the constituents of the gaseous mix, or that there is no deposition of odorous compounds (e.g., by interactions with vegetation). Work by Edgar et al. (2002) has highlighted that for piggeries, the plume may not be conserved.

This, therefore, is potentially a conservative assumption.

Whilst various limitations of the modelling methodology have been addressed, it is a standard method, and the key input in this case is considered to be the representation of odour emissions.

5.4 Results

The results were shown in Section 4.2 above.

Before discussing the results, it is important to note that the hypothesis that led to this work was that modelling produced a larger estimate of impacts than the S Factor method. This is relevant as the S Factor method in the NEGIP is widely used and accepted as being an appropriate tool.

The odour criteria in use in Australia, especially the criteria in the NEGIP, as noted elsewhere, are based on percentiles (see background material in Miedema (1992) and Miedema et al. (2000)).They concluded that the results of odour nuisance surveys compared well to odour modelling results at the 98^{th} percentile. The sites they tested included a pig farm (1984/85). The latter work they performed in the 1990s included a chip factory, pastry factory and tobacco factories, all of which are dissimilar in source types to piggeries (i.e. unlikely to have area sources as the dominant odour source).

This is relevant as point sources (i.e. vents and chimneys) are easy to test, as opposed to emissions from area sources, which can be a function of not only the effluent quality but meteorological conditions, and pose a range of sampling problems.

As noted by Ormerod et al. (2015), for sites that have datasets based on wind tunnel data, and where those sources are the dominant sources on site, the modelling can lead to an overprediction of impacts if the odour flux data are not adjusted to account for real-world influences on the actual emission rates. This effect on model overprediction is greatest where high percentiles (i.e. 99.9th) are used, since the high-end percentiles are almost always associated with the near-calm conditions that are most relevant to the over-estimation of wind tunnel-based emission rates.

When looking at the results in Section 4.2 above, two areas are relevant:

- Effect of odour criterion; and
- Difference in predictions with sites with pond systems compared to non-pond or covered pond system.

The difference between the criteria is evident and has been discussed elsewhere, including in Galvin et al. (2007). Importantly though, the differences between the rural type criteria used here for NSW, QLD and South Australia are relatively small, compared to the Victorian methodology which results in substantially larger contours, and the NEGIP criterion, which is less conservative and produces generally smaller contours. Notably, the NEGIP criterion is consistent with recent European publications including IAQM (2018) that has odour criteria in the order of $C_{98\ 1\ hour}$ ~1.5 - 3 ou as a "slight adverse" risk at a dwelling. For a concentration of $C_{98\ 1\ hour} \leq 1.5$ ou, the risk is considered "negligible". This criterion results in contours similar to the contours generated by the QLD, NSW and SA criteria in the results section above. However, this is a one size fits all approach, and as shown by the results, ends up with large contours around existing sites.

For all systems, the state-based odour criteria (i.e. except the NEGIP criterion) resulted in contours that were larger than the S Factor method. This is relevant, as many of the sites comply with the S Factor method and operate without complaints yet the modelling method tested here indicates that most of the sites would be non-compliant if modelled, especially if the Victorian criterion were adopted.

In the development of the MLA emissions assessment method, this was encountered with the original method. That is, the S Factor method detailed in MLA (2012) for feedlots, which was based on earlier more simplistic modelling, produced smaller odour contours than the original model method. The model was compared to a number of operating feedlots of which the majority had a lack of complaints and met the S Factor method, except one that didn't meet the S Factor method and had received complaints.

As noted in Ormerod et al. (2015), they modified the emission method, based on research and experience, with the wind tunnel data being reduced as a starting point. This is more readily applied to feedlot than piggeries, as the same modification can be applied to all sources. In contrast to this, piggeries have shed systems and ponds so the adjustments would apply only to some sources (i.e., the ponds).

The shed systems are relatively easily quantified, especially the modern tunnel ventilated systems. Therefore, part of the modelling methodology is known, i.e. shed emissions. However, both the model results and complaints evidence indicate that the pond emissions are overstated, at least for the critical meteorological conditions that are associated with highest downwind odour concentrations: light wind, stable conditions. This is most evident in Farm A and Farm F, the two sites with the largest pond systems. It is noted that Farm F has multiple receptors within the contours, and sits in an area in between other intensive livestock operations. In short, the model results are inconsistent with the complaint history for that site, in that the predicted odour footprint covers a large area, yet the site to the best of our knowledge has not received any complaints.

The example of Farm D, which was modelled in this report using two scenarios relating to ponds, illustrates the point about the criteria and emission rates most clearly. In Figure 4-4, showing the results with no pond emissions, the NEGIP contours are very roughly similar to those for the NSW, SA and QLD criteria. Including the ponds (Figure 4-5) increases the extent of all contours, but more markedly so using the dispersion modelling approach and the state-based criteria. This set of differences highlights the exaggerating effect of using wind tunnel-based pond emissions without aerodynamic-based adjustment.

With hindsight, especially considering the work of Ormerod et al. (2015), the potential for overprediction of pond emissions was expected. The potential for overprediction could be addressed by updating the emissions database previously detailed in Nicholas et al. (2003) to include consideration of the emissions measured during this project (see main report), and to consider the implications of the data with regard to the model outputs. As noted in Ormerod et al. (2015), flux chamber emissions may be more relevant as the base point, and then varying these for wind speed and stability, rather than assuming wind tunnel emissions are equivalent to E class light wind conditions (See wind speed and stability class table in Watts (2000) and Assumptions Pond tab in VEF Maker). Or in simple terms, the starting point for emissions should be lower, and then adjusted for wind speed.

6 CONCLUSION

The odour modelling detailed above has been performed in line with standard methods, and relied on the use of the VEF Maker emissions software, which codified data published by Nicholas et al. (2003).

The S Factor methodology was developed to enable consistent and simplified assessment of potential odour impacts from proposed piggeries, and in doing so, included a reasonable safety factor to account for a range of non-specific operating and meteorological conditions. In contrast, odour dispersion modelling is normally expected to produce a less conservative assessment of impacts due to site-specific conditions and operations being considered (i.e. local meteorology, site-specific emissions, emission matched criteria and so on) rather than generalised assumptions.

Experience has shown that the S Factor methodology in the NEGIP is appropriate for assessing and minimising odour impacts from piggeries.

The results from this investigation have shown that the recognised S Factor method results in buffers that are, for the most part, smaller than the modelling results when the modelling predictions are compared to the State-based odour criteria. This is counterintuitive, as theoretically the model results are expected to be smaller if the criteria are matched to the emission rate data (see comments above regarding the MLA project). The previous successful application of the S Factor method at numerous sites shows that the combination of modelling as an additional assessment using standardised emissions based on research data and State-based impact criteria is overly conservative. However, when modelling predictions are compared to the NEGIP criterion, upon which the S Factor method was based (at the 98th percentile at 1, 2 and 3 ou), the S Factor buffers were similar. Additionally, where a piggery has covered ponds, the combination of CALPUFF modelling with the NEGIP criteria tended to produce smaller buffers than the S Factor method.

This difference between NEGIP S Factor and CALPUFF modelling using State-based odour criteria is consistent with the original hypothesis that led to the project.

The reason for the difference is a function of many things, most particularly the emissions from the ponds and using odour criterion that are not matched to the emissions. Given the discrepancy between the modelling results and the NEGIP S Factor method, it would be prudent to evaluate VEF Maker to ensure that the way in which emissions are included in the software is consistent with current practices, and also has regard to the latest data including complaint histories.

The implication for industry is that the modelling of piggeries using the combination of emission rates from VEF Maker and State-based odour impact criterion as required by many regulators is more conservative and results in conservative buffer estimates. This was expected given that the S Factor buffers were based on real world experience, and modelling that made use of the 98th percentile results (see Tonkin Consulting, 2008a). The buffers predicted using a combination of VEF Maker generated emission rates and State-based odour impact criteria (as often required by the regulatory agencies), are not consistent with the complaint history of the farms studied here. Therefore, we recommend that odour modelling outputs be compared to the industry specific criteria, such as those that are defined in the NEGIP.

In order to generate meaningful buffers using CALPUFF modelling and State-based odour criteria, VEF Maker needs to be updated with a view to producing more realistic buffer distances, or as noted above, use industry-based odour criterion. This may involve a similar process to that used for the MLA project where the emissions are adjusted based on real world case studies or further validation is performed regarding existing farms and their complaint histories.

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