Inventory of Ammonia Emissions from UK Agriculture

2015

DEFRA Contract SCF0102

Inventory Submission Report
October 2016

T H Misselbrook, S L Gilhespy, L M Cardenas
Rothamsted Research, North Wyke, Okehampton, Devon EX20 2SB

J Williams
ADAS Boxworth, Battlegate Road, Boxworth, Cambridge CB3 8NN

U Dragosits
CEH Edinburgh, Bush Estate, Penicuik, Midlothian EH26 0QB

Inventory of Ammonia Emissions from UK Agriculture – 2015

Summary

The National Ammonia Reduction Strategy Evaluation System (NARSES) model (spreadsheet version) was used to estimate ammonia (NH_3) emissions from UK agriculture for the year 2015. Year-specific livestock numbers and fertiliser N use were added for 2015 and revised as appropriate for previous years. The estimate for 2015 was 237.6 kt NH_3, representing a 3.3 kt increase from the previously submitted estimate for 2014. There were no major methodological changes, but taking into account minor methodological changes and revisions to the historical time series for activity data, there was an increase in emission of 3.4 kt NH_3 between 2013 and 2014. This increase was primarily due to an increase in cattle numbers (and dairy cow N excretion) and an increase in the proportion of fertiliser N applied as urea, which is associated with a high emission factor, despite an overall decrease in fertiliser N use. Ammonia emissions from agriculture have decreased by 19% over the time period 1990-2015.

Table 1. Estimate of ammonia emission from UK agriculture for 2015

Source		**kt NH_3***	**% of total**
Livestock category			
Cattle		129.6	55
	Dairy	*72.5*	*31*
	Beef	*57.1*	*24*
Sheep†		9.9	4
Pigs		18.2	8
Poultry		31.8	13
Horses		3.6	2
Management category			
Grazing/outdoors		28.9	12
Housing		56.1	24
Hard standings		22.3	9
Manure storage		25.5	11
Manure application		60.6	26
Fertiliser application		44.3	19
TOTAL		**237.6**	**100**

†Including goats and deer

* Totals may differ from sum of components due to rounding

Estimate of ammonia emission from UK agriculture for 2015

The estimate of NH_3 emission from UK agriculture for 2015 was made using the spreadsheet version of the National Ammonia Reduction Strategy Evaluation System (NARSES) model (file: NH3inv2015_NARSES_Final_1_30092016.xls). NARSES models the flows of total nitrogen and total ammoniacal N (TAN) through the livestock production and manure management system, with NH_3 losses given at each stage as a proportion of the TAN present within that stage (Webb and Misselbrook, 2004). NARSES was first used to provide the 2004 inventory estimate for UK agriculture, replacing the previously used UK Agricultural Emissions Inventory model (UKAEI). NARSES brings improvements over the UKAEI model in that emission sources are linked, such that changes in an upstream source will be reflected downstream, it has an internal accounting check that not more than 100% of TAN excreted can be emitted, it can incorporate trends in N excretion by certain livestock classes (e.g. dairy cattle, pigs, poultry) and it is much better suited to scenario testing. The NARSES model was therefore used to provide the NH_3 emissions estimate for UK agriculture for the period 1990-2015. Emissions from fertiliser use within agriculture are estimated using a simple process-based model as described by Misselbrook et al. (2004), which has been incorporated into the NARSES spreadsheet model.

To compile the 2015 inventory of NH_3 emissions from UK agriculture, survey data were reviewed to derive livestock numbers, fertiliser use and other management practice data relevant to 2015 and to update historical activity data (1990-2014) as appropriate. Currently-used emission factors were reviewed in the light of new experimental data and amended if considered appropriate.

Key areas of revision in the 2015 inventory were:

- Inclusion of 2015 livestock numbers
- Inclusion of 2015 N fertiliser use
- Inclusion of 2015 dairy cow milk yield and revision to historic time series to be consistent with UK GHG inventory
- Revision to sheep housing emission factors (to equate with that for beef cattle housing)
- Revisions to historical fertiliser N use data for Northern Ireland

Derivations of emission factors and other data used in NARSES are detailed in Appendix 1.

The estimate of emission from UK agriculture for 2015 was 237.6 kt NH_3. Cattle represent the largest livestock source and housing and land spreading the major sources in terms of manure management (Table 1). The effect of sequential changes made to the inventory during the revision for 2015 are detailed below, with the impact on the total shown in Table 2. A breakdown of the estimate is given in Table 3, together with a comparison with the previously submitted 2014 inventory estimate.

Table 2. Sequential influence of revisions to individual components on the inventory total (NARSES model) during the 2015 revision

	Change (kt NH_3)	Total (kt NH_3)
2014 total		**234.3**
Livestock numbers 2015		
N fertiliser use 2015		
Dairy cow milk yield 2015		
Revision to sheep housing EF		
2015 total		**237.6**

Major changes between 2013 and 2014

1. 2015 Livestock numbers

Headline changes from 2014 are:

Cattle – a 0.8% increase in total cattle numbers, with a 3.0% increase for dairy cows
Pigs – a 1.6% decrease in pig numbers
Sheep – a 1.2% decrease in sheep numbers
Poultry – a 1.2% decrease in total poultry numbers, 0.7% increase in layers, 3.0% decrease in broilers

2. 2015 N fertiliser use

Total UK fertiliser N use decreased by 4.2% between 2014 and 2015. The proportion applied as urea-based fertiliser increased from 23% in 2014 to 28% in 2015.

3. Dairy cow milk yield

Average UK dairy cow milk yield decreased by 0.3% between 2014 and 2015, to 7,893 litres. This resulted in a decrease in the estimate of dairy cow N excretion by 0.2%.

4. Revision to sheep housing emission factor

There are no measurement data for sheep housing and the emission factor is assumed to be the same as that for cattle FYM housing systems at 16.8% of TAN. This was not reflected in the inventory model, so the previously-used value of 21.8% was revised to 16.8%.

Table 3. Estimate of ammonia emissions (kt NH_3) from UK agriculture, 2015

Source	2014	2015*	Reasons for change
Cattle			
Grazing	15.7	**15.7**	
Landspreading	39.7	**40.3**	Increase in the number of cattle and dairy cow N excretion.
Housing	33.1	**33.4**	
Hard standings	21.5	**21.7**	
Storage	18.1	**18.4**	
Total Cattle	125.3	**129.6**	
Sheep			
Grazing	7.6	**7.5**	
Landspreading	0.3	**0.4**	
Housing	1.1	**0.8**	Decrease in sheep numbers. The housing EF was revised downwards.
Hard standings	0.5	**0.5**	
Storage	0.6	**0.7**	
Total Sheep	10.1	**9.9**	
Horses	3.9	**3.9**	
Pigs			
Outdoor	1.1	**1.1**	
Landspreading	4.0	**4.0**	
Housing	9.6	**9.3**	A decrease in total pig numbers.
Hard standings	0.0	**0.0**	
Storage	3.8	**3.7**	
Total Pigs	18.5	**18.2**	
Poultry			
Outdoor	0.8	**0.8**	
Landspreading	16.0	**15.8**	Decrease in total poultry numbers, although layers (associated with greater housing EF) increased.
Housing	12.4	**12.5**	
Storage	2.6	**2.6**	
Total Poultry	31.8	**31.8**	
Fertiliser	41.8	**44.3**	Decrease in total fertiliser N use but a substantial increase in the proportion applied as urea (with a greater EF).
TOTAL	234.3	**237.6**	

*Totals may differ from sum of components due to rounding

Past and Projected Trends: 1990 - 2030

Retrospective calculations based on the most recent inventory methodology were made for the years 1990 to 2015 and projections to 2030 (Table 4). Projected changes in livestock numbers, N fertiliser use and management practices are detailed below. There has been a steady decline in emissions (19%) from UK agriculture over the period 1990 – 2015, largely due to declining livestock numbers (Fig. 1) and fertiliser N use (Fig. 2). The decline is projected to level off under a business as usual scenario, with an estimated 24% reduction between 1990 and 2030.

Table 4. Estimates of ammonia emission from UK agriculture 1990 – 2020 using the NARSES model

Source	1990	2000	2005	2010	2015	2020	2025	2030
						Projections		
Total	**293.7**	**268.7**	**250.5**	**228.6**	**237.6**	**235.9**	**233.7**	**233.7**
Cattle	149.6	140.6	136.4	128.1	129.6	129.9	128.4	128.4
Dairy cattle	*83.7*	*76.5*	*73.3*	*68.0*	*72.5*	*72.5*	*71.8*	*71.8*
Other cattle	*65.9*	*64.1*	*63.2*	*60.1*	*57.1*	*57.5*	*56.6*	*56.6*
Sheep	13.2	12.7	10.6	9.3	9.9	9.8	9.7	9.7
Pigs	41.0	31.3	22.3	17.6	18.2	20.0	19.8	19.8
Laying hens	13.6	10.3	9.7	8.3	8.3	8.7	8.7	8.7
Broilers	17.3	17.0	14.3	9.9	10.9	11.0	11.0	11.0
Other poultry	6.4	15.9	13.5	11.5	12.6	12.3	12.3	12.3
Horses	2.6	3.7	4.4	4.0	3.6	3.6	3.6	3.6
Fertiliser	50.1	37.2	39.2	40.0	44.3	40.7	40.1	40.1

Projections – methodology and assumptions

Livestock numbers

Livestock number projections are based on FAPRI modelling data (Defra project DO108), specifically the June 2016 scenario projections. In addition to these, trends in N excretion have been included: N excretion by dairy cows is a function of annual milk yield, which is forecast to increase as cattle numbers become fewer but total milk output maintained. N excretion by certain pig and poultry categories were forecast to decrease as dietary improvements were taken up by the industry. Current industry ambitions to increase output from the sector for e.g. dairy and poultry sectors are not reflected in these projections. Past and projected trends in livestock numbers are shown in Figure 1.

Fertiliser use

Fertiliser use projections are based on FAPRI modelling data. Proportions of each fertiliser type applied for projection years were assumed to be the average for the years 2012-2014. Past and projected trends in fertiliser N use are shown in Figure 2.

Figure 1. Trends in livestock numbers 1990 – 2030. Changes are relative to a reference value of 100 in 1990. Dashed lines show projections derived from FAPRI June 2016 scenario output (Defra project DO108).

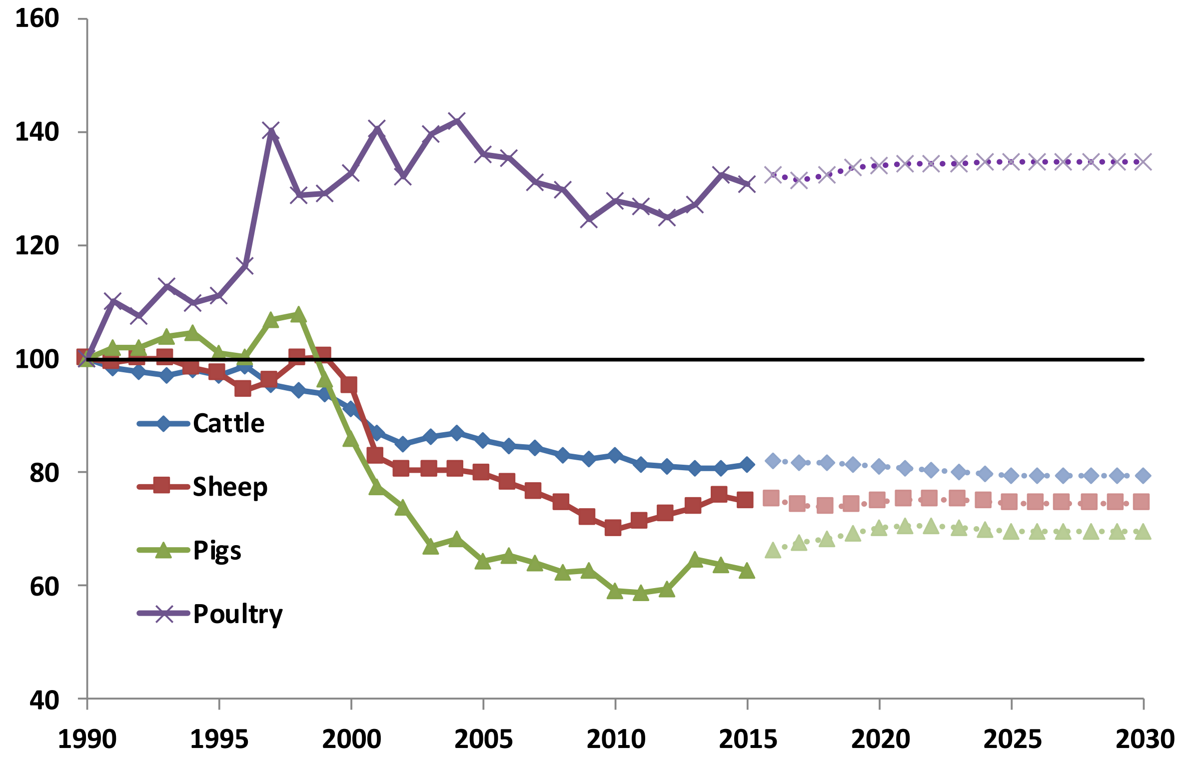
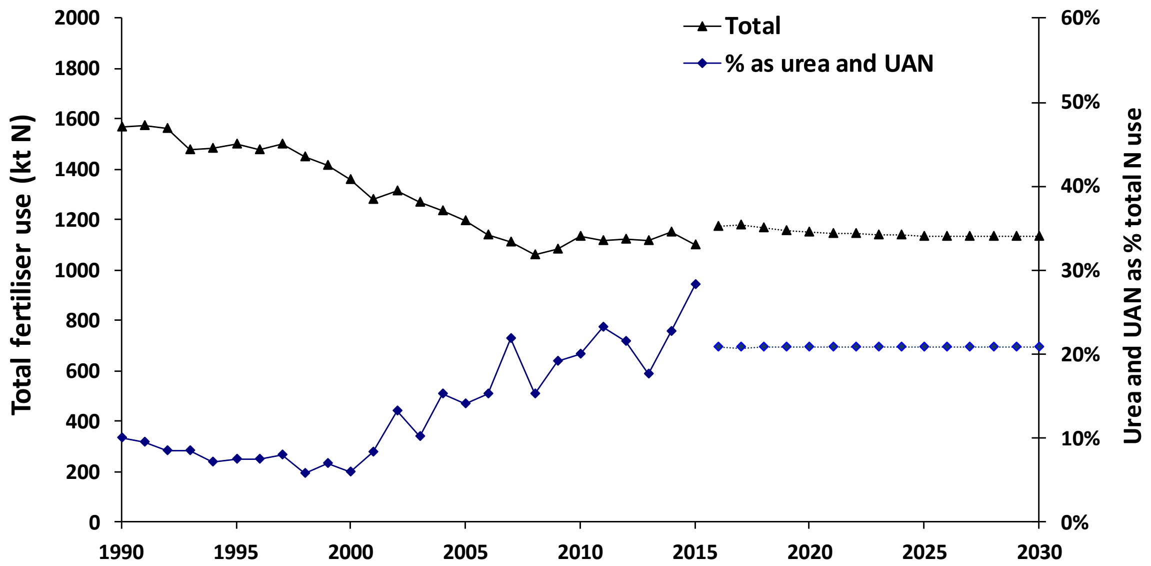


Figure 2. Changes in fertiliser N use 1990 – 2030. Dashed lines show projections derived from FAPRI June 2016 scenario output (Defra project DO108).



Farm management practices

Trends in changes in farm management practices (*e.g.* type and duration of livestock housing, manure storage and application methods) are difficult to quantify as there are relatively few surveys from which to obtain relevant data and those surveys which have been conducted are not always directly comparable. It is hoped that regular and consistent running of the Farm Practices Survey will be able to provide estimates of such trends in the future. For the default scenario, therefore, it has been assumed that no changes will take place in management practice in the absence of legislation or incentive schemes. IPPC legislation will impact on the practices of large pig and poultry farms from 2007 onwards; the assumptions regarding changes in livestock housing and manure management due to IPPC legislation are detailed below.

From 2007, all pig and poultry holdings above the livestock number thresholds have had to apply for a permit and will be required to comply with the legislation. In terms of ammonia emissions, the following assumptions have been made:

a) BAT housing is associated with a 30% reduction in ammonia emissions

b) Premises with existing housing will not be expected to modify immediately, but need to have plans showing how they will move towards compliance. It is assumed that 0% of holdings subject to IPPC complied in 2006 and that 100% will comply by 2020, with a linear trend in moving to compliance.

c) Slurry stores will require a rigid cover and lagoons a floating cover. Move to compliance will be as for housing above.

d) Applications of manure to own premises will have to comply with BAT, applications to other premises do not have to comply. From 2001 Farm Practices Survey, the proportions of manure exported are 25% of pig slurry, 29% of pig FYM and 69% of poultry manure. It is assumed that these proportions apply equally to IPPC and non-IPPC holdings.

e) Compliance will require incorporation within 24h of slurry, FYM or poultry manure to land to be tilled (assumed to be applicable for 50% of slurry, 90% of FYM and 70% of poultry manure applied to arable land), trailing hose application of pig slurry to growing arable crops and trailing shoe or shallow injection of pig slurry to grassland.

The proportion of the national pig herd and poultry flock that will be required to comply has been revised according to data provided by the agricultural statistics units of each of the devolved administrations and a weighted average for the UK (Table 5). These are based on 2006 census livestock numbers, but the proportions will be assumed to remain the same for subsequent years.

From these assumptions and data, the proportion of the UK flock or herd for which IPPC BAT should be applied in the inventory for housing and storage is given in Table 6 and the proportion of manure applications subject to BAT given in Table 7.

Table 5. Proportion (%) of poultry and pigs within each devolved administration and the UK kept on holdings above the IPPC thresholds (750 sows, 2,000 fattening pigs, 40,000 broilers, layers, ducks or turkeys)

Category	E	W	S	NI	UK
Poultry					
Broilers	95	98	94	67	92
Layers	67	49	74	54	66
Ducks	36	0	0	0	35
Turkeys	49	35	49*	0	43
Pigs					
Sows	29	0	23	27	28
Fatteners >20kg	40	0	53	49	42

*not disclosed for Scotland, so value for England used

Table 6. Proportion (%) of UK poultry flock and pig herd complying with IPPC BAT for housing and storage

Category	2006	2007	2010	2015	2020
Poultry					
Broilers	0	7	26	59	92
Layers	0	5	19	42	66
Ducks	0	3	10	23	35
Turkeys	0	3	12	28	43
Pigs					
Sows	0	2	8	18	28
Fatteners >20kg	0	3	12	27	42

Table 7. Proportion (%) of UK poultry and pig manure applied to land required to comply with IPPC BAT (from 2007 onwards)

Category*	%
Of that applied to arable land, % incorporated within 24h	
Poultry manure	18
Pig slurry	15
Pig FYM	26
Of that applied to arable land, % applied by trailing hose	
Pig slurry	15
Of that applied to grassland, % applied by trailing shoe/injection	
Pig slurry	30

*Using a weighted average of poultry numbers (83%) and pig numbers (40%) complying with IPPC (2006 data)

Emission factors

Emission factors associated with individual emission sources and management practices, as used in the current model, were kept constant for all model runs from 1990 – 2030.

Uncertainties

An analysis of the uncertainties in the emission inventory estimate was conducted by Webb and Misselbrook (2004) using @RISK software (Palisade Europe, London), in which a distribution was attached to each of the model inputs (activity or emission factor data), based on the distribution of raw data or, where no or only single estimates exist, on expert assumptions. A large number of model runs (2000) were then conducted in which input values were selected at random from within the given distribution (Latin hypercube sampling) and an uncertainty limit produced for each of the model outputs. The 95% confidence interval for the total inventory estimate was estimated to be ±20% (i.e. ±47.5 kt NH_3 for the 2015 estimate).

APPENDIX 1

DERIVATION OF EMISSION FACTORS FOR THE INVENTORY OF AMMONIA EMISSIONS FOR UK AGRICULTURE

In the NARSES model, all emission factors (EF) are expressed as a percentage of the total ammoniacal nitrogen (TAN) within a given emission 'pool' (livestock house, slurry store, etc.). Emission factors reported in many reports and publications are expressed in units other than this, so require conversion. As far as possible, data relevant to the published study are used to make these conversions, but in some cases where sufficient data are not reported standard values (e.g. for livestock weight or N excretion) have been used.

Cited sources are either scientific publications or Defra project Final Reports (given by Project Code), which are available from the Defra web-site.

CATTLE

Grazing

The average EF for cattle and sheep (there was no evidence to warrant differentiation) was derived from a number of grazing studies (Table A1) with a range of fertiliser N inputs to the grazed pasture. Emissions due to the fertiliser applied to the grazed pasture were discounted using a mean EF for ammonium nitrate applications to grassland (1.4% of N applied). The remaining emission was expressed as a percentage of the estimated urine N (equated here with the TAN in excreta) returned to the pasture by the grazing cattle or sheep.

Mean EF of 6 %TAN (standard error 0.7, n=20) was derived.

Table A1: Cattle and sheep grazing emission factors

	N input	Urine N	NH_3 emission	Due to fertiliser	Due to urine	Emission Factor
			Kg N ha^{-1}			%TAN
CATTLE						
Bussink	*Fert Res 33 257-265*					
1987	550	425	42.2	7.7	34.5	8
1988	550	428	39.2	7.7	31.5	7
1988	250	203	8.1	3.5	4.6	2
Bussink	*Fert Res 38 111-121*					
1989	250	64.2	3.8	3.5	0.3	0
1989	400	76.2	12.0	5.6	6.4	8
1989	550	94.3	14.7	7.7	7	7
1990	250	217.4	9.1	3.5	5.6	3
1990	400	339	27.0	5.6	21.4	6
1990	550	407.1	32.8	7.7	25.1	6
Lockyer	*J Sci Food Agric 35, 837-848*					
1	26	0.6455				2
2	26	0.7025				3
Jarvis et al	*J Ag Sci 112, 205-216*					
1986/87	0	69	6.7	0	6.7	10
1986/87	210	81	9.6	2.94	6.66	8
1986/87	420	207	25.1	5.88	19.22	9
AC0102						
Beef, North Wyke	0			0		10
Beef, Cambridge	0			0		7
SHEEP						
Jarvis et al	*J Ag Sci 117, 101-109*					
GC	0	169	1.1	0	1.1	1
HN	420	321	8.0	5.88	2.08	1
AC0102						
Boxworth	0					4
North Wyke	0					10

Land spreading

Slurry

- EF derived from the MANNER_NPK model (Nicholson et al., 2013)

The ‘standard’ EF for cattle slurry is given as 32.4 %TAN applied, which is then modified according to soil moisture, land use and slurry dry matter (DM) content at the time of application:

a) soil moisture (‘season’):

Dry (summer) EF_1 = ‘standard’ EF x 1.3
Moist (rest of year) EF_1 = ‘standard’ EF x 0.7

b) land use:

Grassland $EF_2 = EF_1 \times 1.15$
Arable $EF_2 = EF_1 \times 0.85$

c) slurry DM content

$$EF_3 = EF_2 \times ((12.3 \times DM) + 50.8)/100$$

<u>Mitigation</u>
Low emission slurry application techniques:
Injection - abatement efficiency of 70% (assumed to be shallow injection)
Trailing shoe – abatement efficiency of 60%
Band spreading – abatement efficiency of 30%
(Misselbrook *et al.*, 2002; Smith *et al.*, 2000b; Bittman et al., 2014)

Incorporation by cultivation:
Table A2. Reduction in emission from cattle slurry and FYM for different incorporation timings and cultivation techniques (Defra ES0116)

Timing	Plough	Disc	Tine
Cattle slurry			
within 4h	59%	52%	46%
within 24h	21%	19%	17%
Cattle FYM			
within 4h	71%	47%	39%
within 24h	34%	23%	19%

FYM

- EF derived from the MANNER_NPK model (KT0105) as 68.3 %TAN applied. No modifiers for soil, manure or weather.
- Abatement by soil incorporation as in Table A2.

Housing

Emission factors for two types of cattle housing are currently defined; slurry systems (solid-floor, cubicle housing with scraped passage) and deep litter straw-bedded housing generating farmyard manure (FYM). There is no differentiation between dairy and beef cattle, but a different EF was derived for calves on deep litter based on limited measurement data and the assumption that the straw bedding to excreta ratio is much greater for calves than for older cattle.

Table A3. Housing emission factors for cattle

Study	Emission g N $lu^{-1}d^{-1}$	No. studies	Emission Factor % TAN	Notes
Slurry-based systems				
Demmers et al., 1997	38.6	1	31.1	Dairy cows 1995, assume N excretion of 100 kg N per year
WA0653	21.2	6	19.2	Dairy cows 1998/99, assume N excretion of 105 kg N per year
Dore et al., 2004	72.5	1	53.1	Dairy cows 1998/99, assume N excretion of 105 kg N per year
WAO632/AM110	50.8	3	39.4	Using actual N balance data
Hill, 2000	29.4	1	22.8	Dairy cows 1997, assume N excretion of 104 kg N per year
AM0102	30.5	2	23.7	Dairy cows 2003, assume N excretion of 113 kg N per year
Mean	40.5		31.6	
Weighted mean	34.3		**27.7 (SE 3.85, n=14)**	
Straw-bedded systems				
WA0618 (PT)	20.6	1	18.3	Growing beef, assume N excretion of 56 kg N per year
WAO632/AM110 (PT)	35.0	3	21.6	Using actual N balance data
WA0722	33.2	1	22.9	Dairy cows, 6,500 kg milk per year, therefore assume N excretion of 112 kg N per year
AM0103 (PT)	13.9	1	11.7	Growing beef, values directly from report
AM0103 (Comm farm)	16.7	1	13.4	Dairy cows, assuming 125 g TAN excretion per day (AM0103 report)
AC0102	14.0	3	12.5	Growing beef, assume N excretion of 56 kg N per year
Mean	22.2		16.7	
Weighted mean	23.1		**16.8 (SE 1.97, n=10)**	
Calves				
Demmers et al. 1997	13.0	1	5.8	Assume calf weight 140 and N excretion 38 kg N per year
Koerkamp et al. 1998	6.2	1	2.6	Assume calf weight 140 and N excretion 38 kg N per year
Mean	9.6		**4.2 (SE 1.62, n=2)**	

It is recognised that slatted-floor slurry systems also exist for dairy and beef systems, particularly in Northern Ireland and Scotland, and that ***the current slurry housing system EF is not representative of these systems***. Emission measurements being undertaken on such systems in the Republic of Ireland may provide useful data from which the UK can derive a system-specific EF.

Seasonal differentiation in the EF is not included in the inventory. The EF for housing might be expected to be greater in summer, because of higher temperatures. However, work by Phillips *et al*. (1998) showed that summer emissions from dairy cattle housing, where the cattle come in for part of the day for milking, were of a similar magnitude to winter emissions. Further measurements have been conducted on modern dairy cow year-round housing units under Defra project AC0123 which will further inform the inventory in this area.

Hard standings

Based on Misselbrook et al. (2006) an EF of 75% of the TAN left after scraping is assumed, based on mean measured values of 0.47 and 0.98 g NH_3-N animal^{-1} h^{-1} for dairy and beef cattle, respectively, with respective standard errors of 0.09 (n=28) and 0.39 (n=30) g NH_3-N animal^{-1} h^{-1}. Project AM0111 indicated that collecting yards, which are scraped at least once a day, are scraped with an efficiency of c. 60%. For feeding yards, which are scraped only once or twice a week on average, the scraping efficiency is assumed to be 30%. Washing down of dairy cow collecting yards is associated with an emission reduction factor of 70% (Misselbrook et al., 2006).

Manure storage

Measurements from slurry lagoons and above-ground tanks are generally reported as emission per unit area, with only few studies containing sufficient information from which to derive an EF expressed as a percentage of the TAN present in the store (Tables A4 and A5). ***The EF for lagoons, in particular, are high and substantiated by very little underlying evidence*** (with no differentiation between pig and cattle slurries) so further measurements are warranted for this source.

Mean EF for slurry storage were derived as 10 (for uncovered, uncrusted slurry) and 52% of TAN in store for slurry tanks and lagoons , respectively. As only few measurement data are available for EF derivation, and some categories of storage ‘read across’ from others, a default uncertainty estimate of ±30% for the 95% confidence interval is suggested for all slurry storage categories. Slurry stores are assumed to develop a crust unless they are stirred frequently.

There is large variability in the EF for cattle and pig FYM, with weather conditions in particular influencing emissions, and a combined EF of 28.2% (SE 6.28) is probably justified (but not currently used).

Table A4. Cattle manure storage emission factors

Mean EF g N $m^{-2}d^{-1}$	Values g N $m^{-2}d^{-1}$	Derived from n values	Emission as % TAN	Source
Slurry stores and lagoons without crusts				
3.42				Assumed to be double that for crusted stores (WA0641, WA0714)
Slurry stores and lagoons with crusts, weeping wall stores				
1.71	0.6		**2.3	(Phillips *et al*., in press)
	1.27, 3.65, 5.7		NA	WA0625
	0.44	2	*6.0	WA0632*
	1.8		NA	WA0641
	1.7		NA	Hill (2000)
	0.48	2	NA	WA0714
	0.5,0.72,0.42,0.73		51.5 (lagoons) 5.3 (w.wall)	WA0717
	4.2		NA	AM0102
Below ground slurry tanks				Assume same as for crusted above-ground tank
FYM heaps	**g N t^{-1} initial heap mass**			
265	421, 101, 106		NA	WA0618
	65, 618, 889		95.0	WA0519
	305, 140		22.0	WA0632
	250, 36, 26		12.0	WA0707
Weighted mean			**26.3 (SE 8.3, n=10)**	

** Emissions expressed per day. This value assumes 90 d storage.
Values derived from measurements made using Ferm tubes have been corrected to account for incomplete recovery of ammonia by Ferm tubes (Phillips *et al*., 1998). (*IGER values have been corrected using a factor of **0.7**).

Mitigation

Slurry stores:
Natural crust development on cattle slurry storage is assumed to reduce emissions by 50% (Misselbrook et al., 2005).

Floating covers (e.g. expanded clay granules) reduce emissions by 60% and tight lid, roof or tent structures reduce emissions by 80% (Bittman et al., 2014).

FYM heaps:
A sheet cover reduces emission by 60% (Chadwick, 2005).

SHEEP

Grazing
See Table A1 under Cattle. An EF of 6 %TAN is assumed.

Land spreading
- FYM - values for cattle used.

Housing

No specific measurements have been conducted for sheep housing, so the same value is used as for straw-bedded cattle housing i.e. 16.8% of the TAN deposited in the house.

Hard standings
Sheep collecting yards are scraped infrequently, if at all, so a scraping efficiency of 0% was applied and an EF of 75% TAN deposited.

Manure storage
- FYM - value for cattle used.

PIGS

Outdoors

Table A4. Emission factors for outdoor pigs

	Emission g N $lu^{-1}d^{-1}$	EF %TAN	Source
Outdoor sows/piglets	25	26.1	Williams et al. (2000)
	66*	NA	Welch (2003)

*This value is probably an overestimate as emission rates were below the detection limit on a number of occasions (and those data were not included).

Emission factor for boars assumed to be the same. For fatteners, EF is based on the ratio of excretal outputs multiplied by the emission factor for outdoor sows.

NARSES EF was derived from the Williams et al (2000) study, assuming the standard N excretion value for sows and a body weight of 200kg, giving a mean EF of 25 %TAN (assumed to be the same across all animal sub-categories), with a an assumed 95% confidence interval of ± 7.5 % of TAN excreted.

Land spreading

Slurry

- EF derived from the MANNER_NPK model (KT0105)

The ‘standard’ EF for pig slurry is given as 25.5 % of TAN applied, which is then modified according to slurry dry matter (DM) content at the time of application:

a) slurry DM modifier:

$$EF_1 = \text{‘standard’ EF x ((12.3 x DM) + 50.8)/100}$$

FYM

The same EF as for cattle FYM is used.

<u>Mitigation</u>

Low emission slurry application techniques:

Injection - abatement efficiency of 70% (assumed to be shallow injection)
Trailing shoe – abatement efficiency of 60%
Band spreading – abatement efficiency of 30%
(Misselbrook *et al.*, 2002; Smith *et al.*, 2000b; Bittman et al., 2014)

Incorporation by cultivation:

Table A5. Reduction in emission from cattle slurry and FYM for different incorporation timings and cultivation techniques (Defra ES0116)

Timing	Plough	Disc	Tine
Pig slurry			
within 4h	67%	59%	52%
within 24h	29%	26%	23%
Pig FYM			
within 4h	71%	47%	39%
within 24h	34%	23%	19%

Housing

As for cattle, housing EFs for pigs have been derived for two management systems, slurry-based and FYM-based, but for a larger number of animal categories (Table A6). A review conducted as part of Defra project AC0123 in 2012 concluded that pig housing has not changed considerably over the inventory reporting period and that the EF reported here are relevant for current housing systems. However, this should be kept under regular review as the Industrial Emissions Directive (previously Integrated Pollution Prevention and Control) and its requirement for large producers to comply with Best Available Techniques for minimising emissions should mean that there is a shift over time towards lower emission housing systems (this may be reflected in uptake of specific mitigation options rather than systemic differences in housing design).

Table A6. Emission factors for pig housing

Study	Emission g N $lu^{-1}d^{-1}$	No. studies	Emission Factor % TAN	Notes
Dry sows on slats				
Peirson,1995	17.0	2	22.9	Assume N excr of 15.5kg
Weighted mean			**22.9 (SE 14.9, n=2)**	
Dry sows on straw				
Peirson,1995	9.4	2	12.6	Assume N excr of 15.5kg
Koerkamp et al., 1998	14.7	1	19.8	Assume N excr of 15.5kg
OC9523	26.2	4	35.3	Assume N excr of 15.5kg
AM0102	50.6	5	68.1	Assume N excr of 15.5kg
Mean	25.2		34.0	
Weighted mean	15.7		**43.9 (SE 9.62, n=12)**	
Farrowing sows on slats				
Peirson,1995	32.4	3	33.8	Assume N excr 22.5kg (1995 value)
Koerkamp et al., 1998	20.7	1	23.1	Assume N excr 22.5kg (1995 value), live weight 240 kg
AM0102	27.0	3	30.4	Assume N excr 15.5kg (2002/03 value)
Mean	26.7	7	29.1	
Weighted mean	20.7		**30.8 (SE 2.96, n=7)**	
Farrowing sows on straw				
	Use dry sows value			

Study	Emission g N $lu^{-1}d^{-1}$	No. studies	Emission Factor % TAN	Notes
Boars on straw				
	Use dry sows value			
Finishers on slats				
Peirson, 1995	71.7	3	26.9	Assume fatteners 20-80 kg, N excr 13.9kg (1995 value)
Demmers, 1999	105.8	1	25.3	Mean weight 25.7kg, N excr 11.2kg (1995 value)
Koerkamp et al. 1998	51.2	1	16.7	Approx 35 kg finishers, assume N excretion 11.2 kg (1995 value)
WA0632	79.2	4	40.4	Using actual N balance data
WA0720 (fan vent, comm farm)	103.5	1	41.5	Assume fatteners 20-80 kg, N excr 13kg (mean of 2 weight ranges for year 2002)
WA0720 (acnv, comm farm)	77.2	3	31.0	Assume fatteners 20-80 kg, N excr 13kg (mean of 2 weight ranges for year 2002)
WA0720 (part slat, comm farm)	51.5	2	20.7	Assume fatteners 20-80 kg, N excr 13kg (mean of 2 weight ranges for year 2002)
WA0720 (fan vent, Terrington)	47.7	1	21.6	40-95 kg finishers, assume N excretion 15.5 kg per year
WA0720 (part slat, Terrington)	38.7	1	17.6	40-95 kg finishers, assume N excretion 15.5 kg per year
Mean	69.6	17	26.8	
Weighted mean	71.4		**29.4 (SE 2.27, n=17)**	
Finishers on straw				
Peirson (1995)	54.2	2	20.3	Assume fatteners 20-80 kg, N excr 13.9kg (1995 value)
Koerkamp et al., 1998	28.2	1	9.2	Approx 35 kg finishers, assume N excretion 11.2 kg (1995 value)
WA0632	122.2	4	53.7	Using actual N balance data
AM0102	24.0	1	9.6	Assume fatteners 20-80 kg, N excr 13kg (mean of 2 weight ranges for year 2002)
AM0103 Terrington	47.0	2	23.6	Values directly from report
AM0103 Commercial	34.1	1	10.9	Finishers 20-60 kg, N excr 13kg (mean of 2 weight ranges for year 2002)
AC0102	42.0	4	16.6	Finishers 30-60 kg, N excr 11.9kg (mean of 2 weight ranges for year 2002)
Mean	50.2	15	20.6	
Weighted mean	63.0		**26.6 (SE 5.11, n=15)**	
Weaners on slats				
Peirson, 1995	34.8	1	9.9	Assume N excr 4.4kg (1995 value)
Koerkamp et al. 1998	20.7	1	5.9	Assume N excr 4.4kg (1995 value)
Mean	27.7		**7.9 (SE 2.01, n=2)**	
Weaners on straw				
			7.2	Based on ratio slurry/straw for finishers

Mitigation

There are a number of potential mitigation options for pig housing:

- Partly slatted floor with reduced pit area 30% reduction (Bittman et al., 2014)
- Acid air scrubbing techniques 80% reduction (Bittman et al., 2014)
- Frequent slurry removal by vacuum 25% reduction (Bittman et al., 2014)
- Floating balls on below-slat slurry surface 25% reduction (Bittman et al., 2014)

Hard standings

EF assumed as 75 % of TAN estimated to be deposited by finished pigs as they await loading for dispatch to market (with scraping efficiency assumed to be 30 %). 5 % of daily excretal output is assumed to be deposited to the loading areas for the days that they are used.

Storage

Measurements from slurry lagoons and above-ground tanks are generally reported as emission per unit area, with only few studies containing sufficient information from which to derive an EF expressed as a percentage of the TAN present in the store (Table A7). No measurement data based on store TAN content were available for lagoons and the EF for cattle slurry lagoons (52 % of TAN) is applied to pigs as well, but as noted above, the ***EF for lagoons is high and substantiated by very little underlying evidence*** so further measurements are warranted for this source. Emissions from below-slat slurry storage inside animal housing are assumed to be included in the animal housing EF, so below-slat storage does not appear as a separate storage category. As only few measurement data are available for EF derivation, and some categories of storage 'read across' from others, a default uncertainty estimate of ±30% for the 95% confidence interval is suggested for all slurry storage categories.

Table A7. Pig manure storage emission factors

Mean EF g N m^{-2} d^{-1}	Values g N m^{-2} d^{-1}	Derived from n values	Emission as %TAN	Source
Slurry stores				
3.16	1.34	4	13.0	WA0632
	2.47, 6.2		NA	WA0625
	2.4		NA	Phillips *et al*. (1997)
	1.56		NA	WA0708
	5.0		NA	Phillips *et al*. (1997)
Weighted mean			**13**	
Below ground slurry tanks			7	Assume 50% of EF for above-ground tank
FYM heaps	**g N t^{-1} initial heap mass**			
1224	539	4	20	WA0632
	1015	2	54	WA0716
Weighted mean			**31.5 (SE 10.3, n=6)**	

Values derived from measurements made using Ferm tubes have been corrected to account for incomplete recovery of ammonia by Ferm tubes (Phillips *et al*., 1998).

Mitigation

Slurry stores:
Floating covers (e.g. expanded clay granules) reduce emissions by 60% and tight lid, roof or tent structures reduce emissions by 80% (Bittman et al., 2014).

FYM heaps:
A sheet cover reduces emission by 60% (Chadwick, 2005).

POULTRY

Outdoors

No studies of emissions from outdoor poultry have been reported. An EF of 35 % of excreted UAN has been assumed, as it is likely that emissions from freshly dropped excreta will be substantially lower than from applications of stored manure in which hydrolysis of the uric acid will have occurred to a greater extent. The 95% confidence interval for this EF is assumed to be ± 15 % of UAN excreted.

Land spreading

For poultry manure a standard EF of 52.3 % of UAN applied is used, with no further modifiers for soil, manure or weather (KT0105, MANNER_NPK)

For duck manure, which is very similar to cattle/pig FYM, an EF of 68.3 % of UAN applied is used.

Mitigation

Incorporation by cultivation:

Table A8. Reduction in emission from cattle slurry and FYM for different incorporation timings and cultivation techniques (Defra ES0116)

Timing	Plough	Disc	Tine
Poultry manure			
within 4h	82%	64%	45%
within 24h	56%	44%	31%
Duck FYM			
within 4h	71%	47%	39%
within 24h	34%	23%	19%

Housing

Measurements have been made from poultry housing for the poultry categories laying hens, broilers and turkeys (Table A9). For pullets, breeding hens and other classes of poultry not categorised in the table above, a weighted average of the broiler and turkey data were used to derive an emission factor of 14.1%. Laying hen systems are further categorised as cages without belt-cleaning, perchery, free-range and cages with belt cleaning. Of these, the cages without belt cleaning, perchery and the housing component of free-range systems are all classified as ‘deep pit’ with a common EF. There are currently no measurements for more recent ‘enriched cage’ systems, although Defra project AC0123 will report on these.

A measurement from Groot Koerkamp *et al*. (1998) for broiler housing (164 g N lu^{-1} d^{-1}) has been excluded from the inventory. This measurement was from an old housing system, not representative of broiler housing over the reporting period, and was also based on a single measurement in time rather than an integrated measurement over the duration of the crop.

Table A9. Poultry housing emission factors

Study	Emission g N $lu^{-1}d^{-1}$	No. studies	Emission Factor % TAN	Notes
Layers – deep-pit (cages, perchery, free-range)				
Peirson, 1995	79.0	3	22.1	Assume N excr 0.82 kg (1995 value)
G Koerkamp, 1998	184.1	1	49.2	Assume N excr 0.82 kg (1995 value)
G Koerkamp, 1998	146.1	1	39.0	Assume N excr 0.82 kg (1995 value)
WA0368	139.2	1	36.8	Assume N excr 0.79 kg (1998 value)
WA0651	196.8	1	57.9	Assume N excr 0.78 kg (2000 value)
Mean	149.0		41.0	
Weighted mean	107.0		**35.6 (SE 8.14, n=7)**	
Layers – deep litter: assume same EF as for perchery				
Layers – belt-cleaned (cages)				
Peirson, 1995	36.0	3	10.1	Assume N excr 0.82 kg (1995 value)
WA0651 Gleadthorpe	79.2	1	23.3	Assume N excr 0.78 kg (2000 value)
WA0651 comm. farm	64.8	1	19.1	Assume N excr 0.78 kg (2000 value)
Mean	60.0		17.5	
Weighted mean	50.4		**14.5 (SE 4.79, n=5)**	
Broilers				
Demmers et al. 1999	42.0	1	7.0	Assume N excr 0.56 kg (1995 value)
Robertson et al 2002	44.0	4	8.3	Assume N excr 0.55 kg (2000 value)
Frost et al 2002	54.0	4	9.2	Assume N excr 0.55 kg (2000 value)
WA0651 winter	36.0	4	9.5	Derived N excretion from N balance
WA0651 summer	67.2	4	15.6	Derived N excretion from N balance
WA0651 drinkers	52.8	2	10.9	Derived N excretion from N balance
Mean	49.3	19	10.1	
Weighted mean	50.1		**9.9 (SE 0.93, n=15)**	
Turkeys				
Peirson et al, 1995	93.0	3	**36.2 (SE 30.5, n=3)**	

Storage

Table A10. Losses from poultry manure storage

Mean EF	Values	Derived from n values	Emission as %TAN	Source
g N t^{-1} initial heap mass				
Layer manure				
1956	318	2	2.2	WA0712
	3172	4	15.1	WA0651 (belt scraped)
	3141	4	29.4	WA0651 (deep pit)
	1193	1	13.4	WA0651 (belt scraped)
Weighted mean			**14.2 (SE 2.99, n=8)**	
Litter				
1435	478	1	2.2	WA0712
	1949	4	19.9	WA0651 (winter)
	158	4	2.0	WA0651 (summer)
	639	2	7.2	WA0651 (drinkers)
	3949		NA	WA0716
Weighted mean			**9.6 (SE 2.69, n=11)**	

Other poultry litter (excluding ducks) was assumed to have the same EF as for broiler litter and duck manure was assumed to have the same EF during storage as cattle FYM (35 % of AUN).

DEER

Grazing

- Sheep grazing (lowland sheep) emission factor used as live weights similar.

Land spreading

- Emission factor for cattle FYM used.

Housing

- Emission factor for sheep housing used.

Storage

- Emission factor for cattle FYM used.

HORSES

Emissions from horses do not currently follow the N-flow approach of the NARSES inventory model, but rather are estimated using fixed emission factors (kg NH_3-N horse^{-1} year^{-1}). This is largely because of a lack of information on horse housing and manure management. As this is a relatively large source, a more detailed approach is warranted.

Emission source strength estimates have been derived for both race/competition horses (with higher protein content in feed and therefore higher N excretion) and other horses (including ponies, donkeys and mules), using a range of scientific literature (Hanson et al. 1996, Coverdale et al. 2004, Davis and Swinker (2002), Hainze et al. 2004, McKiernan 1999, Olsen 1996). The calculations take into account N excretion rates according to different feeding regimes and horse bodyweight (from small ponies to large cart horses), and result in best estimates and uncertainty ranges. An average race/competition horse is estimated to emit 27.3 kg NH_3-N horse^{-1} year^{-1} (previously estimated at 32.6 kg NH_3-N), with a range of 12.4-53.5 kg NH_3-N horse^{-1} year^{-1}. Other horses are estimated to emit 10.55 kg NH_3-N horse^{-1} year^{-1} (previously estimated at 10.6 kg NH_3-N), with a range of 2.3 to 45.7 kg NH_3-N horse^{-1} year^{-1}. For up-scaling to the UK, these wide uncertainty ranges (which include small ponies on a low N/protein diet spending a large proportion of the year outdoors as well as very large horses fed a high N/protein diet) were not used directly, but statistically treated to reduce the overall uncertainty by generating confidence intervals (R. Smith, CEH, pers. comm.).

For more details, see: Dragosits U., Jones S.K., Vogt E. and Sutton M.S. (2006) 2005 Update on Ammonia emissions from non-agricultural sources for the NAEI. CEH Report AS06/20. Centre for Ecology & Hydrology Edinburgh, Bush Estate, Penicuik. 14pp.

Nitrogen fertiliser applications

A model based on Misselbrook et al. (2004) but modified according to data from the Defra-funded NT26 project is used to estimate EF for different fertiliser types. Each fertiliser type is associated with an EF_{max} value, which is then modified according to soil, weather and management factors (Table A11). Soil placement of N fertiliser is categorised as an abatement measure and is detailed in the separate report on NH_3 emission mitigation techniques.

Table A11. Emissions from different fertiliser types

Fertiliser type	EF_{max} (as % of N applied)	Modifiers†
Ammonium nitrate	1.8	None
Ammonium sulphate and diammonium phosphate	45	Soil pH
Urea	45	Application rate, rainfall, temperature
Urea ammonium nitrate	23	Application rate, rainfall, temperature
Other N compounds	1.8	None

†Modifiers:
Soil pH – if calcareous soil, assume EF as for urea; if non-calcareous, assume EF as for ammonium nitrate
Application rate

- if <=30 kg N ha^{-1}, apply a modifier of 0.62 to EF_{max}
- if >=150 kg N ha^{-1}, apply a modifier of 1 to EF_{max}
- if between 30 and 150 kg N ha^{-1}, apply a modifier of ((0.0032xrate)+0.5238)

Rainfall – a modifier is applied based on the probability of significant rainfall (>5mm within a 24h period) within 1, 2, 3, 4 or 5 days following application, with respective modifiers of 0.3, 0.5, 0.7, 0.8 and 0.9 applied to EF_{max}.
Temperature – apply a modifier, with the maximum value constrained to 1, of

$$RF_{temp} = e^{(0.1386\times(T_{month}-T_{UKannual}))}/2$$

where $T_{UKannual}$ is the mean annual air temperature for the UK

An uncertainty bound to the EF_{max} values of ±0.3 x EF_{max} is suggested based on the measurements reported under the NT26 project.

Sources of Activity Data

Animal numbers and weights

Livestock numbers are obtained from June agricultural survey statistics provided by each devolved administration (England, Scotland, Wales and Northern Ireland). The UK total is derived as the sum of the DA values.

Proportion of sheep in uplands from ADAS (pers. comm. Diane Spence).

Excretal outputs and TAN contents

Manure output values per animal are from Smith and Frost (2000) and Smith *et al.*, (2000). Account is taken of time spent indoors and litter/bedding is included for FYM outputs. For milking dairy cattle, time indoors is increased to account for time in summer spent in buildings or yards for milking operation (equivalent to 3h per day throughout the grazing period). N excretion values are derived from Cottrill, B.R. and Smith,K.A. (2007) 'Nitrogen output of livestock excreta', Final report, Defra Project WT0715NVZ.

Manure volume output data were derived by K Smith (ADAS) using data from Smith et al. (2000c, 2001a, 2001b) with interpretation for animal place and annual outputs – see spreadsheets 'UK excreta_2010_02May.xls' and 'Livestock excretal outputs.xls'. Nitrogen excretion data were derived from project WT0715NVZ with interpretation by B Cotteril and K Smith (ADAS) – see document 'NExcr190506 bc.doc'.

Tonnages of poultry litter incinerated in each year were obtained directly from EPRL and Fibropower websites (K Smith, ADAS).

Table A12. Manure output and N excretion by livestock category (2015 values)

Livestock type	Manure output kg d^{-1} Slurry	FYM	N excretion kg yr^{-1}	%TAN at excretion
Cattle				
Dairy cows & heifers	54.6	68.9	127.6	60
Dairy heifers in calf	41.2	52.0	67	60
Dairy replacements	33.0	41.6	56	60
Dairy calves <1yr	20.6	26.0	38	60
Beef cows & heifers	45.7	51.8	79	60
Beef heifers in calf	32.5	36.8	56	60
All other beef >1yr	32.5	36.8	56	60
Beef calves <1yr	20.3	23.0	38	60
Sheep				
Ewes - lowland		5.8	9.0	60
Ewes - upland		3.8	9.0	60
Lambs - lowland		2.1	1.62	60
Lambs - upland		2.1	1.62	60
Goats		4.0	20.6	60
Deer		15.0	13	60
Pigs				
Maiden gilts	5.7	6.4	15.5	70
Sows	11.1	12.5	18.1	70
Boars	8.8	10.0	21.8	70
Fatteners >110 kg	5.2	5.9	15.4	70
Fatteners 80-110 kg	5.2	5.9	15.4	70
Fatteners 50-80 kg	3.8	4.3	13.3	70
Fatteners 20-50 kg	3.8	4.3	8.9	70
Weaners (<20 kg)	1.3	1.5	3.4	70
Poultry				
Laying hens (cages)		0.12	0.67	70
Laying hens (free-range)		0.12	0.75	70
Broilers		0.07	0.40	70
Pullet		0.04	0.33	70
Breeding Hens		0.12	1.02	70
Turkeys (m)		0.18	2.18	70
Turkeys (f)		0.13	1.46	70
Ducks		0.1	1.71	70
Horses		28.2	50	60

Livestock housing and manure management activity data

A review of livestock housing and manure management practices conducted by Ken Smith (ADAS) as part of Defra project AC0114 was used as the basis of developing the time series 1990 to 2015 of livestock housing and manure management practices for each country (England, Wales, Scotland and Northern Ireland). Uptake of mitigation methods was included in the review.

Livestock housing

Cattle housing periods, as derived from the AC0114 Manure management report, are 179, 151, 168 and 167 for dairy cows, dairy followers, beef cattle and calves, respectively. For sheep, ewes are assumed to be indoors for 30 d, lambs not indoors at all. For poultry and pigs we assume 100 % occupancy for housing, as the June agricultural surveys take snapshots of animal numbers which will reflect the actual % occupancy.

Table A13. The proportion (%) of cattle using slurry housing systems

	England		Wales		Scotland		Northern Ireland	
	1990	2015	1990	2015	1990	2015	1990	2015
Dairy cows	70	80	70	75	45	50	99	99
Dairy followers	20	20	20	33	45	50	99	99
Beef cattle	20	20	20	33	45	50	85	85
Calves	0	0	0	0	0	0	0	0

Table A14. The proportion (%) of pigs in different housing systems (Wales and Scotland assume to be same as for England)

	1990	2015	1990	2015	1990	2015	1990	2015
Dry sows, slurry	28	12	28	12	28	12	72	53
Dry sows, FYM	52	47	52	47	52	47	8	6
Dry sows, outdoors	20	41	20	41	20	41	20	41
Farrowing sows, slurry	60	34	60	34	60	34	72	51
Farrowing sows, FYM	20	23	20	23	20	23	8	6
Farrowing sows, outdoors	20	43	20	43	20	43	20	43
Boars, slurry	0	0	0	0	0	0	72	65
Boars, FYM	80	72	80	72	80	72	8	7
Boars, outdoors	20	28	20	28	20	28	20	28
Fatteners (20-110kg), slurry	50	34	50	34	50	34	90	88
Fatteners (20-110kg), FYM	50	64	50	64	50	64	10	10
Fatteners (20-110kg), outside	0	2	0	2	0	2	0	2
Weaners (<20kg), slurry	90	36	90	36	90	36	90	71
Weaners (<20kg), FYM	10	43	10	43	10	43	10	8
Weaners (<20kg) outside (%)	0	21	0	21	0	21	0	21

The proportion of poultry droppings estimated to be voided outside the house for free-range systems is estimated to have increased from 12 % to 20 % in more recent years as newer systems are designed such that birds do spend longer outside (Pers. comm. Elson, ADAS).

Table A15. The proportion of poultry in different housing systems

	England		Wales		Scotland		Northern Ireland	
	1990	2015	1990	2015	1990	2015	1990	2015
Layers:								
Free range	15	44	15	44	10	15	7	7
Perchery	15	7	15	7	5	8	7	7
Deep litter	20	0	20	0	0	19	50	50
Cages – deep pit	50	25	50	25	65	11	16	16
Cages – belt-clean	0	24	0	24	20	47	21	21
Broilers:								
Free range	0	7	0	7	0	7	0	7
Housed	100	93	100	93	100	93	100	93
Pullets:								
Free range	10	6	10	6	10	6	10	6
Housed	90	94	90	94	90	94	90	94
Breeding hens:								
Free range	10	1	10	1	10	1	10	1
Housed	90	99	90	99	90	99	90	99
Turkeys:								
Free range	10	18	10	18	10	18	10	18
Housed	90	82	90	82	90	82	90	82
Ducks:								
Free range	10	10	10	10	10	10	10	10
Housed	90	90	90	90	90	90	90	90

Hard standings

Survey data, collected as part of project WA0516, indicate that 65% of dairy cattle have access to collecting yards and 30% have access to feeding yards while 45% of beef cattle have access to feeding yards. Survey data from FPS2006 indicates that dairy cows with access to collecting yards spend an average of 33% of the day on the yards, so the amount of excreta deposited is assumed to be pro-rata to the time spent. Data from project NT2402 indicate that 21% of daily N excretion is deposited on feeding yards by dairy cattle which have access to them. Expert opinion was that approximately 40% of daily excreta from beef cattle on feeding yards is deposited to the yard (FPS2006 indicates that the animals have access for the majority of the day, but they would also have access to housing during this period).

Usage derived from survey conducted under WA0628 (Webb *et al*., 2001) and from NT2402†.

Table A16. Survey data on use of livestock hard standings

Hard standing	Area per animal (m^2)	% animals using hard standing	Usage (Days per year)
Dairy cow collecting yard	2.15 (1.74, 2.55†)	65	358 (365, 358†)
Dairy cow feeding/loafing yard	3.03 (1.70, 3.03†)	30	303 (365, 240†)
Dairy cow self-feed silage yard	4.75	14	180
Beef cattle feeding/loafing yard	4.32	45	180
Beef cattle self-feed silage	4.71	9	180
Sheep handling area – lowland sheep	0.92	67	24
- upland sheep	0.92	67	6
Pig loading area	1.00	19	4

NB Area per animal not actually used in calculation, but included here for reference.

Storage

The proportion of manure stored in different store categories was derived from Farm Practices Surveys (various).

The proportion of cattle stores crusted estimated from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), with stores stirred never or only occasionally assumed to be crusted.

Land spreading

The proportion of pig or cattle manure applied to grassland and arable, the proportion applied in summer (May-July), the proportion applied by injection or irrigated and the proportion incorporated within 1d or 1wk of application were obtained from ADAS Surveys of Animal Manure Practices in the Dairy, Beef, Pig and Poultry Industries (Smith *et al*., 2000c, 2001a, 2001b). The proportion of cattle and pig FYM spread to land without storage was also obtained from the same source. The proportion of poultry manure applied to grassland and arable was obtained from the Farm Practices Survey (Defra 2001).

The proportion of slurry in each dry matter category was derived from ADAS unpublished (K Smith, B Chambers).

Fertiliser

Fertiliser usage in England, Wales and Scotland derived from British Survey of Fertiliser Practice 2015 (http://www.defra.gov.uk/environ/pollute/bsfp/index.htm) and for Northern Ireland from DARDNI stats (http://www.dardni.gov.uk/econs/.htm).

References

Baines, S., Svoboda, I. F. and Sym, G. (1997*) Estimates of slurry, manure storage and housings in use in Scotland and Northern Ireland*. Report to MAFF (WA0620), SAC Ayr.

Bittman, S., Dedina, M., Howard, C.M., Oenema, O., Sutton, M.A., (eds), 2014. *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*, Centre for Ecology and Hydrology, Edinburgh, UK

Bussink, D.W. (1994). Relationship between ammonia volatilization and nitrogen fertilizer application rate, intake and excretion of herbage nitrogen by cattle on grazed swards. *Fertilizer Research* **38**, 111-121

CAMAR: Groot Koerkamp, P. W. G., Metz, J. H. M., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O. and Wathes, C. M., 1998. Concentrations and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research* **70**, 79-95.

Chadwick, D.R. (2005). Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. *Atmospheric Environment* **39**, 787-799.

Chalmers, A. G., et al. (2001). *Fertiliser use on farm crops for crop year 2000*. British Survey of Fertiliser Practice, Edinburgh: The Stationery Office.

Chambers, B.J., Smith, K.A. and van der Weerden, T.J. (1997). Ammonia emissions following the land spreading of solid manures. In *Gaseous Nitrogen Emissions from Grasslands*. Eds S.C. Jarvis and B.F. Pain, CAB International, Oxford, pp. 275-280.

Chambers, B. J., Lord, E. I., Nicholson, F. A. and Smith, K. A. (1999). Predicting nitrogen availability and losses following application of organic manures to arable land: MANNER. Soil Use and Management 15, 137-143.

DANI (1998). Statistical Review of Northern Ireland Agriculture, 1997. Department of Agriculture for Northern Ireland, Economics and Statistics Division, Belfast, Northern Ireland, UK.

Defra (2001) http://www.defra.gov.uk/esg/work_htm/publications/cs/fps/fpsfinalreport.PDF

Demmers, T.G.M., Phillips, V.R., Short, J.L., Burgess, L.R., Hoxer, R.P. and Wathes, C.M (1997). Validation of ventilation rate measurement methods and the ammonia emission from a naturally-ventilated UK dairy and beef unit. In*: Ammonia and Odour Emissions from Animal Production Facilities*. Eds J.A.M. Voermans and G.J. Monteney, Proceedings of an international symposium held at Vinkeloord, Netherlands, 6-10 October 1997. Published by NTVL, Rosmalen, NL pp. 219-230.

Demmers, T.G.M., Burgess, L.R., Short, J.L., Phillips, V.R., Clark, J.A. and Wathes, C.M. (1999). Ammonia emissions from two mechanically ventilated UK livestock buildings. *Atmospheric Environment* **33**, 217-227.

Dore, C. J., Jones, B. M. R., Scholtens, R., Burgess, L. R., Huis in't Veld, J. W. H., Phillips, V. R. (2004). Robust methods for measuring ammonia emission rates from livestock buildings and manure stores. Part 1 Comparative demonstrations of three methods on the farm. *Atmospheric Environment* **38**, 3017-3024.

Hill, R.A. (2000). Emission, dispersion and local deposition of ammonia volatilised from farm buildings and following the application of cattle slurry to grassland. PhD Thesis, University of Plymouth.

Hodge, I. and Renwick, A. (2006). Business as usual projections of agricultural activities for the water framework directive: Phase 2. Final Report. Rural Business Unit, Environmental Economy and Policy Research Group, Department of Land Economy, 19 Silver Street, Cambridge CB3 9EP.

Jarvis, S.C; Hatch, D. J; Orr, R.J. and Reynolds, S.E. (1991). Micrometeorological studies of ammonia emissions from sheep grazed swards. *Journal of Agricultural Science Camb*ridge, **117**, 101-109

Jarvis, S. C. and Bussink, D. W. (1990). Nitrogen losses from grazed swards by ammonia volatilization. Proceedings of the 13th General Meeting of the European Grassland Federation, June 25-29, 1990, Banska Bystrica, Czechoslovakia, p.13-17.

Kirchmann, H., and Witter, E. (1989). Ammonia volatilization during aerobic and anaerobic manure decomposition. *Plant and Soil* **115**, 35-41.

Koerkamp, P., Metz, J. H. M., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O. and Wathes, C. M. (1998). Concentrations and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research* **70**, 79-95.

Ledgard, S. F. (1996). Nitrogen inputs and losses from New Zealand dairy farmlets, as affected by nitrogen fertilizer applications: year one. *Plant and Soil* **181**, 65-69.

MAFF (2000). *Fertilizer Recommendations for Agricultural and Horticultural Crops (RB209), 7th Edition.* Her Majest's Stationery Office, London, UK.

Mercer, D. R. (1993*) Estimates of the number and types of poultry housing in use in England and Wales.* Report to MAFF, ADAS Nottingham.

Misselbrook, T.H., Webb, J. and Gilhespy, S.L. (2006). Ammonia emissions from outdoor concrete yards used by livestock – quantification and mitigation. *Atmospheric Environment* **40**, 6752-6763.

Misselbrook, T.H., Brookman, S.K.E., Smith, K.A., Cumby, T.R., Williams, A.G., McCrory, D.F. (2005). Crusting of stored dairy slurry to abate ammonia emissions: pilot-scale studies. *Journal of Environmental Quality* **34**, 411-419.

Misselbrook, T.H., Sutton, M.A. and Scholefield, D. (2004). A simple process-based model for estimating ammonia emissions from agricultural land after fertilizer applications. *Soil Use and Management* **20**, 365-372.

Misselbrook, T. H., Smith, K. A., Johnson, R. A. and Pain, B. F. (2002). Slurry application techniques to reduce ammonia emissions: Results of some UK field-scale experiments. *Biosystems Engineering* **81**, 313-321.

Nicholson, F.A., Bhogal, A., Chadwick, D., Gill, E., Gooday, R.D., Lord, E., Misselbrook, T., Rollett, A.J., Sagoo, E., Smith, K.A., Thorman, R.E., Williams, J.R., Chambers, B.J. (2013). An enhanced software tool to support better use of manure nutrients: MANNER-NPK. *Soil Use and Management* **29**, 473-484.

Nicholson, F. A., Chambers, B. J. and Smith, K. A. (1996) Nutrient composition of poultry manures in England and Wales. *Bioresource Technology* **58**, 279-284.

Nicholson, R. J. and Brewer, A. J. (1994) *Estimates of the numbers and types of slurry and manure stores in use in England and Wales related to livestock species*. Report to DEFRA (WA0611), ADAS Cambridge.

Pain, B. F., Rees, Y. J. and Lockyer, D. R. (1988). Odour and ammonia emission following the application of pig or cattle slurry to land. In*: Volatile emissions from livestock farming and sewage operations*, eds V C Neilsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, pp. 2 - 11.

Pain, B. F., Phillips, V. R., Clarkson, C. R. and Klarenbeek, J. V. (1989). Loss of nitrogen through ammonia volatilisation following the application of pig or cattle slurry to grassland. *Journal of the Science of Food and Agriculture* **47**, 1-12.

Peirson, S. (1995). Measurement of odour and ammonia emissions from livestock buildings, Phase 1 - Final Report to MAFF. Project no. WAO601, ADAS Beverley.

Phillips, V.R., Sneath, R.W., Williams, A.G., Welch, S.K., Burgess, L.R., Demmers, T.G.M. and Short, J.L. (1997). Measuring emission rates of ammonia, methane and nitrous oxide from full-sized slurry and manure stores. In*: Ammonia and Odour Emissions from Animal Production Facilities*. Eds J.A.M. Voermans and G.J. Monteney, Proceedings of an international symposium held at Vinkeloord, Netherlands, 6-10 October 1997. Published by NTVL, Rosmalen, NL pp. 197-208.

Phillips, V. R., Bishop, S. J., Price, J. S. and You, S. (1998). Summer emissions of ammonia from a slurry-based, UK, dairy cow house. *Bioresource Technology* **65**, 213-219.

Robertson, A. P., Hoxey, R. P., Demmers, T. G. M., Welch, AS. K., Sneath, R. W., Stacey, K. F., Fothergill, A., Filmer, D. and Fisher, C. (2002). Commercial-scale studies of the effect of broiler-protein intake on aerial pollutant emissions. *Biosystems Engineering* **82**, 217-225.

Sheppard, A. (1998) The Structure of Pig Production in England and Wales. Results of the National Survey of Pig Production Systems. *Special Studies in Agricultural Economics Report No. 40*, University of Exeter.

Smith, K. A. and Chambers, B. J. (1995). Muck from waste to resource - utilization: the impacts and implications. *Agricultural Engineer*, **50**, 33-38.

Smith, K. A. and Frost, J. P. (2000). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 1: cattle and sheep. *Bioresource Technology* **71**, 173-181.

Smith, K. A., Charles, D. R. and Moorhouse, D. (2000a). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 2: pigs and poultry. *Bioresource Technology* **71**, 183-194.

Smith, K. A., Jackson, D. R., Misselbrook, T. H., Pain, B. F. and Johnson, R. A. (2000b). Reduction of ammonia emission by slurry application techniques. *Journal of Agricultural Engineering Research* **77**, 277-287.

Smith, K. A., Brewer, A. J., Dauven, A. and Wilson, D. W. (2000c). A survey of the production and use of animal manures in England and Wales. I. Pig manure. Soil Use and Management 16, 124-132.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001a). A survey of the production and use of animal manures in England and Wales. II. Poultry manure. Soil Use and Management 17, 48-56.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001b). A survey of the production and use of animal manures in England and Wales. III. Cattle manures. Soil Use and Management 17, 77-87.

Sommer, S.G., Christensen, B.T., Nielsen, N.E., and Schjrrring, J.K. (1993). Ammonia volatilization during storage of cattle and pig slurry: effect of surface cover. *Journal of Agricultural Science, Cambridge*, **121**, 63-71.

Sutton, M. A., Dragosits, U., Tang, Y. S. and Fowler, D. (2000). Ammonia emissions from non-agricultural sources in the UK. *Atmospheric Environment* **34**, 855-869.

Thompson, R. B., Pain, B. F. and Lockyer, D. R. (1990a). Ammonia volatilization from cattle slurry following surface application to grassland. I. Influence of mechanical separation, changes in chemical composition during volatilization and the presence of the grass sward, *Plant and Soil* **125**, 109-117.

Thompson, R. B., Pain, B. F. and Rees, Y. J. (1990b). Ammonia volatilization from cattle slurry following surface application to grassland. II. Influence of application rate, windspeed and applying slurry in narrow bands. *Plant and Soil* **125**, 119-128.

van der Weerden, T. J. and Jarvis, S. C. (1997). Ammonia emission factors for N fertilisers applied to two contrasting grassland soils. *Environmental Pollution* **95**, 205-211.

Wathes, C. M., Holden, M. R., Sneath, R. W., White, R. P. and Phillips, V. R. (1997). Concentrations and emission rates of ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. *British Poultry Science* **38**, 14-28.

Webb, J., (2001). Estimating the potential for ammonia emissions from livestock excreta and manures. *Environmental Pollution* **111**, 395-406.

Webb, J., and Misselbrook, T. H. (2004). A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* **38**, 2163-2176.

Webb, J., Misselbrook, T., Pain, B. F., Crabb, J. and Ellis, S. (2001). An estimate of the contribution of outdoor concrete yards used by livestock to the UK inventories of ammonia, nitrous oxide and methane. *Atmospheric Environment* **35**, 6447-6451.

Welch, D.C. (2003) A methodology for the measurement of distributed agricultural sources of ammonia outdoors. PhD thesis, University of Nottingham.

Williams, J. R., Chambers, B. J., Hartley, A. R., Ellis, S. and Guise, H. J. (2000). Nitrogen losses from outdoor pig farming systems. *Soil Use and Management* **16**, 237-243.

DEFRA Projects

Final reports from the following projects are available from Defra:

AC0114	GHG Platform – data management
AC0123	Developing new ammonia emissions factors for modern livestock housing and manure management systems
AM0101	National ammonia reduction strategy evaluation system (NARSES)
AM0102	Modelling and measurement of ammonia emissions from ammonia mitigation pilot farms

AM0103	Evaluation of targeted or additional straw use as a means of reducing ammonia emissions from buildings for housing pigs and cattle
AM0110	Additional housing measurements for solid vs. liquid manure management systems
AM0111	Measurement and abatement of ammonia emissions from hard standings used by livestock
AM0115	Investigation of how ammonia emissions from buildings housing cattle vary with the time cattle spend inside them
DO108	Food and Agriculture Policy Research Institute – UK Project
ES0116	Field work to validate the manure incorporation volatilization system (MAVIS)
KT0105	Manure Nutrient Evaluation Routine (MANNER-NPK)
LK0643	UK Poultry Industry IPPC Compliance (UPIC)
NT2001	Integration of animal manures in crop and livestock farming systems: nutrient demonstration farms
NT2402	Impact of nutrition and management on N and P excretions by dairy cows
OC9117	Ammonia emission and deposition from livestock production systems
WA0516	Run-off and emissions from hardstandings
WA0519	Enhancing the effective utilisation of animal manures on-farm through effective compost technology
WA0618	Emissions from farm yard manure based systems for cattle
WA0625	The effects of covering slurry stores on emissions of ammonia, methane and nitrous oxide
WA0628	Ammonia emissions from the hardstandings used by cattle
WA0632	Ammonia fluxes within solid and liquid manure management systems
WA0633	Predicting ammonia loss following the application of organic manures to land
WA0638	Low cost, aerobic stabilisation of poultry layer manure
WA0641	Low-cost covers to abate gaseous emissions from slurry stores
WA0651	Ammonia fluxes within broiler litter and layer manure management systems
WA0652	Field ammonia losses in sustainable livestock LINK Project LK0613
WA0653	Quantifying the contribution of ammonia loss from housed dairy cows to total N losses from dairy systems (MIDaS2)
WA0707	Effect of storage conditions on FYM composition, gaseous emissions and nutrient leaching during storage
WA0708	Covering a farm scale lagoon of pig slurry
WA0712	Management techniques to minimise ammonia emissions during storage and land spreading of poultry manures
WA0714	Natural crusting of slurry storage as an abatement measure for ammonia emission on dairy farms
WA0716	Management techniques to reduce ammonia emissions from solid manures
WA0717	Ammonia emissions and nutrient balance in weeping-wall stores and earth banked lagoons for cattle slurry storage
WA0720	Demonstrating opportunities of reducing ammonia emissions from pig housing
WA0722	Ammonia emission from housed dairy cows in relation to housing system and level of production
WT0715NVZ	Nitrogen and phosphorus output standards for farm livestock