Australian Government
Department of Agriculture and Water Resources

AUSTRALIAN Pork

Revised Calculation Methods for Calculating Piggery Ammonia Emissions in the NPI

Final Report

APL Project 2018/0030

7th May, 2019

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List of Abbreviations

ADG	Average daily gain
DEE	Department of Environment and Energy – Commonwealth Government department which administers the National Inventory Report
NIR	National Inventory Report - The Australian Government Submission to the United Nations Framework Convention on Climate Change Australian National Greenhouse Accounts
NPI	National Pollutant Inventory - Australian Government scheme which tracks production, emissions and transfers of defined pollutants including ammonia.
EF	Emission Factor – a factor for determining the amount of a substance (as a fraction) which is emitted to the atmosphere.
EET	Emissions Estimations Technique – the EET manual for an industry describes the important processes, emissions sources estimation methods and emission factors.
SPU	Standard Pig Unit

1 Introduction

The National Pollutant Inventory (NPI) is an Australian Government scheme which tracks production, emissions and transfers of defined pollutants. Facilities which trigger threshold levels for reportable substances are required to calculate and report their emissions to the NPI.

Piggeries are required to report to the NPI when they exceed one or more thresholds for reporting. The NPI includes a wide range of emissions, associated with various industrial processes, chemical use, fuel use and other sources. The NPI includes ammonia (NH_3) as a reportable emission and this gas can be emitted at high rates from intensive livestock facilities, including piggeries. As a result, NPI reporting by piggeries is typically required when the ammonia reporting threshold is exceeded. The NPI requires piggeries to report once numbers exceed 1,137 SPU (at a conventional piggery) or up to 7,143 SPU (at a deep litter piggery with litter removed off farm), as farms of these size exceed the reporting thresholds for ammonia.

Emissions Estimation Technique (EET) manuals have been prepared by the NPI team for a number of industries including pig farms, with the relevant EET manual being '*Emission estimation technique manual for Intensive livestock - pig farming Version 2.0 June 2007*' (NPI, 2007) also known as the 'Pig Farming EET'. These manuals describe the sources of emissions associated with each industry, as well as providing guidance on applying the approved NPI emissions calculations methods. Where the 'emissions factor' method is chosen, the NPI provides standard emissions factors and calculation templates for users to determine reportable emissions.

Most piggeries that trigger NPI reporting currently use the simple reporting template in the pig farming EET to estimate gross NH_3 emissions. The NPI EET and the emission factors contained therein are over a decade old, with the EET last updated in 2007. The emissions factors used in the pig farming EET do not align with those used in the National Inventory Report for greenhouse gas emissions (NIR)(Commonwealth of Australia, 2018). Recent scientific research (Phillips *et al.*, 2016; McGahan *et al.*, 2016) also showed different ammonia emission levels than reported in the NPI, indicating that a revision may be warranted. It is also noted that the emissions factors in the Pig Faming EET do not reflect the range of manure management systems (MMS) which are currently used by producers, which limits the accuracy of reporting and may result in over-reporting in some instances. One specific MMS that may be over-reported are covered ponds / digesters.

Over prediction of emissions may result in an increased regulatory burden and higher reporting costs for producers.

1.1 Objectives

This project aimed to develop a method or tool that enables producers to more accurately calculate ammonia emissions to meet NPI reporting requirements, by developing a simple spreadsheet with multiple manure management system options.

The project objectives were to –

1) Develop a simple spreadsheet to determine ammonia emissions from piggeries, covering common types of piggery systems and alternative effluent treatment systems (such as covered ponds).
2) Review the emission factors used in the current EET manual and provide a summary of recommended factors, and an outline of the basis for the spreadsheet, in a final report & discussion paper for submission to DEE.
3) Engage with the DEE to describe the factors and recommend changes to the EET.

1.2 Ammonia Emissions from Pigs

Pig production creates significant quantities of manure by-products, resulting in ammonia emissions to air. Different types of piggeries operate in Australia, with a range of MMS. The ammonia emissions from piggery manure depend on both the type of MMS in use, and the composition of the manure (which varies by the age and class of pig, as well as diet). These factors are the primary factors in determining emission rates under the current NPI EET.

Piggery Manure Management Systems

Three main types of piggery operate in Australia; conventional, deep litter and outdoor piggeries. Conventional piggeries accommodate pigs within sheds with partly or fully slatted flooring, to allow for the collection of faeces and urine in channels or pits under the flooring. Water is used to regularly flush effluent from the under-floor channels or pits, making the primary by-product from conventional piggeries a liquid effluent stream. Conventional piggeries typically treat this effluent in an anaerobic pond or digester, prior to irrigation of treated effluent on land.

Deep litter piggeries house pigs in enclosed structures with pens bedded with a layer of organic material such as straw, sawdust, rice hulls or similar. The bedding material absorbs the faeces and urine, with the resulting by-product being a solid 'spent litter', eliminating the need to use water to handle the manure. Bedding is topped up as needed to ensure the system remains relatively dry. Bedding material is removed from pig housing after the pigs are removed and is either removed immediately from the site (disposed/sold for use off farm) or stockpiled/composted and subsequently sold or applied to land on-site.

In outdoor systems, manure is directly excreted to land and ammonia losses are typically considered to be low according to the EET. As such, the NPI does not require emissions from outdoor piggeries to be reported.

Manure Composition and Ammonia Emissions

The composition of manure can vary depending on the pig class, as defined by the age, sex and pregnancy status of the pigs. Pig nutrient intake varies by class, as does the amount of nutrients which are retained in the body, and therefore the amount which is excreted. Additionally, the level of crude protein in the diet relative to the requirements for the pig is a critical determinant of N excretion. As the amount of N in manure limits the amount of ammonia which can be formed, N excretion in manure is a primary factor in determining ammonia emissions.

The amount of nitrogen in manure can be determined from a nitrogen (N) balance for each pig class – where the amount of N in manure is equal to the amount ingested in feed, less the amount retained in the body (determined by weight gain and body composition) combined with the amount in feed waste. An N balance can be performed using a program such as PigBal, and requires accurate input data for each major diet, and accurate pig performance data. A simplified approach is to determine N excretion using 'text book' values for each class of pigs, such as those provided in the National Environmental Guidelines for Indoor Piggeries (NEGIP) (Tucker 2018).

Manure Management Systems and Ammonia Emissions

Manure storage and treatment encourages the growth of microorganisms to consume organic material in manure, either in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). These processes principally relate to the breakdown of organic matter, but nitrogen transformations are also affected. Ammonia emissions post-excretion are influenced by a series of processes described as follows.

Nitrogen is deposited from pigs in the form of organic N in solids (sloughed protein from the pig digestive system and excess feed protein) and urea in urine. Harper et al. (2004) reported that 15% of the N fed to the pig will be excreted in the faeces, while 55% is excreted in the urine, and the residual is retained in the animal. Following excretion, manure (solids and urine) are exposed to the processes of ammonification, nitrification, denitrification and transformation into organic nitrogen. However, the extent to which these processes occur, and the rate at which they occur, depend on the initial form of nitrogen supply, the presence of urease enzymes, the pH, oxygen availability, temperature, microbial activity and air flow in the MMS.

As noted, most excreted nitrogen is in urine, in the form of urea which is readily converted to ammonia in the presence of the urease enzyme. Depending on a range of other conditions, this ammonia can be lost through volatilisation, or can be transformed to the aqueous ammonium ion in a pH dependent, reversible reaction:

Equations 1 and 2:

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} 2NH_3 + CO_2 \qquad NH_{3\,(l)} + H_2O \rightleftarrows NH_4^+{}_{(aq)} + OH^-$$

Ammonia loss is a temperature dependent reaction where $NH_{3\,(l)}$ (i.e. in liquid form) is transferred to $NH_{3\,(g)}$ (i.e. gaseous form). High temperature and dry conditions result in higher gaseous losses following equation 1. In high moisture conditions, equation 2 occurs, resulting in lower immediate losses. Loss rates are also pH dependant, and are influenced by air movement, which alters the concentration of ammonia in air immediately above the emitting surface.

Shed Losses

Depending on the conditions, the transformation of urea to ammonia can happen rapidly in both conventional and deep litter pig sheds, resulting in losses from the shed. With respect to conventional systems, some losses occur when urine evaporates from the shed floor or from the pits or channels below the floor. There is a relatively small amount of time for loss processes to occur, because in most sheds the effluent is flushed once or more times per week. In deep litter systems, manure and urine are handled in a relatively dry system that is kept in the shed for the duration of the batch of pigs, which may be several weeks. In deep litter systems, organic material absorbs moisture from urine and faeces as it is mixed by the behaviour of the pigs. Microbial transformations in the litter pad may utilise excess nitrogen, reducing the risk of volatilisation. In Australian systems, pH has been found to range from 6.8-7.1 according to Tucker (2018), which is below optimum levels for ammonia losses. Air flow is also moderated at the surface where ammonia transformations occur. Considering these factors, ammonia losses are expected to be moderate from deep litter.

Liquid effluent systems

Where ammonia is transformed to ammonium in liquid systems, losses still occur depending on the storage conditions. Additionally, nitrogen in faeces is released during anaerobic breakdown, resulting in a larger pool of available nitrogen for loss from the system. The processes influencing losses during manure treatment are described as follows.

In conventional liquid effluent treatment systems, ammonia losses are strongly influenced by pH, air movement and temperature. NH_3 emissions are highest at pH > 9 and almost stop at pH < 7 (Groot Koerkamp and Klarenbeek, 1998). Thus, effluent stream pH has a substantial impact on ammonia emissions. Typical anaerobic effluent treatment systems operate at a pH of around 8.0 (Tucker 2018) which indicates ammonia losses are likely. As with conditions that influence emissions in the shed, ammonia volatilisation is increased by higher temperatures (FSA Consulting, 2007) because this results in elevated evaporation rates and subsequently ammonia losses. Air movement increases ammonia volatilisation by removing ammonia in the air immediately above the emitting surface, which is relevant to ammonia emissions from pond surfaces (Harper et al. 2004). Where gaseous losses are prevented by the presence of a cover or a closed digestion chamber, ammonium can build up in the effluent stream, resulting in a potential problem with anaerobic digestion because pH can increase beyond the ideal range for methanogenesis. This can be managed by ammonia stripping from the effluent stream. The build-up of ammonium indicates a reduction in the loss rate compared to uncovered ponds, because gas diffusion can't occur in a closed digester system. However, the loss rate from the whole MMS will be determined by the management of effluent after it leaves the digester. If effluent is subsequently stored in long HRT ponds, high ammonia loss levels would be expected. However, if effluent is irrigated immediately from the digester or pond, these losses would not occur.

Solid systems

In deep litter systems, the spent litter material is typically removed from the shed as a solid and stored on site until conditions are most suitable for land application. Storage may be a period of several months. Conditions within litter stockpiles vary, but in response to microbial action and preferable conditions, ammonia emissions can occur. This is particularly apparent where temperature increases because of microbial breakdown in the litter and where variable moisture conditions occur, such as if the material is turned. Because storage times can extend to months, additional emissions are likely.

Suitable emission factors to predict losses can be determined from relevant research and/or theoretical estimates, as described in the following sections.

2 Methods

The project conducted a review of the emission factors used in the current NPI EET. Emission factors in the EET are based on nitrogen excretion rates for each class of pig, and ammonia emission rates for various MMS. Both the MMS emission rates and the N excretion rates were investigated.

Manure N excretion rates were compared to predictions derived from PigBal 4, while ammonia emission rates for each MMS were reviewed by comparing these with emission factors used in the National GHG inventory (Commonwealth of Australia, 2018) and more recent Australian research conducted by Australian researchers (e.g. McGahan et al. 2016, Phillips et al. 2014).

Based on the findings of this review, new emission factors have been proposed to determine emissions from conventional systems with covered ponds or digesters. This included assessment of both the covered pond/digester and wet weather storage used to handle effluent after the covered pond/digester. A simple spreadsheet calculator that can predict emissions from piggeries, including those with covered ponds or other manure management systems, was developed using the updated emission factors determined by the review.

3 Review of Emissions Factors

3.1 Approach Taken in the NPI EET

As discussed in Section 1.2, ammonia emission from piggeries are dependent on the N excretion rate and the MMS. The NPI determines N excretion rates using 'textbook values', with different values for each class of pig derived from standard pig unit (SPU) conversions as described below in section 3.2. Different ammonia emission factors are provided for different MMS, as described in section 3.3. Recommendations for revised values are provided in Section 3.4.

3.2 Nitrogen Excretion Rates

Values Used in the NPI

The NPI uses modified SPU factors as the basis for predicting N excretion. The SPU was developed as a means of quantifying manure output from piggeries, based on the amount of volatile solids (VS) produced by a 40 kg grower pig (90 $kg.yr^{-1}$). The amount of volatile solids present in manure varies depending on the dry matter digestibility of diets and feed wastage. As such, the SPU provides a basis for comparing the amount of VS produced by each class of pig. SPU equivalents for all other classes were calculated based on the ratio of VS produced by each class to that produced by an SPU. The NEGIP (Tucker, 2018) details the SPU equivalence factors for each class, which are equivalent to those used in the NPI. The VS production and SPU Equivalents are reported in Table 1.

Table 1 – Standard Pig Unit Equivalent for each Class of Pig (NPI, 2007)

Pig Class	Weight Range (kg)	Age range (weeks)	VS Production (kg/yr)	Equivalent SPU Multipliers [A]
Gilt	100 - 160	24 - 30	162	1.8
Boar	100 – 300	24 – 128	151	1.6
Gestating Sow	160 - 230		151	1.6
Lactating Sow	230 - 160		215	2.5
Sucker	1.4 - 8	0 – 4	11	0.1
Weaner	8 - 25	4 – 10	47	0.5
Grower	25 - 55	10 – 16	**90**	**1.0**
Finisher	55 - 100	16 – 24	149	1.6
Heavy Finisher	100 - 130	24 – 30	162	1.8

[A] *calculated based on VS production data.*

Previous research done for the NPI by the author and colleagues (FSA Consulting 2007) showed that SPU multipliers did not accurately predict N excretion for some classes of breeding pigs, mainly because of differences in the concentration of crude protein fed to these pig classes (see Table 2).

Table 2 – Comparison of SPU Equivalent based on VS and N excretion for each Class of Pig

Pig Class	Equivalent SPU (based on VS)	Nitrogen Excretion (kg/yr)	Ratio of N Excretion (based on a grower pig)	Difference (%)
Gilts	1.8	12	1.3	-28
Boars	1.6	15	1.6	-3
Gestating Sows	1.6	13.9	1.5	-10
Lactating Sows	2.5	27.1	3.0	+23
Suckers	0.1	2.3	0.2	+104
Sow and litter (10 piglets)	3.5	50.1	5.4	+36
Weaners	0.5	3.9	0.4	-19
Growers	1.0	**9.2**	**1.0**	0
Finishers	1.6	15.8	1.7	+4

Replicated from FSA Consulting (2007)

Based on the established difference between SPU equivalents for N excretion compared to VS, a multiplier factor was incorporated into NPI SPU equivalent factors, as shown in Table 3, and modified SPU factors were then applied.

Table 3 – Multiplier Factors for SPU Nitrogen Excretion Rates in Different Classes of Pig

Pig Class	SPU (based on VS)[A]	Multiplier [B]	NPI modified SPU[C]
Gilts	1.8	0.73	1.314
Boars	1.6	n.a.	1.600
Gestating Sows	1.6	0.95	1.520
Sow and litter (10 piglets)	3.5	1.55	5.425
Weaners	0.5	0.85	0.425
Growers	1.0	n.a.	1.000
Finishers	1.6	n.a.	1.600

[A] NEGIP (Tucker 2018). [B] FSA Consulting (2007). [C] NPI (2007) (calculated by the SPU x Multiplier)

Revised Values

The values used to determine N excretion for the 2007 NPI manual were based on an earlier version of PigBal (version 2.3) and standard diets. Since this time, PigBal has been updated to version 4, which incorporates changes in the estimation of feed nitrogen that relate to a change in the dry matter and as-fed feed calculations. N excretion was therefore re-estimated using PigBal 4 to determine the difference in excreted N for each class of pigs. The same set of assumptions were applied as in the example calculations in the NEGIP (Tucker, 2018). The N excretion rates calculated using this method are shown in Table 4.

Table 4 – Nitrogen excretion rates (kg N.hd^{-1}.yr^{-1}) for each class of pig, calculated using PigBal 4

Pig Class	Weight range	kg N excreted / pig.yr
Gilts	115-160	17.0
Boars	115-300	16.9
Gestating sows	160-215	15.4
Lactating sows	215-160	30.0
Suckers	1.4-6.7	2.4
Weaner pigs	6.7-30	5.6
Porkers	30-55	13.1
Growers	55-80	18.5
Finishers	80-104	20.5

Some changes in the pig classes have been made in PigBal 4 and the NEGIP (2018) making direct comparison difficult for some classes of pigs. For example, growers are now a heavier class of pigs, and 'porkers' are closest to the weight range and manure production of an SPU (approx. 1.08 SPU). When the N excretion for porkers (see Table 4) was converted to a single SPU this resulted in 12.2 kg N excreted, which was 33% higher than N excretion per grower pig (1 SPU, see Table 2). This difference is related to changes in PigBal 4 compared to the previous PigBal versions, which were the basis for the NPI. The difference is also apparent when the updated NEGIP and earlier versions are compared.

3.3 MMS Emission Factors

The ammonia emission rates and emissions factors used in the NPI are detailed below. These emissions rates were reviewed by comparison with emission factors derived from the National Inventory Report (NIR) (Commonwealth of Australia, 2018) and more recent Australian research conducted by Australian researchers (e.g. McGahan et al. 2016, Phillips et al. 2016).

MMS Emission Factors Derived From the NPI

Emission rates for the three different MMS provided in the EET are:

- Conventional Piggery: 8.8 kg NH_3/SPU/year
- Deep Litter Piggery: 4.80 kg NH_3/SPU/year where litter is stockpiled/composted and used on farm
- Deep Litter Piggery: 1.40 kg NH_3/SPU/year where litter is sold and not stockpiled on farm

These emission rates were based on excretion rates and ammonia emission factors, the latter of which were not reported explicitly in the NPI (2007) though values were provided in the supporting literature for deep litter systems. Emission factors used in the NPI are shown in Table 5, and have been calculated based on the following formula:

$EF_{MMS} = ER_{MMS} / N_{excrSPU} / N_{conv}$

Where:

EF_{MMS} = the emissions factor for the MMS (kg NH_3-N.kg N^{-1})

ER_{MMS} = the emissions rate for the MMS (kg NH_3.$SPU^{-1}yr^{-1}$) detailed above

$N_{excrSPU}$ = N excretion from an SPU as calculated for the NPI 9.2kg NH_3. yr^{-1}as shown in Table 2

N_{conv} = factor to convert NH_3 to equivalent NH_3-N (17/14)

Table 5 –Implied Ammonia Emission Factors (kg NH_3-N.kg N^{-1}) *derived from the NPI*

	Conventional piggery (shed, uncovered pond - long HRT, land application on-farm)	Conventional piggery (shed, short HRT, land application on-farm)	Conventional piggery (shed, covered pond, no secondary ponds, land application on-farm)	Deep litter (storage, land application on-farm)	Deep litter (litter removal)
NPI 2007	0.79 [A]	n.r [B]	n.r [B]	0.43 [A]	0.13 [A]

[A] *Implied emission factor based on emission rates in NPI,* [B] *Not reported as a management system in current NPI*

MMS Emission Factors Derived From the NIR

In addition to the three MMS listed in the EET, emissions factors are required for covered ponds/engineered digesters, which now represent a substantial part of the industry (>13%). When these systems are operated with direct irrigation of effluent, ammonia emissions are expected to be substantially lower than conventional effluent treatment. This review also differentiates emission rates and emission factors for uncovered ponds with short and long hydraulic retention time (HRT) as this is known to affect effluent composition and subsequent ammonia emission rates.

The following tables (Table 6 through to Table 10) derive integrated emissions factors for each MMS based on the values reported in the NIR. MMS values reported in the NIR relate solely to the treatment of manure once it has left the shed, and as such, shed losses have been calculated based on McGahan et al. (2010). NIR MMS emission factors also do not include ammonia losses from application to land. To address this, the following calculations incorporate the default IPCC emission factor of 0.2 as used in the NIR.

Table 6 – Implied Ammonia Emission Factors derived from the NIR for a conventional piggery (shed, uncovered pond - long HRT, land application on-farm)

	Flow In	Emissions Factor	NH_3-N Emissions	Flow Out
Reference in-flow	1.00kg			1.00kg
Shed Losses	1.00kg	0.10 [A]	0.10	0.90kg
MMS Losses – Long HRT pond	0.90kg	0.55 [B]	0.50	0.41kg
Land Application	0.41kg	0.20 [B]	0.08	0.32kg
Integrated Emissions Factor (kg NH_3-N.kg N^{-1})			0.68	

[A] *McGahan et al.(2010),* [B] *Commonwealth of Australia (2018)*

Table 7 – Implied Ammonia Emission Factors derived from the NIR for a conventional piggery (shed, short HRT, land application on-farm)

	Flow In	Emissions Factor	NH_3-N Emissions	Flow Out
Reference in-flow	1.00kg			1.00kg
Shed Losses	1.00kg	0.10 [A]	0.10	0.90kg
MMS Losses – short HRT	0.90kg	0.25 [B]	0.23	0.68kg
Land Application	0.68kg	0.20 [B]	0.14	0.54kg
Integrated Emissions Factor (kg NH_3-N.kg N^{-1})			0.46	

[A] McGahan et al.(2010), [B] Commonwealth of Australia (2018)

Table 8 – Implied Ammonia Emission Factors derived from the NIR for a conventional piggery (shed, covered pond, no secondary ponds, land application on-farm)

	Flow In	Emissions Factor	NH_3-N Emissions	Flow Out
Reference in-flow	1.00kg			1.00kg
Shed Losses	1.00kg	0.10 [A]	0.10	0.90kg
MMS Losses – covered pond	0.90kg	0.00 [B]	0.00	0.90kg
Land Application	0.90kg	0.20 [B]	0.18	0.72kg
Integrated Emissions Factor (kg NH_3-N.kg N^{-1})			0.28	

[A] McGahan et al.(2010), [B] Commonwealth of Australia (2018)

Table 9 – Implied Ammonia Emission Factors derived from the NIR for a deep litter piggery (shed, storage/composting, land application on-farm)

	Flow In	Emissions Factor	NH_3-N Emissions	Flow Out
Reference in-flow	1.00kg			1.00kg
Shed Losses	1.00kg	0.13 [A]	0.13	0.87kg
MMS Losses – storage and/or composting	0.87kg	0.20 [B]	0.17	0.70kg
Land Application	0.70kg	0.20 [B]	0.14	0.56kg
Integrated Emissions Factor (kg NH_3-N.kg N^{-1})			0.44	

[A] McGahan et al.(2010), [B] Commonwealth of Australia (2018)

Table 10 – Implied Ammonia Emission Factors derived from the NIR for a deep litter piggery (shed, litter removal)

	Flow In	Emissions Factor	NH_3-N Emissions	Flow Out
Reference in-flow	1.00kg			1.00kg
Shed Losses	1.00kg	0.13 [A]	0.13	0.87kg
Integrated Emissions Factor (kg NH_3-N.kg N^{-1})			0.13	

[A] *McGahan et al.(2010),*

MMS Emission Factors Reported in Recent Literature

Recent studies conducted by McGahan et al. (2016) and Phillips et al. (2016) reported ammonia emission factors at conventional and deep litter piggeries respectively. In the case of McGahan et al. (2016) these more recent values included emission rates from within conventional pig housing, as well as uncovered anaerobic ponds (long HRT) and a short HRT tank, while Phillips et al. (2016) reported emissions from both deep litter housing and the spent litter stockpile. The ammonia emission rates calculated from these studies are reported in Table 11.

Table 11 – Ammonia emission factors (kg NH_3-N. kg N^{-1} excreted) for conventional housing MMS (McGahan et al. 2016) and deep litter housing MMS (Phillips et al. 2016)

MMS	Conventional piggery (uncovered pond - long HRT)[a]	Conventional piggery (shed, short HRT) [a]	Deep litter (shed and storage) [b]	Deep litter (litter removal) [c]
Emission factor	0.93[a]	0.28[a]	0.23[b]	0.10[c]

a) McGahan et al. (2016) – based on a simple average of a winter and a summer sampling period, each covering 30 days.
b) Authors calculations based on the combined shed and stockpile emissions reported by Phillips et al. (2016)
c) Phillips et al. (2016)

Comparison of MMS Emission Factors

Table 12 shows the implied ammonia N emission factors (kg NH_3-N. kg N^{-1} excreted) derived from the NPI, NIR and recent literature. The NIR values were 14% lower than NPI values for conventional piggeries with no substantial change for deep litter piggeries. New emission factors are provided for covered ponds with immediate irrigation, & short HRT systems, which were both much lower than the previous factor for conventional piggeries.

The NIR values for MMS losses were substantially lower than the reported values by McGahan et al. (2016) for the long HRT system, while the values for the short HRT and both deep litter systems were comparable to the reported values of McGahan et al. (2016) and Philips et al. (2016). The very high ammonia emissions reported by McGahan et al. (2016) should be interpreted with caution. This study measured emissions over two periods of one month, in winter and summer. Emission rates were much higher in summer, exceeding N flow rates to the pond for the sampling period. While the study reported a 'simple average' emission rate based on the winter and summer period, it is not necessarily the case that this is representative of a year of data. Additionally, the summer trial took place in hot conditions (SE Queensland) that may not be representative of the industry. With these factors taken into consideration, the study should be considered to be closer to a theoretical maximum ammonia loss rate. None-the-less, it does show that ammonia losses from ponds can be very high, at least during part of the year. Based on the wider review of literature used to develop the NIR, these values should be reasonably representative and were therefore more suited for updating the NPI.

Table 12 – Comparison of Implied Ammonia Emission Factors derived from the NPI and NIR

	Conventional piggery (shed, uncovered pond - long HRT, land application on-farm)	Conventional piggery (shed, short HRT, land application on-farm)	Conventional piggery (shed, covered pond, no secondary ponds, land application on-farm)	Deep litter (storage, land application on-farm)	Deep litter (litter removal)
NPI 2007	0.79 [A]	n.r [B]	n.r [B]	0.43 [A]	0.13 [A]
NIR 2018	0.68 [C]	0.46 [C]	0.28 [C]	0.44 [C]	0.13 [C]
Recent Literature	0.93[a]	0.28[a]	n.r [B]	0.23[b]	0.10[c]

[A] Implied emission factor based on emission rates in NPI,
[B] Not reported
[C] Integrated factor derived from the NIR and McGahan(2010)

a) McGahan et al. (2016)
b) Authors calculations based on the combined shed and stockpile emissions reported by Phillips et al. (2016)
c) Phillips et al. (2016)

3.4 Calculated Emission Rates

NPI Emission Rates

The NPI emission rates for each combination of pig class and manure management is calculated by multiplying the *'Nitrogen Excretion'* by the *'MMS emission factor'* for each class of pig on the farm.

$$ER_{Class} = N_{EX} \text{ x } EF_{MMS}$$

Where:
ER_{Class} = *the ammonia emissions rate for each class of pig (kg $NH_3.hd^{-1}.yr^{-1}$)*
N_{EX} = *the N excretion equivalent of each class (SPU.hd^{-1})*
EF_{MMS} = *the emission factor for the MMS (kg $NH_3.SPU^{-1}.yr^{-1}$)*

Appendix B of the EET lists the emission rates for each pig class and MMS type (calculated using the above method). These emission rates are replicated in Table 13 below.

Table 13 – Ammonia emission rates (kg $NH_3.hd^{-1}.yr^{-1}$) in the Pig Farming EET (NPI, 2007) for each manure management system and pig class

Pig Class	Conventional Piggery	Deep-litter piggery	
		Stockpiling on farm	Manure removed from farm upon pig removal
Gilt	11.56	6.31	1.84
Boar	14.08	7.68	2.24
Gestating sow	13.38	7.30	2.13
Lactating sow and litter (10 piglets)	47.74	26.04	7.60
Weaner	3.74	2.04	0.60
Grower	8.80	4.80	1.40
Finisher	14.08	7.68	2.24

Adapted from (NPI, 2007)

Based on the findings of this review, new and updated ammonia emissions rates have been determined, as provided in Table 14. These emission rates are based on the revised N excretion rates (kg $N.hd^{-1}.yr^{-1}$) calculated using the most recent version of PigBal (PigBal 4) (as detailed in Section 3.2 of this report), and revised MMS emission factors (kg NH_3-N. kg N^{-1} excreted) for conventional piggeries derived from the NIR (as detailed in Section 3.3).

Table 14 – Recommended revised ammonia emission rates (kg $NH_3.hd^{-1}.yr^{-1}$) for different pig classes

Pig Class	Weight range	Conventional piggery (shed, uncovered pond - long HRT, land application on-farm)	Conventional piggery (shed, short HRT, land application on-farm)	Conventional piggery (shed, covered pond, no secondary ponds, land application on-farm)	Deep litter (storage, land application on-farm)	Deep litter (litter removal)
Gilts	115-160	14.1	9.5	5.8	8.9	2.7
Boars	115-300	13.9	9.4	5.7	8.8	2.7
Gestating sows	160-215	12.7	8.6	5.2	8.0	2.4
Lactating sows	215-160	24.7	16.7	10.2	15.6	4.7
Suckers	1.4-6.7	2.0	1.4	0.8	1.3	0.4
Weaner pigs	6.7-30	4.6	3.1	1.9	2.9	0.9
Porkers	30-55	10.9	7.3	4.5	6.9	2.1
Growers	55-80	15.2	10.3	6.3	9.6	2.9
Finishers	80-104	16.9	11.5	7.0	10.7	3.2

[A] *Where effluent from covered ponds is not irrigated immediately (i.e. – when it is stored in open ponds prior to irrigation), it is recommended that the emission factor for uncovered ponds is used.*

4 Spreadsheet Calculator

A simple spreadsheet calculator has been developed that allows estimation of ammonia emissions using the updated emission factors outlined in this report. To provide greater versatility and accuracy for piggeries with specific diet and pig performance data, it would also be possible to provide a calculation page in existing spreadsheet tools for piggeries such as PigBal or the 'Piggery assessment spreadsheet' developed by QLD DAF.

The spreadsheet calculation tool developed as part of this project has been provided to APL with submission of this report.

5 Consultation with Regulators

The Department of Environment and Energy administer the NPI system and have been consulted with respect to updating the NPI to reflect the new emissions factors detailed in this report. The project team engaged with DEE staff to provide an outline of the results and updated emissions factors in comparison to the current NPI EET (which are inconsistent with current research).

Based on consultation with Departmental staff, the process for recommending changes to an EET is via presentation of a discussion paper to the NPI annual review. Adoption of the calculator tool as an 'approved alternative' estimation method requires consultation with state environmental regulators.

6 Conclusions and Recommendations

6.1 Conclusions

Ammonia emission rates are a function of N excretion rates and ammonia emission factors, the latter of which differ substantially from one MMS to the next.

This project found that changes to PigBal 4 resulted in elevated N excretion levels compared to previous estimates that were the basis for the NPI (2007). Due to changes in the classes reported the 'grower' class previously used to define an SPU is most comparable to the current 'porker' class. When the updated N excretion for porkers (see Table 4) was converted to a single SPU this resulted in 12.2 kg N excreted, which was 33% higher than N excretion per grower pig SPU used in the NPI (see Table 2). This increase is substantial. It should be noted that this difference was also apparent when comparing the updated NEGIP with previous versions.

Conversely, the project found that emission factors for conventional piggeries were lower than the NPI, and that factors for MMS that currently aren't included in the NPI (covered ponds and short HRT systems) were much lower than the value for a 'conventional piggery'. Emission factors for deep litter piggeries were not substantially different between the NIR and NPI.

While the difference in the emission factors was anticipated, the difference in N excretion rates was a confounding factor that diminished the difference between the current NPI and a proposed revision.

6.2 Recommendations

Revised ammonia emission rates for conventional piggeries have been provided in this report and are recommended for adoption in the NPI. These are summarised in Table 15.

Table 15 – Recommended Ammonia Emission Factors for revision of the NPI

	Conventional piggery (shed, uncovered pond - long HRT, land application on-farm)	**Conventional piggery (shed, short HRT, land application on-farm)**	**Conventional piggery (shed, covered pond, no secondary ponds, land application on-farm)**	**Deep litter (storage, land application on-farm)**	**Deep litter (litter removal)**
Revised / new factor	0.68	0.46	0.28	No change	No change

These factors could be adopted either by updating the NPI manual, or by using the spreadsheet calculator (supplied with this report) as an approved alternative.

Currently, the spreadsheet calculator uses the recommended revised emission factors, but has not updated the N excretion rates. This demonstrates the potential impact of the improved factors, but for correctness, the N excretion rates should also be updated.

It is recommended that the pig industry consider tabling this report with the DEE as the basis for revisions to the NPI. Concurrently, the industry could seek to have the spreadsheet calculator accepted as an approved alternative calculation method, enabling a wider range of MMS to be reported with greater accuracy. To use the calculator as an approved alternative, approval must be gained from state environmental regulators.

7 References

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