Inventory of Ammonia Emissions from UK Agriculture

2010

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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 2010. Year-specific livestock numbers and fertiliser N use were added for 2010 and revised for previous years. The estimate for 2010 was 233.3 kt NH_3, representing a 1.5 kt increase from the previously submitted estimate for 2009. Historical livestock numbers were revised (back to 1990) according to statistical data published by each Devolved Administration. Projections of livestock numbers and fertiliser use to 2019 were revised using data derived from FAPRI. Backward and forward projections using the 2010 model structure gave estimates of 311 and 226 kt NH_3 for the years 1990 and 2019, respectively. This inventory reports emission from livestock agriculture and from nitrogen fertilisers applied to agricultural land. There are a number of other minor sources reported as 'agriculture' in the total UK emission inventory, including horses not kept on agricultural holdings, emissions from composting and domestic fertiliser use, which are not reported here.

Table 1. Estimate of ammonia emission from UK agriculture for 2010

Source		**kt NH_3**	**% of total**
Livestock category			
Cattle		134.1	57
	Dairy	*73.4*	*31*
	Beef	*60.7*	*26*
Sheep†		10.0	4
Pigs		17.4	7
Poultry		29.7	13
Horses		4.0	2
Management category			
Grazing/outdoors		28.9	12
Housing		62.7	27
Hard standings		21.9	9
Manure storage		29.7	13
Manure application		52.0	22
Fertiliser application		38.2	16
TOTAL		**233.3**	

†Including goats and deer

Estimate of ammonia emission from UK agriculture for 2010

The estimate of NH_3 emission from UK agriculture for 2010 was made using the spreadsheet version of the National Ammonia Reduction Strategy Evaluation System (NARSES) model (file: NH3inv2010_NARSES_draft2_200911.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 2010 and projections to 2019. 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 2010 inventory of NH_3 emissions from UK agriculture, survey and census data were reviewed to derive livestock numbers, fertiliser use and other management practice data relevant to 2010. Currently used emission factors were reviewed in the light of new experimental data and amended if considered appropriate.

Key areas of revision in the 2010 inventory were:

- Inclusion of 2010 fertiliser use data
- Inclusion of 2010 livestock numbers
- Revision of projections to 2019
- Revision of historical livestock data
- Revision of cattle sub-categories

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

The estimate of emission from UK agriculture for 2010 was 233.3 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 2010 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 2009 inventory estimate.

Table 2. Sequential influence of revisions to individual components on the inventory total (NARSES model) during the 2010 revision

	Change (kt NH_3)	Total (kt NH_3)
2009 total		**231.8**
Fertiliser use activity data 2010	+2.2	
Livestock numbers 2010	-0.1	
Revision to dairy cattle N excretion	+0.2	
Revision to cattle sub-categories	-0.8	
2010 total		**233.3**

Table 3. Estimate of ammonia emissions (kt NH_3) from UK agriculture, 2010

Source	2009	**2010**	**Reasons for change**
Cattle			Small increase in cattle numbers, increase in N excretion by dairy cows
Grazing	15.5	**15.7**	
Landspreading	33.7	**34.1**	
Housing	40.1	**40.6**	
Hard standings	21.1	**21.3**	
Storage	22.2	**22.4**	
Total Cattle	132.5	**134.1**	
Grazing	7.3	**7.1**	
Landspreading	0.2	**0.2**	
Housing	1.2	**1.1**	
Hard standings	0.6	**0.6**	
Storage	0.9	**0.9**	
Total Sheep	10.1	**10.0**	Small reduction in sheep numbers
Horses	4.8	**4.0**	Reduction in horse numbers
Pigs			
Outdoor	1.2	**1.1**	
Landspreading	4.1	**3.9**	
Housing	9.2	**8.5**	
Hard standings	0.0	**0.0**	
Storage	4.3	**3.9**	
Total Pigs	18.8	**17.4**	Reduction in pig numbers
Poultry			
Outdoor	0.9	**0.9**	
Landspreading	13.8	**13.8**	
Housing	12.3	**12.5**	
Storage	2.5	**2.5**	
Total Poultry	29.5	**29.7**	Increase in total poultry numbers
Fertiliser	36.0	**38.2**	Increase in total N use, small increase in proportion as urea
TOTAL	231.8	**233.3**	

Major changes between 2009 and 2010

1. 2010 fertiliser use data

Date were derived from BSFP for crop year 2010 for England, Wales and Scotland and from DARD statistics for Northern Ireland.

The steady decline in fertiliser N use in UK agriculture since 1990 appears to be levelling out, with a low point reached in 2008 and increases in use in both years since then. Total fertiliser N use increased by 8% between 2009 and 2010, and there was a further increase in the proportion applied as urea (up from 21% in 2009 to 22% in 2010). The combined effects of greater fertiliser N use and a higher proportion as urea gave an overall increase in emissions of 2.2 kt NH_3.

2. 2010 livestock numbers

Headline changes from 2009 are:

Cattle – a 0.8% increase in total cattle numbers (0.6% total dairy cattle and 1.0% total beef cattle)

Pigs – a 5.4% decline in pig numbers

Sheep – a 3.0% decline in sheep numbers

Poultry – a 2.9% increase in total poultry numbers, with a 7.5% increase in the laying flock and a 2.5% increase in broiler numbers

It should be noted that the June survey methodology from 2010 covers only commercial holdings (> 10 cows, 50 pigs, 20 sheep, 20 goats or 1,000 poultry), with the exception of cattle where all animals are covered by the cattle tracing scheme. Previous June surveys covered all agricultural holdings and therefore some livestock, with the exception of cattle, will not be counted under the new methodology.

3. Dairy cow N excretion

Dairy cow N excretion values were previously derived from project WT0715NVZ with interpretation by B Cotteril and K Smith (ADAS). This project gave projected values for 2006 onwards, based on projected milk yields. These data have now been revised according to reported average annual milk yields for each year (derived from Agriculture in the UK publications, Defra), using the empirical relationship between N excretion and milk yield as reported in WT0715NVZ.

4. Cattle sub-categories

The previously used sub-categories within the beef and dairy cattle sectors have been revised and rationalised, reflecting changes in the reporting of livestock statistics by Devolved Administration and harmonising with the categories used in the revised greenhouse gas inventory model. Cattle sub-categories now comprise: dairy cows and heifers, dairy heifers in calf, dairy replacements >1yr, dairy calves, beef cows and heifers, beef heifers in calf, all other beef >1yr (also will include dairy bulls), beef calves.

Past and Projected Trends: 1990 - 2019

Retrospective calculations based on the 2010 inventory methodology were made for the years 1990 to 2010 and projections to 2019 (Table 4). Projected changes in livestock numbers, N fertiliser use and management practices are detailed below. There has been a steady decline in emissions (25%) from UK agriculture over the period 1990 – 2010, 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 27% reduction from 1990-2019. These projections are subject to much uncertainty and further work is required to both generate more robust projections in agricultural activity data and an estimate of uncertainties relating to the assumptions made in deriving the projections.

Table 4. Estimates of ammonia emission from UK agriculture 1990 – 2019 using the NARSES model

Source	1990	1995	2000	2005	2009	2010	2015	2019
							Projections	
Total	**311.4**	**290.3**	**264.5**	**251.1**	**231.2**	**233.3**	**226.1**	**226.2**
Cattle	154.3	150.2	143.9	140.1	132.0	134.1	126.9	127.6
Dairy cattle	*87.9*	*83.9*	*79.8*	*77.0*	*71.8*	*73.4*	*70.0*	*70.5*
Other cattle	*66.3*	*66.3*	*64.2*	*63.1*	*60.2*	*60.7*	*56.9*	*57.1*
Sheep	14.0	13.9	13.5	11.4	10.1	10.0	9.8	9.7
Pigs	42.0	39.8	31.1	22.1	18.8	17.4	21.0	21.4
Laying hens	13.7	12.0	10.0	9.5	8.2	8.7	7.9	7.6
Other poultry	21.1	24.0	28.4	25.4	21.3	21.0	21.2	21.0
Horses	2.6	3.4	3.7	4.5	4.8	4.0	4.8	4.8
Fertiliser	63.7	47.1	33.7	38.1	36.0	38.2	34.5	34.1

Figure 1. Trends in livestock numbers 1990 – 2019. Changes are relative to a reference value of 100 in 1990. Dashed lines show projections from derived from FAPRI data.

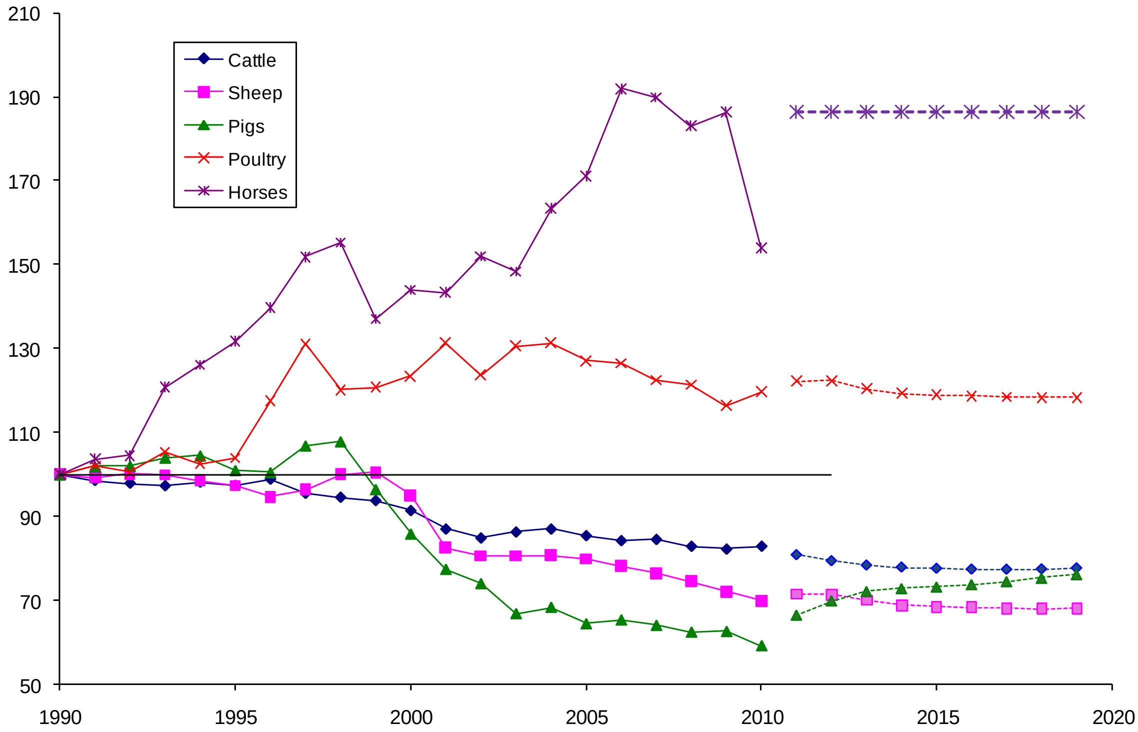
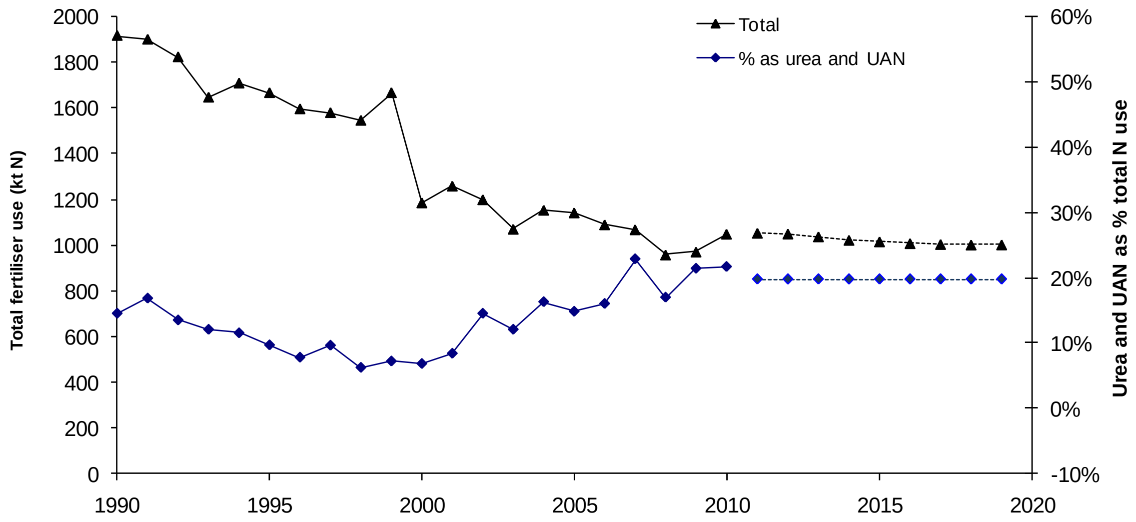


Figure 2. Changes in fertiliser N use 1990 – 2020. Dashed lines show projections from derived from FAPRI data.



Projections – methodology and assumptions

Livestock numbers

Previously, livestock number projections were based on projections made in Defra project SFF0601 (Baseline projections for Agriculture), using June 2004 census data as the base year. However, these have now been replaced with projections provided by Mario Deconti (Defra), based on FAPRI data (file FAPRI GHG model UKbase04Aug.xls). In addition, trends in N excretion were included: N excretion by dairy cattle was forecast to increase as cattle numbers became fewer but milk quota was maintained. N excretion by certain pig and poultry categories were forecast to decrease as dietary improvements were taken up by the industry. Past and projected trends in livestock numbers use are shown in Figure 1.

Fertiliser use

Previously, fertiliser use projections were also taken from Defra project SFF0601, using 2004 data as the base year. These are still used as the basis of the revised projections, but have been revised according to FAPRI projections of crop production, with data provided by Mario Deconti (Defra; file FAPRI GHG model UKbase04Aug.xls). Proportions of each fertiliser type applied for projection years were assumed to be the average for the years 2006-2010. Past and projected trends in fertiliser N use are shown in Figure 2.

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.

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

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 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 as used in the current model were kept constant for all model runs from 1990 – 2020.

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. ±46.6 kt NH_3 for the 2010 estimate).

APPENDIX 1

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

NB: Derivation of emission factors as used in the previous inventory model (UKAEI) and in the currently-used NARSES model are given.

All emission factors (EF) are given in terms of NH_3-N or, where expressed as a percentage, these are as a % TAN (total ammoniacal nitrogen) within the current 'emission pool' (e.g. losses at spreading are expressed as %TAN in the manure at spreading).
Cited sources are either scientific publications or Defra project Final Reports (given by Project Code), which are available from the Defra web-site.

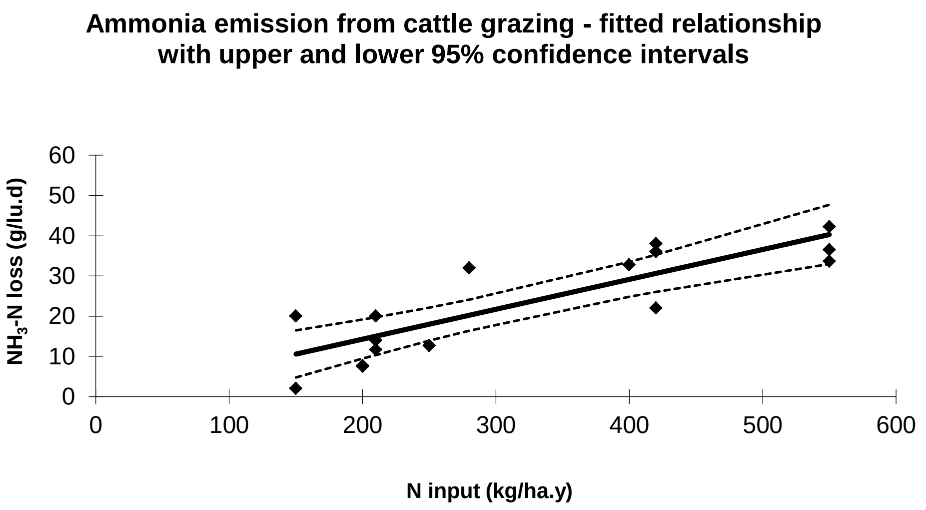
CATTLE

Grazing

UKAEI

- A updated version of the relationship between N input (kg N/ha) and ammonia emission (g N lu^{-1} d^{-1}) from cattle grazed swards (Jarvis & Bussink 1990) was used, including data from Jarvis *et al*. 1989, Bussink 1992 and 1994, Ledgard 1996 and IGER (OC9117).

N input	Jarvis *et al.* ‘89	Bussink ‘92	Bussink ‘94	Ledgard ‘96	IGER OC9117	WA0652
150	2					
150	20					
200						7.5
200						7.7
210	20					
210	14			11.64		
250		12.73	12.73			
280					32	
280					32	
400			32.73			
420	38					
420	36					
420	22					
550		42.27	33.64			
550		36.54				



Fitted relationship: $y = -0.51+0.0742\,x$ (r^2 0.68)

NARSES

EF for NARSES was derived from source data, where sufficient data were available. 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 TAN return to the pasture via cattle urine.

Bussink	Fert Res 33 257-265					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
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					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
1989	250	64.2	3.8	3.5	0.3	0%
1989	400	76.2	12	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	5.6	21.4	6%
1990	550	407.1	32.8	7.7	25.1	6%
Lockyer	J Sci Food Agric 35, 837-848					
	Urine applied	Emission				%TAN
1	26	0.6455				2%
2	26	0.7025				3%
Jarvis et al	J Ag Sci 112, 205-216					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
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%

An overall mean EF of 6 %TAN was derived.

Land spreading

NARSES

Slurry

- EF derived from the MANNER_PSM model (KT0106)

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>Abatement techniques</u>
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)

Incorporation
Incorporation within 4h gives 60% reduction
Incorporation within 24h gives 30% reduction
Values derived from using MANNER PSM (Project KT0106), assuming incorporation by plough.

FYM

- EF derived from the MANNER_PSM model (KT0106) as 68.3 %TAN applied. No modifiers for soil, manure or weather.

<u>Abatement</u> – incorporation
Incorporation within 4h gives 70% reduction
Incorporation within 24h gives 35% reduction
Values derived from using MANNER_PSM (Project KT0106), assuming most incorporation by plough.

Housing

Mean EF g N $lu^{-1}d^{-1}$	Values g N $lu^{-1}d^{-1}$	Derived from n values	Emission as % TAN	Source
Slurry (cubicle house)				
36.8	38.5		29.4	Demmers *et al*. (1997)
	29.0	9	19.9	WA0653
	43		42.4	Dore *et al*., (2004)
	51	3	*57.0	WA0632/AM0110 (Polytunnels)
	29.4	1	51.0	Hill (2000)
	30		29.6	AM0102 (commercial farm)
Straw-bedded				
22.2	13.7			Demmers (1997)
	20.6		NA	WA0618 (IGER polytunnels)
	35	3	*56.0	WA0632/AM0110 (Polytunnels)
	33.2		47.0	WA0722
	13.9		18.4	AM0103 (IGER polytunnels)
	16.7		14.0	AM0103 (commercial farm)
Calves				
10.6	10.6		7.0	Koerkamp *et al*., 1998
	13.7		11.0	Demmers (1997)

NARSES EF were calculated from standard values for N excretion in buildings, except for those results marked with an asterisk for which data were available on diets and liveweight gain during the measurement period to allow calculation of actual N excretion. The NARSES EF, using a mean weighted according to the number of measurements reported are 31.5, 22.9 and 7.6 % TAN for cattle on slurry, cattle on straw and calves on straw respectively.

No distinction is made between dairy and beef cattle housing emission factor. Values from IGER (WA0632) and IGER (WA0618) refer to beef cattle; all others are for dairy cattle.
CAMAR data was not used (with exception of calves), as there were doubts about the methodology of measurements from naturally ventilated buildings.

The value for cattle on cubicles from SRI (Dore *et al*., 2004) excludes measurements made by the external tracer method. The data for the 3rd year of WA0653 was not used; measured emissions were very much lower than for the first 2 years, with several negative values for individual sampling points and dates, although there were no obvious explanatory factors.

Work by Phillips *et al*. (1998) suggests that summer emissions from dairy cattle housing, where the cattle come in for part of the day for milking, may be of a similar magnitude to winter emissions. An EF for summer housing emissions is not explicitly included in the inventory, but housing period is increased to account for the hours each day during the summer when the cattle are in. The EF for housing is likely to be greater in summer, because of higher temperatures. However, it is also likely that the floor area from which emission take place will be much reduced, as access to housing may be restricted.

Hard standings

UKAEI
Data from AM0111, incorporating data from Misselbrook *et al*., (1998, 2001)

Source	Means EF (g N animal^{-1} d^{-1})
dairy cow collecting yard	10.7
dairy cow feeding/loafing yard	10.7
beef feeding/loafing yard	23.3

Emission factors were expressed per animal rather than per m^2 surface area because annual changes in livestock numbers are known with much greater certainty than changes in areas of hard standing.

For NARSES, the following data/assumptions were used: Survey data, collected as part of project WA0504, 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 NT2601 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). Project AM0111 indicated that collecting yards, which are scraped at least once a day, are scraped with an efficiency of c. 60%. Based on Misselbrook et al (2006) it is assumed that 75% of the TAN left after scraping is emitted as NH_3. For feeding yards, which are scraped only once or twice a week on average, the scraping efficiency is assumed to be 30%.

Storage

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
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

** Emissions expressed per day. This value assumes 90 d storage.

Slurry stores are assumed to develop a crust unless they are stirred frequently.
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 divided by **0.7**).

Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES EF were derived as a weighted mean of those studies which supplied information on the amounts of N and TAN put into store. Mean EF were derived as 5.0 and 51.5 % TAN for tanks (assumed to be crusted and equivalent to weeping wall store) and lagoons, respectively. For FYM a weighted mean EF of 35% was derived.

SHEEP

Grazing

UKAEI

- Upland sheep based on values from Jarvis *et al*. (1991) 0N, and grass/clover plots. Mean values for the 2 years were 0.92 and 0.19 g N animal^{-1} d^{-1}, giving a mean EF of 0.56 g N animal^{-1} d^{-1}.
- Lowland sheep based on values from Jarvis *et al*. (1991) - 420N, clover and grass clover plots giving mean values over 2 yrs of 1.05 and 1.16 g N animal^{-1} d^{-1}- and on new IGER unpublished data from North Wyke with values of 1.36, 3.95, 2.47, 0.89, 3.11 and 1.78 g N animal^{-1} d^{-1}. Overall mean gives an EF of 2.0 g N animal^{-1} d^{-1}.
- EF for grazing lambs taken to be half the value for sheep, as lamb excretal output is approximately half that of sheep.

NARSES

Insufficient data regarding N returns to the pasture by grazing sheep were available from the source publications listed above, so the EF used for cattle grazing (6 %TAN) was assumed for sheep.

Land spreading

- FYM - value for cattle used.

Housing

NARSES EF was derived directly by back-calculation of the UKAEI, giving an EF of 21.6% TAN, since there are no reported measurements of NH_3 emission from buildings housing sheep.

Hard standings

UKAEI

A mean emission factor of 5.0 g N animal^{-1} d^{-1} derived from data from 2 sites (7.20 and 2.82 g NH_3-N animal^{-1} d^{-1}) from Misselbrook *et al*., 2001.

NARSES

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

Storage

- FYM - value for cattle used.

PIGS

Outdoors

	Mean EF g N $lu^{-1}d^{-1}$	Values g N $lu^{-1}d^{-1}$	Emission as %TAN	Source
Outdoor sows/piglets	**46**	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).

Land spreading

Slurry

- EF derived from the MANNER_PSM model (KT0106)

The ‘standard’ EF for pig slurry is given as 25.5 %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, 68.3 %TAN applied

<u>Abatement techniques</u>

Slurry injection – abatement efficiency of 90% (assumed to be deep injection to arable land)
Band spreading (trailing hose) – abatement efficiency of 30%

Incorporation
Incorporation within 6h gives 60% reduction
Incorporation within 24h gives 30% reduction
Values derived from using MANNER PSM (Project KT0106), assuming most incorporation by plough

Housing

Mean EF ($gN.lu^{-1}d^{-1}$)	Values ($gN.lu^{-1}d^{-1}$)	Derived from n values	Emission as %TAN	Source
Dry sows on slats				
17.0	17.0	2	13.0	Peirson (1995)
Dry sows on straw				
25.8	9.4	2	10.0	Peirson (1995)
	14.6		14.7	Koerkamp *et al*., 1998
	26.2	4	26.2	OC9523
	53		59.6	AM0102
Farrowing sows on slats				
29.3	32.4	3	19.0	Peirson (1995)
	20.6		14.3	Koerkamp *et al*., 1998
	35		24.0	AM0102
Farrowing sows on straw				
44.5				Estimated from ratio of EF for dry sows
Boars on straw				
25.8				As for dry sows
Fatteners >20kg on slats				
71.9	70.1		20.0	Peirson (1995)
	51.4		18.5	Koerkamp *et al*., 1998
	105.8		38.2	Demmers (1997)
	72.5	2	20.0	Peirson (1995)
	79.2	4	40.0	WA0632
	103.5†, 48*		39.2	WA0720 (full-slat fv)
	80.0†, 70.0†		38.7	WA0720 (fs acnv)
	71.0†, 39*		28.5	WA0720 (part slat)
Fatteners >20kg on straw				
51.6	54.2	2	14.0	Peirson (1995)
	28.3		10.2	Koerkamp *et al*., 1998
	122.2	4	61.0	WA0632
	24		10.4	AM0102
	47.0		27.2	AM0103 Terrington
	34.1		10.8	AM0103 Commercial
Fatteners <20kg on slats				
27.7	34.8		14.0	Peirson (1995)
	20.6		15.6	Koerkamp *et al*., 1998
Fatteners <20kg on straw				
19.9				Based on ratio for fatteners >20kg

†From measurements on commercial farms
*From experimental studies at ADAS Terrington

Derivation of NARSES EF: weighted means of 25, 13, 19, 33.2 and 14.8 %TAN for dry sows on straw, dry sows, farrowing, finishing pigs and weaners on slurry, respectively. However, because of the large variation and subsequent uncertainty in measurements of emissions from finishing pigs on straw, the reverse engineered estimate of 22.4% TAN is used for finishing pigs on straw.

Hard standings

UKAEI
An emission factor of 0.32 g NH_3-N animal^{-1} d^{-1} for pig loading areas (Misselbrook *et al*., 2001).

NARSES EF derived 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.

Storage

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				
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., in press
FYM heaps	**g N t^{-1} initial heap mass**			
1224	539	4	20.0	*WA0632
	1015	1	68.0	WA0716

UKAEI
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).

As for cattle slurry, a common EF is used for circular tanks and lagoons.

Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES
NARSES EF for slurry tanks was derived as 13 %TAN and for lagoons the same values as for cattle slurry lagoons (52 %TAN) was used. The weighted mean of measurements made during storage of FYM is 30% of TAN, similar to that for emissions during storage of cattle FYM.

POULTRY

Outdoors

NARSES – a lower EF of 35 %UAN has been applied, 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. 20% of poultry droppings are estimated to be voided outside the house (Pers. comm. Elson, ADAS); this is an increase on the previous estimate of 12%, and represents a real change in that newer systems are designed such that birds do spend longer outside.

Land spreading

For poultry manure a standard EF of 52.3 %UAN applied is used, with no further modifiers for soil, manure or weather (KT0106, MANNER_PSM)

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

Abatement – incorporation
Incorporation within 4h gives 85% reduction
Incorporation within 24h gives 55% reduction
Values derived from using MANNER_PSM (Project KT0106), assuming incorporation by plough.

Housing

Mean EF gN $lu^{-1}d^{-1}$	Values gN $lu^{-1}d^{-1}$	Derived from n values	Emission as %TAN	Source
Layers – deep-pit (cages, perchery, free-range)				
149	146		35.9	Groot Koerkamp *et al*., 1998 (perchery)
	184		45.2	Groot Koerkamp *et al*., 1997 (deep-pit)
	79	3	18.0	Peirson (1995) (deep-pit)
	139		33.1	WA0368 (deep-pit)
	197	6	46.8	WA0651 (belt-scraped, Bitteswell)
Layers – belt-cleaned (cages)				
60	36	3	4.0	Peirson (1995)
	79	6	23.9	WA0651 (weekly scraping)
	65	7	15.4	WA0651 (belt scraped, Bitteswell)
Broilers/all other poultry				
64	79		14.7	Demmers et al (1999)
	92	3	46.0	Peirson (1995, turkeys)
	44	4	4.8	Robertson et al. (2002)
	36	4	10.7	WA0651 (winter)
	67	2	10.3	WA0651 (summer)
	53	2	10.8	WA0651 (drinker study)

NARSES EF was derived as 37.4 %UAN for buildings housing laying hens in deep-pit or perchery systems and 16.5% belt cleaning (a reduction of 56%). For broilers the weighted mean is 8.1 %UAN.

Layers in cages – systems where manure is scraped from a collection shelf through a floor slot to a deep-pit are included in the cages deep-pit category. Measurements under WA0651 indicated that a much lower emission factor was obtained for a daily belt-cleaning system as compared with weekly cleaning. However, such frequent cleaning would not be practised on commercial farms and the value is therefore not included here.

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, no longer representative of current broiler housing, and was also based on a single measurement in time rather than an integrated measurement over the duration of the crop.

Storage

Storage losses can be divided into storage and 'break-out' (*i.e.* when loading to trailer/spreader takes place).

Storage losses

Mean EF **g N t^{-1} initial heap mass**	Values	Derived from n values	Emission as %TAN	Source
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)
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

UKAEI
Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES
NARSES EF were derived from weighted means as 17.8 %UAN for layer manure and 8.7% for poultry litter. Duck manure was assumed to have the same EF during storage as cattle FYM (35%).

DEER

Grazing

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

Land spreading

- Emission factor for cattle FYM used.

Housing

- Emission factor for sheep housing used.

Storage

- Emission factor for cattle FYM used.

HORSES

Mean EF of 10.6 kg NH_3-N per animal per year used, as for ‘other horses’ in non-agricultural emissions inventory (Sutton *et al*., 2000).

NARSES EF derived using reverse-engineering as 35 %TAN, based on the UKAEI EF.

CONSERVED GRASSLAND & TILLAGE

NARSES
A model based on Misselbrook et al. (2004) but modified according to data from the NT26 project is used to estimate EF for different fertiliser types:

- Ammonium nitrate (and ‘other N’ category) – a fixed emission factor of 1.8% N applied is now used as there was no consistent evidence of temperature, rainfall, land-use or crop height effects on emission. The only modifier applied is for direct placement of fertiliser into soil on tillage, where a reduction efficiency of 80% is assumed.
- Ammonium sulphate, diammonium phosphate – for this minor category of fertilisers, soil pH has an influence on emissions. The rules for ammonium nitrate are applied for applications to non-calcareous soils and the rules for urea are applied for applications to calcareous soils.
- Urea ammonium nitrate – a maximum EF of 23% is applied (from NT26 data-set) and the rules for urea applications are applied.
- Urea – EF is derived according to EF_{max}, application rate, rainfall and temperature. EF_{max}, is 45% (from NT26 data-set). The modifiers for application rate, rainfall and temperature were revised to be consistent with the NT26 model.
- 10% of fertiliser applied to tillage is assumed to be by soil placement
- Mean application rate of urea for a given application timing is assumed to be 60 kg ha^{-1} N (previously 120)

Sources of Activity Data

Animal numbers and weights

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

Livestock weights (required in UKAEI but not NARSES) are from ADAS unpublished data:

Animal	Weight (kg)
Dairy cow (inc. heifers)	550
Dairy heifer in calf	400
Beef cow (inc. heifers)	
Beef heifer in calf	
Bull	340
Others > 2 yr	
Others 1-2 yr	
Others < 1yr	140

Animal	Weight (kg)
Sow	200
Farrower	225
Boar	250
Fattener >110 kg	120
Fattener 20 – 110 kg	65
Fattener <20 kg	12
Layer	2.2
Broiler	0.9
Pullet	1.0
Breeding hen	2.0
All other poultry	4.0

Proportion of sheep in uplands from ADAS (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, June 2007. Manure TAN contents from expert opinion.

Proportion of waste produced as slurry or FYM from ADAS Surveys of Animal Manure Practices in the Dairy, Beef, Pig and Poultry Industries (Smith *et al*., 2000c, 2001a, 2001b).

Slurry TAN contents from Smith and Frost (2000) and Smith *et al*., (2000a) with 50 % of total N assumed to be ammoniacal-N. TAN contents of FYM assumed to be 10 % of total N for stored FYM and 25 % for FYM spread to land directly from the house, obtained from MAFF (2000), Tables 1 & 2. Poultry AUN contents from MAFF (2000).

Tonnage of poultry litter incinerated obtained directly from EPRL and Fibropower websites (K Smith, ADAS).

Manure output and N excretion by livestock category (2010 values)

Livestock type	Manure output kg d^{-1}		% manure produced as …		N excretion kg yr^{-1}	%TAN at excretion
	Slurry	FYM	Slurry	FYM		
Cattle						
Dairy cows & heifers	52.7	68.5	66	34	121.1	60
Dairy heifers in calf	31.9	41.5	66	34	67	60
Dairy replacements >2 yrs	31.9	41.5	18	82	56	60
Dairy replacements 1-2 yrs	25.8	33.5	18	82	56	60
Dairy bulls > 2 yrs	31.9	41.5	18	82	53	60
Dairy bulls 1-2 yrs	25.8	33.5	18	82	56	60
Dairy calves	14.5	18.9	0	100	38	60
Beef cows & heifers	31.9	41.5	18	82	79	60
Beef heifers in calf	25.8	33.5	18	82	56	60
Bulls >2 yrs	31.9	41.5	18	82	53	60
Bulls 1-2 yrs	25.8	33.5	18	82	56	60
Beef > 2 yrs	31.9	41.5	18	82	56	60
Beef 1-2 yrs	25.8	33.5	18	82	56	60
Beef calves	14.5	18.9	0	100	38	60
Sheep						
Ewes - lowland		5.3	0	100	10.5	60
Ewes - upland		5.3	0	100	9.9	60
Lambs - lowland		2.6	0	100	0.6	60
Lambs - upland		2.6	0	100	0.7	60
Goats					20.6	60
Deer					13	60
Pigs						
Maiden gilts	10.9	13.6	35	65	15.5	70
Sows			35	65	18.1	70
Boars	10.9	13.6	0	100	21.8	70
Fatteners >110 kg			33	67	15.4	70
Fatteners 80-110 kg			33	67	15.4	70
Fatteners 50-80 kg			33	67	13.3	70
Fatteners 20-50 kg			33	67	8.9	70
Weaners (<20 kg)	1.3	1.4	53	47	3.4	70
Poultry						
Laying hens (cages)		0.11	0	100	0.67	70
Laying hens (free-range)		0.11	0	100	0.75	70
Broilers		0.05	0	100	0.40	70
Pullet		0.02	0	100	0.33	70
Breeding Hens		0.11	0	100	1.02	70
Turkeys (m)		0.09	0	100	2.18	70
Turkeys (f)		0.09	0	100	1.46	70
Ducks		0.09	0	100	1.71	70
Horses			0	100	50	60

Manure volume output data derived from Smith et al. (2000c, 2001a, 2001b) with interpretation for animal place and annual outputs by K Smith (ADAS). Nitrogen excretion data from project WT0715NVZ with interpretation by B Cotteril and K Smith (ADAS).

Land spreading

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

Proportion of slurry in each dry matter category from ADAS unpublished (K Smith, B Chambers).

Housing

Proportion of animals in each housing type - cattle from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), pigs from Sheppard (1998, 2002). Proportion of pigs outdoors from Sheppard (1998, 2002). Poultry housing and % manure dropped outdoors provided by A Elson (ADAS). Regular revisions are made using data from the Farm Practices Surveys (England). Although surveys are often only for England or England and Wales, data are extrapolated across the whole UK.

Cattle housing

	Smith et al 2001 2000	FPS2010 2010
Dairy cows kept on slurry (%)	66%	83%
Dairy followers kept on slurry (%)	18%	35%
Beef cattle kept on slurry (%)	18%	17%

Beef cattle on slurry are kept at a constant 18%. Values for dairy cows and dairy followers on slurry are interpolated between 2000 and 2010 and are assumed fixed before and after these years.

Cattle housing periods obtained from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), with housing period of milking dairy cattle extended to account for time in for milking during the summer months. For sheep, ewes indoors for 30 d, lambs not indoors at all. Poultry and pigs assume 100 % occupancy as June census takes a snapshot of animal numbers which will reflect the actual % occupancy.

Pig housing

	Smith et al., 2000c	Sheppard 1998	Sheppard 2002	FPS2009	FPS2009
	1993	1998	2002	2006	2009
Dry sows on full slats (%)	3%	3%	3%	1%	2%
Dry sows on part slats (%)	24%	22%	22%	2%	10%
Dry sows on straw (%)	52%	47%	47%	68%	47%
Dry sows outdoors (%)	20%	28%	28%	29%	41%
Farrowing sows on full slats (%)	13%	11%	10%	10%	12%
Farrowing sows on part slats (%)	48%	42%	39%	17%	22%
Farrowing sows on straw (%)	20%	18%	17%	46%	23%
Farrowing sows outdoors (%)	20%	30%	34%	27%	43%
Boars on full slats (%)	0%	0%	0%	0%	0%
Boars on part slats (%)	0%	0%	0%	0%	0%
Boars on straw (%)	80%	72%	72%	72%	72%
Boars outdoors (%)	20%	28%	28%	28%	28%
Fatteners (20-110kg) on full slats (%)	25%	15%	15%	18%	9%
Fatteners (20-110kg) on part slats (%)	25%	20%	20%	26%	25%
Fatteners (20-110kg) on straw (%)	50%	64%	64%	53%	64%
Fatteners (20-110kg) outside (%)	0%	1%	1%	3%	2%
Weaners (<20kg) on full slats (%)	35%	27%	24%	19%	9%
Weaners (<20kg) on part slats (%)	55%	23%	20%	25%	27%
Weaners (<20kg) on straw (%)	10%	50%	45%	40%	43%
Weaners (<20kg) outside (%)	0%	1%	11%	16%	21%

Data are interpolated between years to derive the trend. FPS2010 gives some information on pig housing types, but does not break down into sub-categories of pig.

Poultry housing

	Smith et al., 2001a 2000	FPS2009 2009	FPS2010 2010
Layers free-range (%)	13%		44%
Layers in perchery (%)	5%		7%
Layers free-range/perchery on BAT	0%		1%
Layers in cages, deep-pit (%)	57%		25%
Layers in cages, belt-cleaned (%)	25%		24%
Broilers free-range (%)	1%	7%	
Broilers indoors, standard housing (%)	99%	74%	
Broilers indoors, reduced emission housing (%)	0%	19%	
Pullets free-range (%)	10%	6%	
Pullets indoors, standard housing (%)	90%	70%	
Pullets indoors, reduced emission housing (%)	0%	24%	
Breeding hens free-range (%)	10%	1%	
Breeding hens indoors, standard housing (%)	90%	99%	
Breeding hens indoors, reduced emission housing (%)	0%	0%	
Turkeys free-range (%)	10%	18%	
Turkeys indoors, standard housing (%)	90%	73%	
Turkeys indoors, reduced emission housing (%)	0%	9%	
Ducks free-range (%)	10%		
Ducks indoors, standard housing (%)	90%		
Ducks indoors, reduced emission housing (%)	0%		

FPS2009 data for laying hens was considered to be insufficiently robust (free-range laying hens were estimated at 5%, far below industry and expert opinion).

Storage

Proportions of manure stored in different store categories derived from Farm Practices Surveys.

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.

Hard standings

UKAEI input data

Usage derived from survey conducted under WA0528 (Webb *et al.*, 2001) and from NT2402†.

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.

Fertiliser

Fertiliser usage in England, Wales and Scotland derived from British Survey of Fertiliser Practice 2008 (http://www.defra.gov.uk/environ/pollute/bsfp/index.htm) and for Northern Ireland from DARDNI stats (http://www.dardni.gov.uk/econs/.htm).

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DEFRA Projects

Final reports from the following projects are available from DEFRA

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
KT0106	MANNER - Policy Support Model (MANNER-PSM)
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
NT2605	The behaviour of some different fertiliser-N materials - Main experiments
OC9117	Ammonia emission and deposition from livestock production systems
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
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