Modelling and mapping UK emissions of ammonia, methane and nitrous oxide from agriculture, nature, waste disposal and other miscellaneous sources for 2009

Dragosits U. and Sutton M.A.

Centre for Ecology & Hydrology (Edinburgh Research Station)
Bush Estate, Penicuik, Midlothian, EH26 0QB, UK.

April 2011

Client: AEA Technology	
Client Project number: 14714779	CEH Project number: C03614
Project Title: National Atmospheric Emissions Inventory (NAEI) and Greenhouse Gas Inventory (GHGI)	
Start date: 1/10/2008	Completion date: 30/09/2011
Client Project Officers: Anne Wagner (AEAT) for Defra	
CEH Project Officer: Ulli Dragosits(NH_3, CH_4, N_2O)/Amanda Thomson (LULUCF)	
Main authors: Dragosits U. and Sutton M.A.	
Reporting period: 05/10 – 04/11	
Report date: 01/04/2011	

EXECUTIVE SUMMARY

Modelling and mapping UK ammonia emissions from agriculture, nature, waste disposal and other miscellaneous sources for 2009

1. Ammonia emission estimates for 2009 were spatially distributed for agriculture (SNAP Codes 10.1, 10.2 and 10.5), natural sources (SNAP Codes 11.3, 11.7), waste disposal (SNAP Code 9.4), sewage works and sewage sludge spreading (SNAP Code 9.10), solvents (SNAP Code 6.4) and other miscellaneous sources for the UK.

2. Emissions from non-agricultural sources such as waste disposal, sewage, solvents, pets, composting, biomass burning, wild animals and seabirds as well as humans were spatially distributed through a combination of population census data, landcover data, data on landfill and sewage, mammal distribution data from the Biological Records Centre (BRC), seabird census data (Seabird2000 survey, JNCC), locations of composting plants, golf courses, public parks & gardens, etc.

3. Overall, non-agricultural NH_3 emissions from sources estimated by CEH under the current contract (covered by SNAP codes 6, 9, 10 and 11) amount to 40.8 kt NH_3-N year^{-1} for 2008, with a range of 18.4-82.9 kt NH_3-N year^{-1}. This constitutes an increase of 3.1 kt NH_3-N yr^{-1}, compared with the estimate for the same sources for 2008 (37.7 kt NH_3-N yr^{-1}).

4. The main changes in non-agricultural emissions between 2008 and 2009 are increased emissions from non-agricultural horses and composting, and a decrease of emissions from landfill due to less material being land-filled. The latter two developments are linked, with materials being diverted from landfill to composting plants for recycling.

5. The UK estimate of NH_3 emissions from UK agriculture increased by 2.3 kt NH_3 between 2008 and 2009, with 229.5 and 231.8 kt NH_3 emitted, respectively. This includes decreases in livestock emissions by 1.9 kt NH_3 and increases in fertiliser emissions by 4.2 kt NH_3. The changes are mainly due to decreases in livestock numbers for most sectors and slightly increased fertiliser N application rates, combined with a higher proportion of urea fertiliser being used.

6. Emission source strength data for non-agricultural NH_3 sources were used as reported in Dragosits and Sutton (2011a) and agreed with AEAT under the NAEI/GHGI project in early 2011.

7. Emission source strength data for CH_4 and N_2O were used as reported to Defra under the NAEI/GHGI project for 2009 for all agricultural and non-agricultural sources, and all maps correspond to the totals reported.

8. Agricultural NH_3, CH_4 and N_2O maps (livestock manures, enteric fermentation, soils, fertilisers) were submitted to the NAEI/GHGI under Defra contract AC0112 (Dragosits and Sutton 2011b), but are included in this report for completeness. These maps were derived from output of the CEH/University of Edinburgh AENEID model, which incorporates agricultural census data, landcover data, agricultural practice information (e.g. fertiliser application rates, stocking densities) and emission source strength data. The latter are closely coordinated with the UK agricultural emissions inventories for NH_3, CH_4 and N_2O in 2009 calculated annually at North Wyke Research (Misselbrook *et al.* 2010, Cardenas *et al.* 2010).

CONTENTS

1. INTRODUCTION

1.1. Background NH_3

Emissions of ammonia for 2009 were spatially distributed using the AENEID model (Dragosits *et al*. 1998, Hellsten *et al*. 2008) and mapped for the UK for SNAP codes 6 (use of solvents), 9 (waste disposal, excluding incineration), and 11 (other sources and sinks, including natural sources) under this contract. This report briefly describes the methodology used for the sources listed above, including any changes in the methodology and the consequences of these changes.

The spatial distribution of emissions from agriculture is not part of the current contract between CEH and AEA, but is being carried out under Defra Project AC0112 in collaboration Rothamstead Research North Wyke Research. As part of AC0112, the final emission maps for ammonia (NH_3) from agricultural sources (livestock, fertilisers) are submitted for inclusion in the National Atmospheric Emissions Inventory (NAEI) annually (Dragosits and Sutton 2011b). A short summary on the methods and results for the agricultural sources is included in this report.

The spatially distributed NH_3 emissions for non-agricultural sources are coordinated with the best estimates produced by CEH and AEA and submitted to Defra (by AEA) under this project in late 2010 (see Table 1). The agricultural emission estimates from fertilisers and livestock are coordinated with results from Defra project AC0112 (NH_3 inventory by Misselbrook *et al*. (2010); see also Table 1).

The current contract exploits the expertise of CEH in spatially distributing emissions from agricultural sources, nature and other miscellaneous sources (e.g., Sutton *et al.* 2000), and complements the expertise of AEAT regarding combustion, industry and transport sources.

Table 1: UK ammonia emissions (SNAP Codes 6, 9, 10, 11) as collated by AEAT from Rothamstead Research North Wyke and CEH data for 2009.

Source	SNAP Code	Best estimate (kt NH_3)
Human breath & sweat, babies' nappies and smoking	0	1.2
Appliances &household products (solvents)	6.4	1.2
Sewage works and sewage spreading	9.10	5.5
Landfill	9.4	2.5
Agricultural fertilizers	10.1	36.0
Composting	10..2	4.6
Livestock manures	10.5	195.8
Biomass burning	11.3	0.5
Pets and non-agricultural horses	11.7.2	22.8
Nature (wild mammals, seabirds, pheasants)	11.7.3	7.2
Public parks, gardens and golf courses	0	0.8

1. Background CH_4 and N_2O

Emissions of methane (CH_4) and nitrous oxide (N_2O) for 2009 are spatially distributed using the greenhouse gas version of the AENEID model (Dragosits *et al*. 1998, Sutton *et al*. 2004 and 2006) and mapped for the UK for SNAP codes 9 (waste disposal, excluding incineration), 10 (agriculture) and 11 (other sources and sinks, including natural sources).

As for NH_3, emissions from agricultural sources were modelled under Defra Project AC0112 in collaboration with Rothamstead Research, North Wyke (i.e., not as part of the current project with AEA), but are submitted to AEA for inclusion in the Greenhouse Gas Inventory (GHGI) and are therefore discussed briefly in here. This report describes the methodology used for the sources listed above, presents the results and discusses uncertainties.

Non-agricultural emission estimates are coordinated with the values submitted to Defra under this project for 2009 (see Table 2).The agricultural emission estimates (enteric fermentation, livestock manures and soils) are coordinated with detailed results from the CH_4 and N_2O inventories by Rothamstead Research, North Wyke (Cardenas *et al*. 2010; see Table 2), derived following the IPCC methodology.

Table 2: CH_4 and N_2O emission sources as reported to Defra, for 2009.

Source	kt CH_4	kt N_2O
Waste disposal to land (landfill)	755.7	-
Sewage sludge decomposition	16.0	4.4
Agriculture-soils (including sewage sludge applied to agricultural land)	-	80.3
Agriculture-livestock manures	133.3	6.4
Agriculture-enteric fermentation	718.7	-
Peat & wetlands	126.3	-

1.3. Summary of work schedule/deliverables

- Task 1: To model, map and submit spatially distributed emissions of NH_3, CH_4 and N_2O from selected non-agricultural sources at a 5km grid resolution and SNAP level 2, and to convert results for Northern Ireland to the Ordnance Survey GB grid
- Task 2: To provide a description of the methodology, highlighting changes and their consequences.
- Spatially distributed emissions from agricultural sources of NH_3, CH_4 and N_2O are produced outwith this contract (by Defra project AC0112), but are submitted to AEA for inclusion into the NAEI/GHGI.

2. METHODS

2.1. Spatial distribution of emissions from agricultural sources - SNAP Code 10

Agricultural census/survey data for 2009 were acquired at the finest available spatial resolution from the devolved authorities in the UK and aggregated to a common set of categories, referred to as the “NARSES categories” (see Appendix A), to ensure compatibility between the different countries’ systems.

The agricultural emission inventory for NH_3 was mapped using output from the NARSES model at Rothamstead Research, North Wyke (Misselbrook *et al*. 2010, Cardenas *et al*. 2010, Defra project AC0112). As in previous years, detailed emission source strength estimates were derived for the main livestock emission components (housing, manure storage, landspreading of manures, grazing) for each NARSES category. Average fertiliser N application rates to different crops were taken from the British Survey of Fertiliser Practice for 2009 (BSFP 2010). For CH_4 and N_2O emissions, the greenhouse gas version of AENEID was used, which builds on the same input datasets but takes account of the spatial location of CH_4 and N_2O sources.

These detailed data were applied in the AENEID model, and livestock and fertiliser emissions were distributed to different land cover types (e.g. arable land, improved grass, part-improved grass, rough grazing, etc.) derived from the CEH landcover map (LCM2000).

The resulting spatially distributed emission estimates were then aggregated as follows:

- NH_3: emissions from **livestock manures** and **fertilisers**,
- CH_4: emissions from **enteric fermentation** and **livestock manures**
- N_2O: emissions from **livestock manures** and **soils**

All output data were checked for consistency with the NARSES inventory and then aggregated to the categories listed in Tables 1 and 2 (above). It should be noted that N_2O emissions from the application of livestock manures are included in the "soils" category, rather than with livestock manure emissions, as is usual for NH_3.

2.2. Spatial distribution of emissions from non-agricultural sources (SNAP Codes 6, 9 and 11)

2.2.1. Emissions of NH_3 from household products (solvents) – SNAP Code 6.4

The most suitable spatial distribution for these sources is to scale by population (UK Population Census 2001, adjusted to account for mid-2010 population estimates), considering that emissions occur from normal household activities such as cleaning with products containing ammonia, hair perming, levelling floors using latex screed, refrigerants etc.

2.2.2. Emissions of NH_3 and CH_4 from landfill – SNAP Code 9.4

For the spatial distribution of ammonia emissions from landfill sites, the composition of land-filled materials was assumed to be equal across the UK. For Scotland, locations and size of landfill sites were available from the Scottish Environmental Protection Agency for 2009 (SEPA 2010). For Northern Ireland, no locations of landfill sites were available, thus emissions were mapped using population density data, but excluding areas with a population density greater than 1000 people per square kilometre, as an approximation. For England and Wales, data from the Environment Agency (EA) website (http://www.environment-agency.gov.uk) were used. Emissions of CH_4 were calculated by scaling the 2009 NH_3 emission map to the CH_4 total provided for 2009 by AEA.

2.2.3. Emissions of NH_3, CH_4 and N_2O from sewage – SNAP Code 9.10

For the spatial distribution of emissions from **sewage works**, locations of sewage treatment works used from the Environment Agency website for England and Wales, complete with OS Grid references and population equivalents of sewage processing capacity. Together, the recorded sewage works covered a total of 21,182,680 population equivalents, which corresponds to ~ 40% of the population of England and Wales. These sewage works are covered by the Urban Waste Water Treatment Directive, and include only works larger than 10,000 population equivalents. Also, the population equivalents listed do not reflect the amount of sewage processed at the works exactly, but are an indication of the available capacity, and other (non-domestic) sewage will be treated at these locations to a varying extent.

There are also considerable rural areas with low-density housing, where septic tanks are used rather than sewage works. The rest of the population is assumed to be covered by smaller sewage works not registered on the EA website. Currently, there are no estimates of NH_3 emissions from septic tanks, which is an area needing further investigation in the future. A spatial assessment of sewage work capacities and population density was carried out, and sewage emissions were spatially distributed by population in areas found to have insufficient coverage by works registered with the EA. Emissions from the sewage works registered with the EA were mapped using the population equivalents supplied. For Scotland and Northern Ireland, emissions from sewage works were spatially distributed by population, excluding densely populated inner-city areas and areas with very low population density, due to lack of spatial data on sewage works.

Landspreading of sewage sludge has increased since the ban on dumping of sewage sludge in the sea in 1999. Only treated sewage is permitted to be spread, and is used on grass, forage crops (excluding crops grown for human consumption such as vegetables), for land reclamation and nutrient supply in areas of afforestation. However, only a small part of the agricultural area of the UK receives sewage sludge at present. It is not possible to spatially-distribute ammonia emissions from the landspreading of sewage sludge to exactly where they occur, due to the lack of data. Thus, as an approximation, emissions were distributed over all grassland, arable land and areas of coniferous woodland, using a combination of agricultural census and landcover data. Emissions of CH_4 and N_2O from landspreading of sewage sludge were spatially distributed by scaling from NH_3 emissions.

2.2.4. EMISSIONS OF NH_3 FROM COMPOSTING – SNAP CODE 10.2.

The comprehensive survey of composting facilities in the UK by the Composting Association for 2008/2009 (Stone *et al.* 2010) contains data from several hundred composting sites in the UK, including amounts and types of materials composted, processes used, etc. The best available data source was a list of producers from the certification scheme of the Association for Organics Recycling (formerly known as the Composting Association, www.organics-recycling.org.uk). Postcodes for approx. 200 sites on this list (status May 2010) were converted to OS grid coordinates for the 2009 inventory, and the UK total of 4.6 kt NH_3 for 2009 (Dragosits and Sutton 2011a) was distributed across these sites, depending on amounts and types of materials and processes recorded.

2.2.5. EMISSIONS OF NH_3 FROM DOMESTIC ANIMALS AND NATURE – SNAP CODE 11.7

Separate emission maps were produced for non-agricultural horses and pets (cats & dogs) and nature (wild mammals, seabirds and pheasants).

Emissions from **non-agricultural horses** (i.e., horses that are not already counted with the annual agricultural census) were distributed using a combination of landcover data (LCM2000) and population census data. Emissions from **pets (cats and dogs)** were scaled by population, assuming an even distribution of pets over the UK population, except for densely populated urban areas, where it was assumed that fewer pets were present per human population. It should be noted that populations of wild or semi-wild horses and ponies in areas such as Dartmoor, Exmoor or the New Forest are not mapped specifically, and that the methodology used is a statistical approximation from secondary data (human populations and landcover) at a UK scale.

Emissions from **wild animals** (deer, seals, rabbits and hares, foxes, badgers and feral cats) were distributed for Great Britain using 10 km presence/absence maps from the Biological Records Centre (BRC) based at CEH Monks Wood, landcover data (LCM 2000) and data for Scottish populations of wild deer (Hunt 2003).

Emissions from **pheasants** were included in the "nature" category. The spatial distribution was derived from a combination of landcover data (feeding of pheasants occurring in woodlands) and a county map of numbers of pheasants shot, provided by the Game Conservancy Trust.

Emissions from **seabirds** were spatially distributed according to the approach of Wilson *et al.* (2004a, 2004b). There was no change to these data, compared with the 2007 and 2008 inventory, so the 2007 map was carried forward unchanged.

Emissions from **wild geese** are ideally mapped using either geo-located bird counts from the Wetland Birds Survey or atlas data, neither of which were available in time for the submission deadline. Negotiations for these datasets are ongoing, and it is anticipated that they will be available for the next inventory mapping cycle. As a surrogate, the emissions were distributed over suitable landcover categories from the CEH Landcover Map (LCM2000), representing suitable geese habitats, such as "fen, marsh, swamp", some grassland categories etc.

Emissions from the sources described above were aggregated to a) non-agricultural horses and pets and b) natural sources for inclusion in the NAEI.

2.2.6. EMISSIONS OF NH_3 FROM BIOMASS BURNING (MUIRBURN) – SNAP CODE 11.3

Emissions from biomass burning were revised completely for the 2007 inventory, with burning of straw and stubble having been phased out. The revised estimate focuses on controlled burning of patches of heather ("muirburn"), a practice used in upland areas to encourage heather growth. In the UK, approximately 3,000 km^2 of heather are estimated to be managed by controlled burning on a rotational basis (muirburn"). The practice of muirburn involves controlled burning of heather in the uplands, approx. every 10-15 years, in patches, to encourage fresh growth on grouse moors and for sheep grazing. This new source is described in detail in Dragosits *et al.* (2009). Emissions of NH_3 from muirburn were spatially distributed over suitable landcover categories from the CEH Landcover Map (LCM 2000), i.e., dwarf shrub heaths. As the spatial distribution of these emissions is not based on actual year-to-year spatial data of exact locations where muirburn occurred, but on the statistical likelyhood of present moorland potentially being burned, the 2007 map was carried forward unchanged.

2.2.7. EMISSIONS OF CH_4 FROM PEAT AND WETLANDS – SNAP CODE 11.4

The most suitable simple spatial distribution for this source is to scale by the distribution of relevant landcover categories according to the CEH landcover map (LCM2000), and to assume an equal distribution of emissions per unit area of peatland and wetland. Emissions from this source were aggregated to a 5 km grid resolution for inclusion in the GHGI, and checked against the total derived using calculations derived from Hargreaves and Fowler (1998).

2.2.8. EMISSIONS OF NH_3 FROM PUBLIC PARKS, GARDENS AND GOLFCOURSES – SNAP CODE 0.0

Emissions from nitrogen fertilisers applied to public parks, gardens and golfcourses were included in the NAEI for the first time in 2008 (Dragosits *et al*. 2010). The detailed spatial distribution of these emission sources was kept unchanged for 2009, however, revised emission factors from Dragosits and Sutton (2011a) were applied.

2.2.9. EMISSIONS OF NH_3 FROM OTHER SOURCES (HUMANS) – SNAP CODE 0.0

Emissions from humans (breath and sweat, cigarette smoking, babies' nappies) were scaled by population, assuming an equal distribution of these sources within the UK population. Emissions from these sources are provided at a 1km grid resolution for inclusion in the NAEI.

3. RESULTS –EMISSION MAPS OF NH_3, CH_4 AND N_2O FOR 2009

3.1. Improved spatial resolution of the inventory maps

An additional task under this project was to investigate the possibility to improve the spatial resolution from a 5 km by 5 km grid resolution to a 1 km by 1 km grid resolution, where feasible. There were several issues to consider, with the three main constraints being:

- resolution of input data used for spatial distribution of emissions
- data licensing and permissions/disclosivity of underlying data sources
- uncertainty due to methodology of spatial distribution and input data quality

For sources where detailed spatial data are freely available and no major uncertainties need to be considered, emissions were mapped at a 1 km grid resolution for 2009.

Emission sources that are mapped by scaling with the 1 km population census map, such as human breath, sweat, pets, or household products, were mapped at a 1 km grid resolution, as there are no restrictions on use of the data or concerns about significant uncertainties associated with the spatially distributed emissions.

The combined dataset from the sources under the heading "Nature" (wild mammals, seabirds, etc) is provided at a nominal 1 km resolution, with the different contributing components combined at their respective best possible spatial resolution. Some datasets are provided at a coarse resolution, e.g., mammal distributions from the Biological Record Centre, where a 10 km by 10 km grid is the best available resolution. By contrast, for other sources mapped with auxiliary landcover data, an improved resolution of the NH_3 emission map to a 1 km grid resolution was feasible.

Other sources, such as biomass burning (muirburn), or land spreading of sewage sludge, are mapped by using landcover data (CEH Landcover map, LCM2000) as a proxy, with muirburn practice (a very small source of emissions in the UK context) being evenly distributed over suitable landcover types. However, this is not representative of real year-on-year burning events, as individual patches are, on average, only managed periodically, every 10-20 years. Land spreading of sewage sludge is limited to certain types of land cover/land use (see Section 2.2.3 above), but as there are no UK-wide data on precise locations, the emissions had to be apportioned over all potentially used land. The resulting maps are the best possible distribution, without expending substantial additional effort that would be disproportionate to the amount of NH_3 emitted from these sources. Due to the uncertainty associated with the maps, any increase in spatial resolution would provide a merely cosmetic improvement, without any scientific justification. Instead, it could potentially be counter productive, as users of the data may take the spatial resolution at face value.

Emissions from landfill and composting are currently distributed using incomplete sets of spatially located sources. For instance, detailed landfill site locations with amounts of materials land-filled per site are available routinely from SEPA, with data for the other parts of the UK of different quality/completeness and age. At present, the spatial distribution is considered too uncertain to increase the spatial resolution beyond the current 5 km by 5 km grid, as this may create unrealistic hot spots. However, work is underway for this source, to improve data access and subsequently to decrease the uncertainty in this map.

In conclusion, there were no scientific or data permission obstacles for emissions from humans, solvents, parks & golf courses, and nature to be provided at a true 1 km grid resolution (depending on resolution of available input data for individual sub-sources). For other datasets, such as landfill emissions (CH_4 and NH_3), work is underway to improve the underlying datasets. Once this is completed satisfactorily, it should be possible to provide these maps at a 1 km grid resolution. For sources such as biomass burning or land spreading of sewage sludge, the spatial location of sources is very difficult to derive, even indirectly by using proxy datasets, and for these an increase in resolution is not recommended, due to the inherent uncertainty.

The datasets of agricultural emissions of NH_3, CH_4 and N_2O are modelled independently under a separate project (Defra AC0112), but are submitted for inclusion in the NAEI & GHGI here. These data are reliant upon access to detailed disclosive agricultural census/survey data from the devolved authorities of the UK, with strict rules agreed for the level of detail of any output under the Data Protection Act. For this reason, the current 5 km by 5 km grid resolution is the best resolution possible for the foreseeable future.

3.2. Ammonia emission maps for 2009

In a change to previous years, all datasets were produced at a 1 km grid resolution for the UK for 2009. Please note that this is a nominal 1 km resolution for some sources, as detailed in Section 3.1 above. The following maps are shown below (units: kg NH_3 ha^{-1} $year^{-1}$):

- Figure 1. livestock manures – SNAP Code 10.5
- Figure 2. agricultural and non-agricultural fertilisers – SNAP Code 10.1
- Figure 3. biomass burning – SNAP Code 11.3
- Figure 4. household products (solvents) – SNAP Code 6.4
- Figure 5. landfill – SNAP Code 9.4
- Figure 6. sewage works and landspreading of sewage sludge – SNAP Code 9.10
- Figure 7. human breath and sweat, smoking and babies' nappies – SNAP Code 0.0
- Figure 8. nature (wild mammals, seabirds, pheasants) – SNAP Code 11.7
- Figure 9. composting – SNAP Code 10.2
- Figure 10. non-agricultural horses and pets (cats, dogs)
- Figure 11. parks, gardens and golf courses

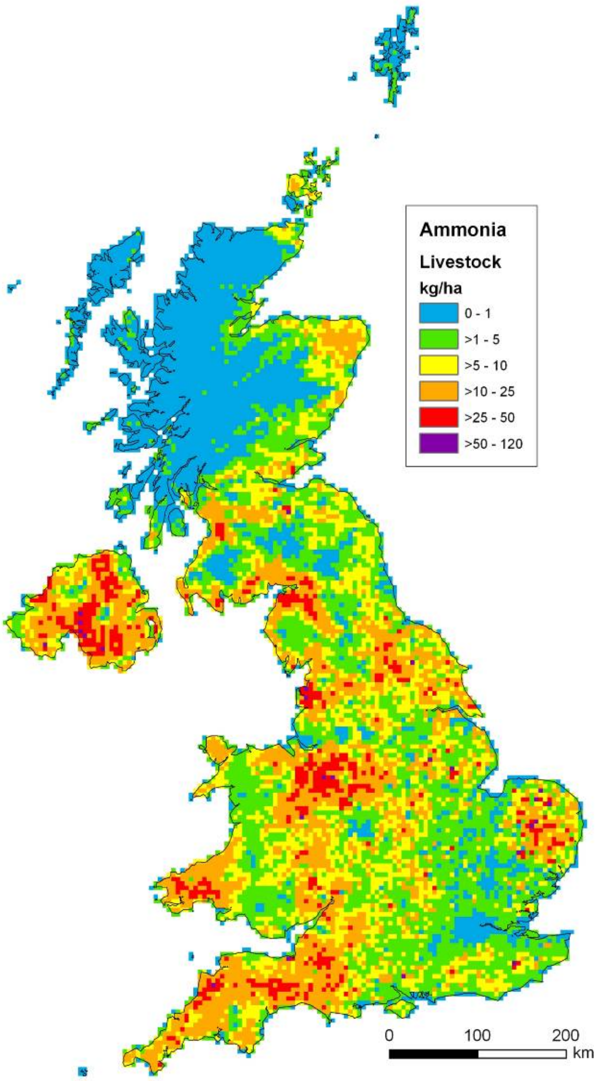

Figure 1. Ammonia emissions from livestock manure

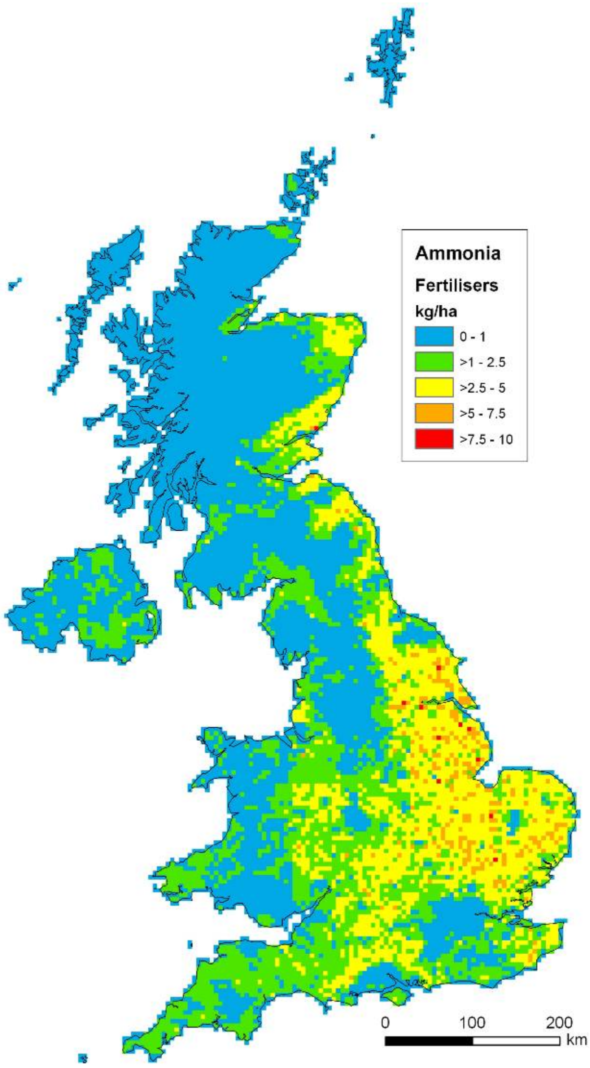

Figure 2. Ammonia emissions from fertilisers

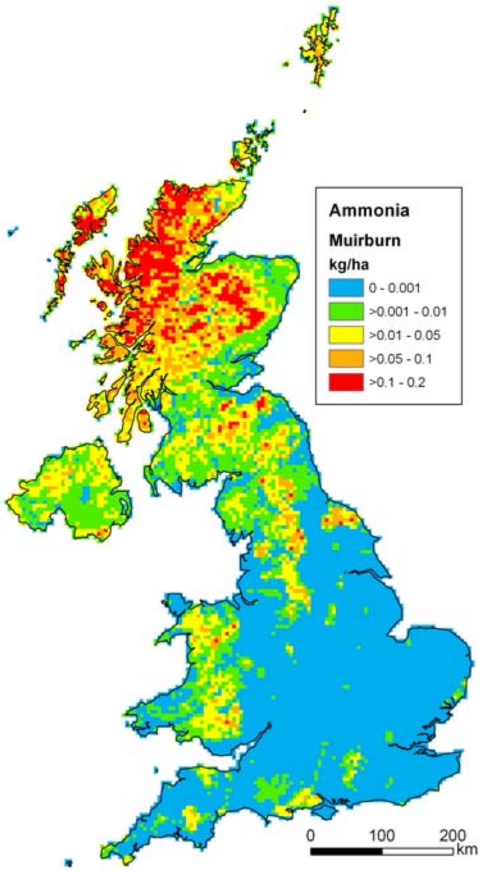

Figure 3. Ammonia emissions from biomass burning

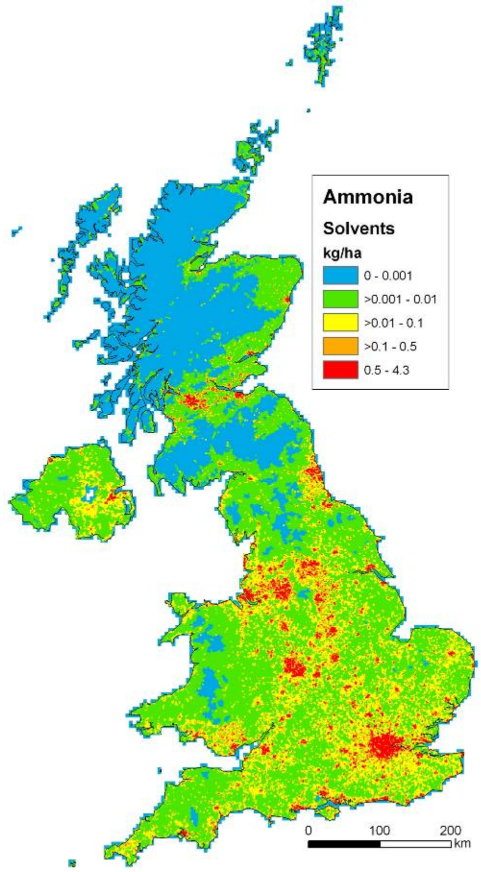

Figure 4. Ammonia emissions from solvents

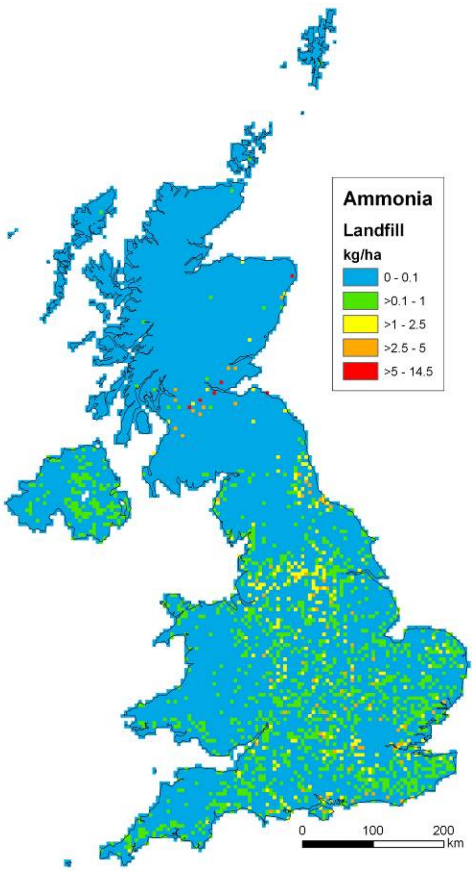

Figure 5. Ammonia emissions from landfill

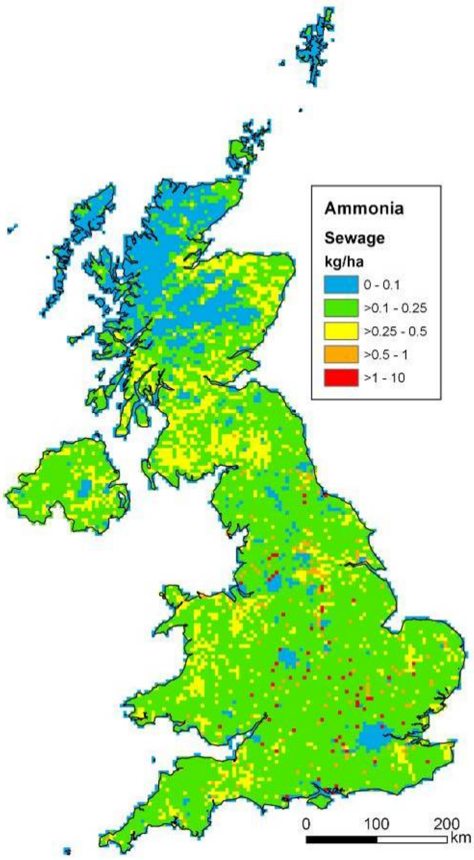

Figure 6. Ammonia emissions from sewage

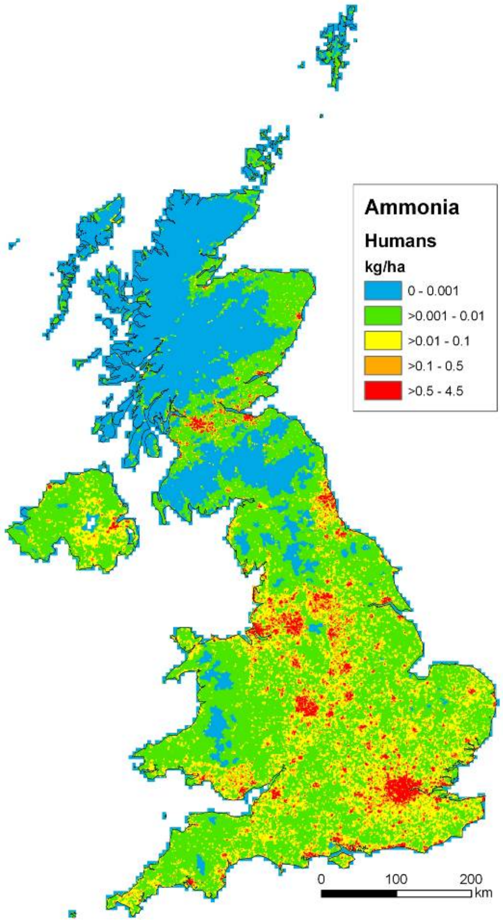

Figure 7. Ammonia emissions from humans

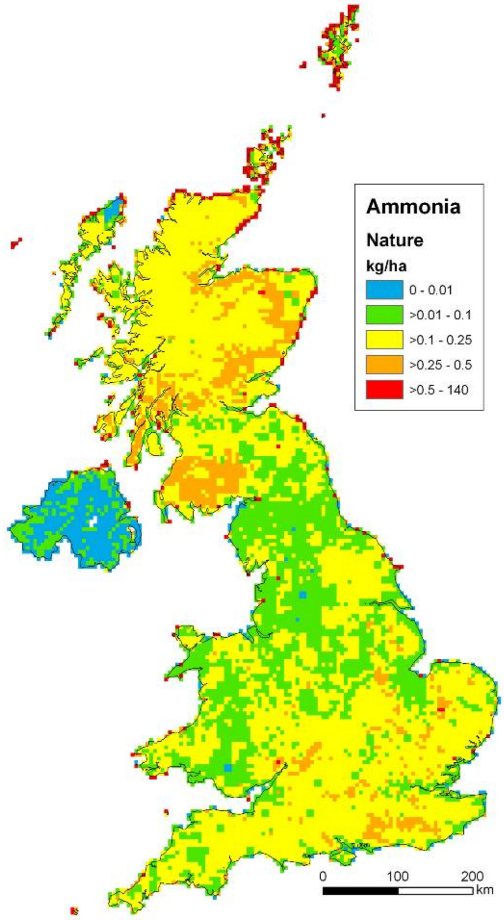

Figure 8. Ammonia emissions from nature

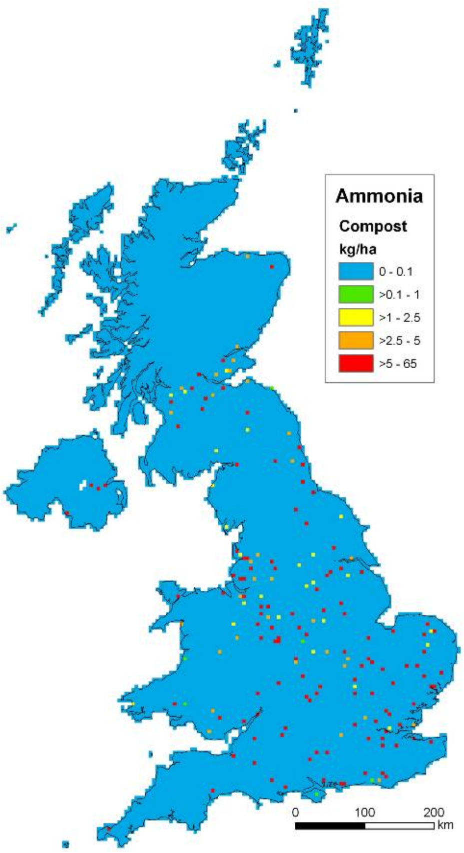

Figure 9. Ammonia emissions from composting plants

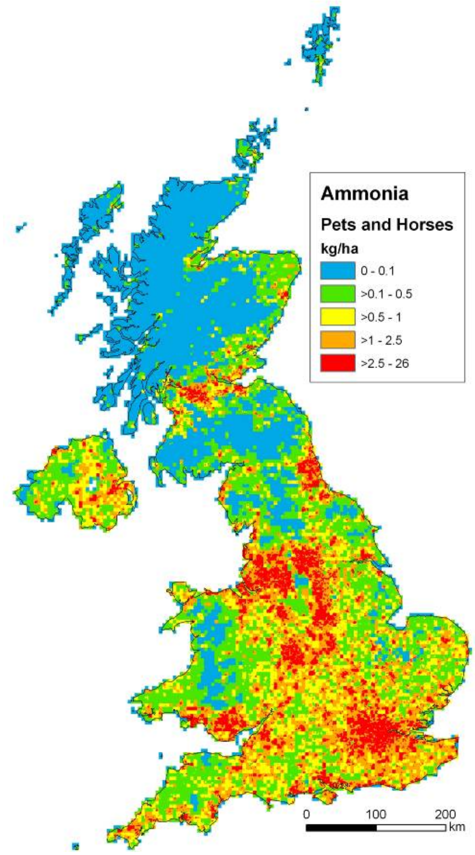

Figure 10. Ammonia emissions from pets (cats and dogs) and non-agricultural horses

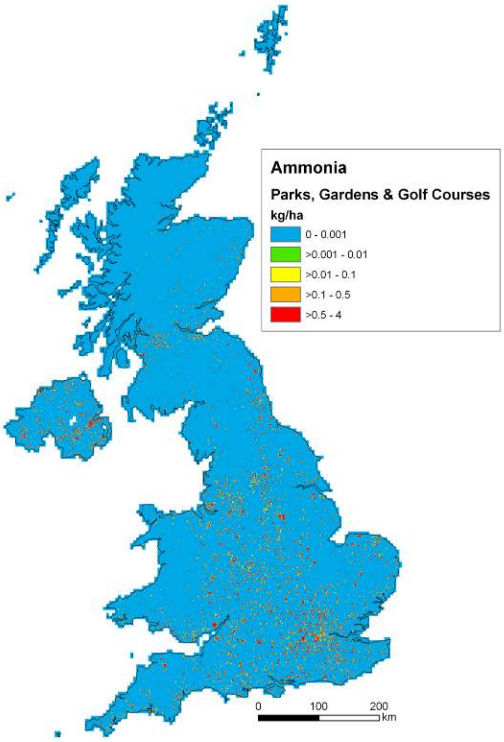

Figure 11: Ammonia emissions from parks, gardens and golf courses

3.2. Methane and nitrous oxide emission maps for 2009

The following spatial datasets were produced for the UK for 2009 and are mapped below (Figures 11-18); units: kg CH_4 and N_2O ha^{-1} year^{-1}, respectively):

- livestock manures (CH_4, N_2O)
- enteric fermentation (CH_4 only)
- agricultural soils (crops/ grasslands etc.) (N_2O)
- nature (peat & wetlands, (CH_4 only))
- landfill (CH_4 only)
- land spreading of sewage sludge (CH_4, N_2O)

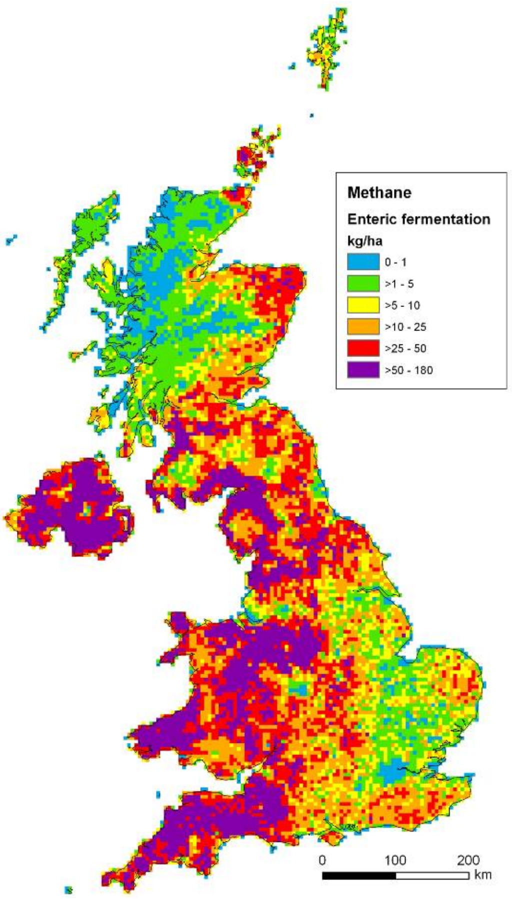

Figure 11. Methane emissions from enteric fermentation

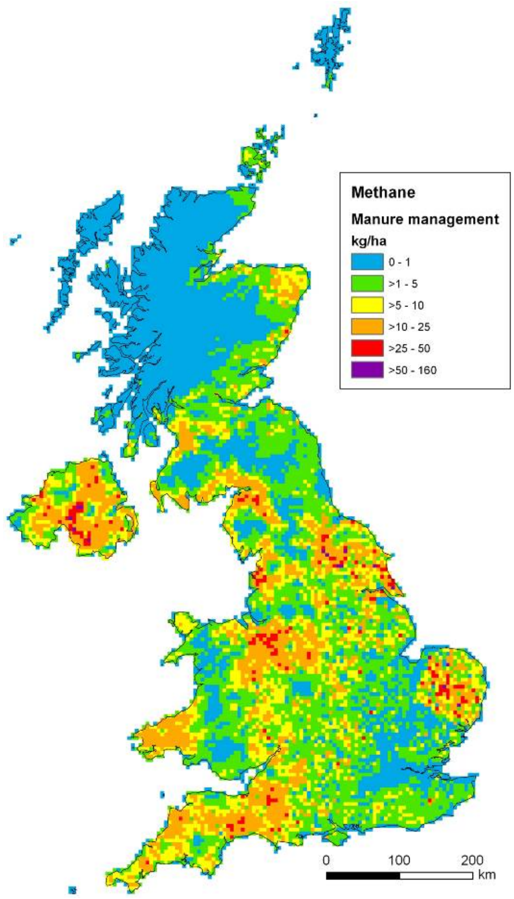

Figure 12. Methane emissions from livestock manure

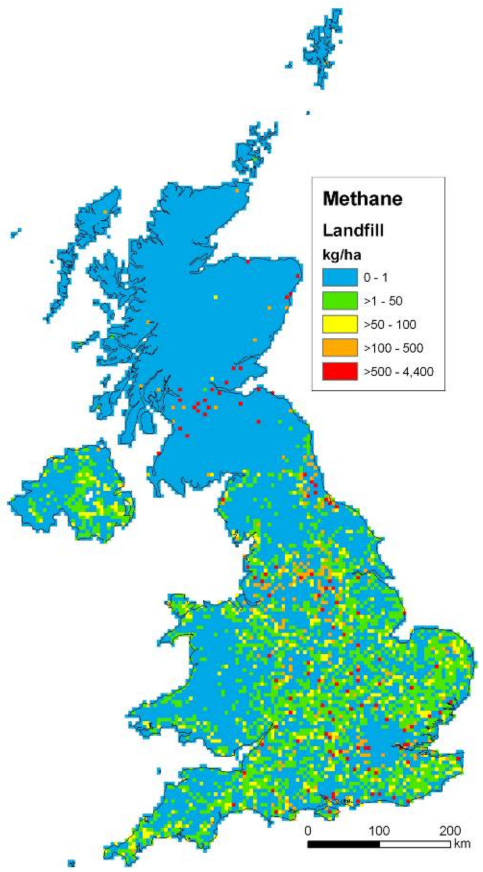

Figure 13. Methane emissions from landfill

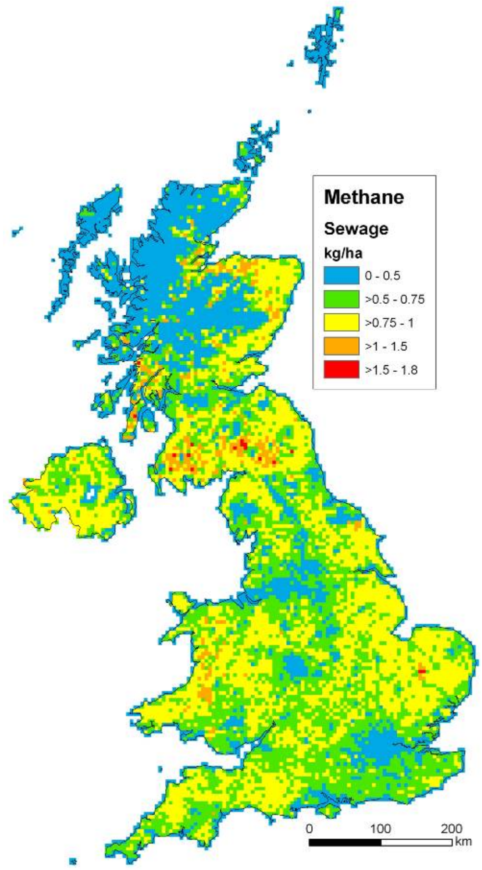

Figure 14. Methane emissions from sewage spreading

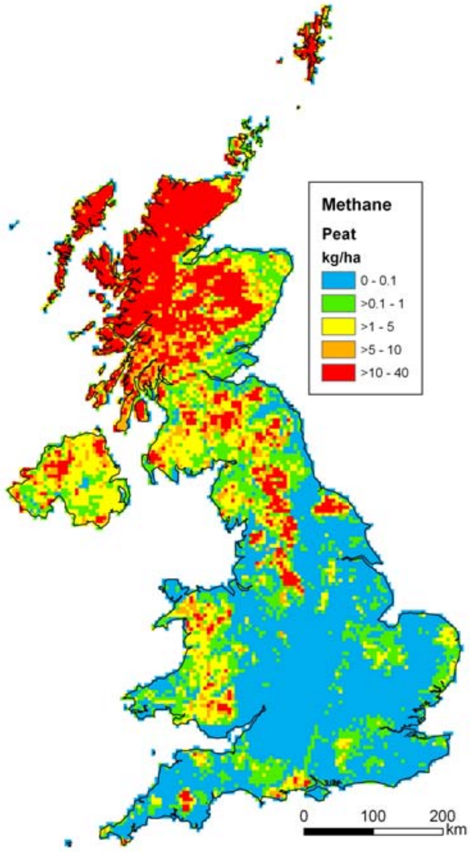

Figure 15. Methane emissions from peatland

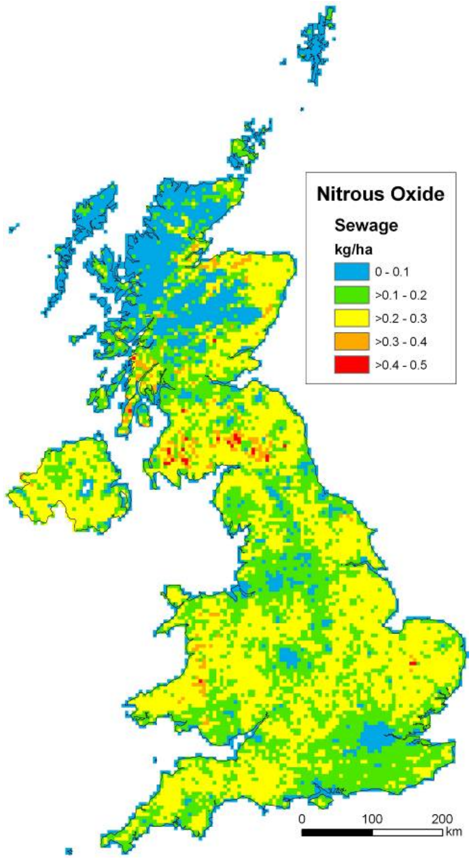

Figure 16. Nitrous oxide emissions from sewage spreading

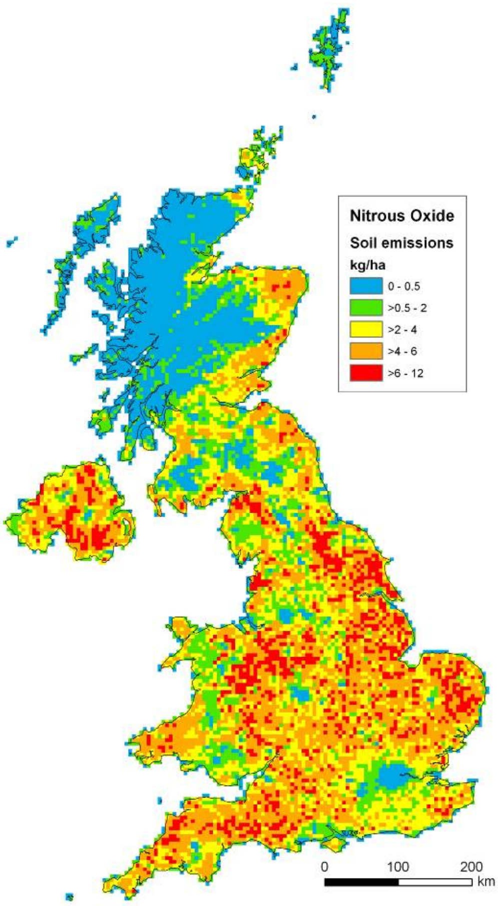

Figure 17. Nitrous oxide emissions from soil

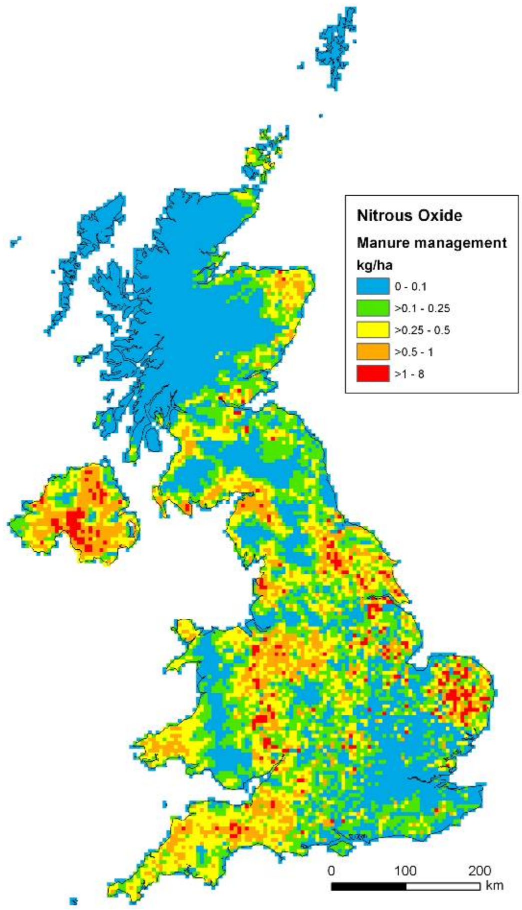

Figure 18. Nitrous oxide emissions from manure management

3.3. Spatial datasets for submission to the NAEI/GHGI

The units for all spatial datasets submitted are kg ammonia (NH_3), methane (CH_4) or nitrous oxide (N_2O) per grid square, respectively. The datasets were produced on the Ordnance Survey GB Grid at a resolution of 1 km x 1 km and were delivered to AEA (see Section 3.1. for details on spatial resolution). The units of the submitted datasets are kg NH_3, CH_4 and N_2O, respectively, per grid square.

5. MAJOR CHANGES AND CONSEQUENCES IN EMISSIONS FROM NON-AGRICULTURAL SOURCES

5.1. Changes in emissions from non-agricultural sources

Overall, non-agricultural NH_3 emissions from sources estimated by CEH under the current contract (covered by SNAP codes 6, 9, 10 and 11) amount to 40.8 kt NH_3-N (or 49.5 kt NH_3) year^{-1} for 2009, with an uncertainty range of 18.4-82.9 kt NH_3-N year^{-1} (Dragosits and Sutton 2011a). This constitutes an increase of 3.1 kt NH_3-N yr^{-1}, compared with the estimate for the same sources in 2008 (37.7 kt NH_3-N yr^{-1}). The main changes to the inventory are increased emissions from non-agricultural horses (due to revised population figures) and composting (growing sector), and a decrease of emissions from landfill due to less material being land-filled. The latter two developments are linked, with materials being diverted from landfill to composting plants for recycling.

5.2. Changes in emissions from agricultural sources

Spatially distributed emissions from agricultural sources, while submitted for inclusion in the NAEI/GHGI here, are not part of the current contract between AEA and CEH, but are modelled as part of Defra Contract AC0112. Any changes in emissions between years are described in detail by Misselbrook *et al.* (2010) as part of reporting of that project. The main changes are summarized here:

For NH_3, revisions to the NARSES model during the current inventory year include improved calculations of emissions from livestock housing and management of manures. The overall decrease in livestock emissions by 1.9 kt NH_3-N between 2008 and 2009 is mainly due to the continuing decline in livestock numbers for most sectors. Fertiliser emissions increased due to increased urea application (associated with a much larger NH_3 volatilisation rate) in addition to generally increased fertiliser N application rates.

For CH_4, emissions from agriculture decreased by 14.1 kt CH_4, mainly due to the real general decline in livestock numbers for most sectors. This decrease has been partly offset by new, slightly higher, Tier 2 emission factors for dairy cows. For N_2O, emissions increased between 2008 (82 kt N_2O) and 2009 (87 kt N_2O), mainly due to revised calculations for indirect leaching, increased fertiliser application and the inclusion of land spreading of sewage sludge to agricultural land for the first time. These increases are only partially offset by the ongoing decrease in livestock numbers.

In terms of the methodology applied for the spatial distribution of emissions from these sources, only very small adjustments have been made to the model, with regard to changing categories in the agricultural census/survey data supplied by the devolved authorities.

6. CONCLUSIONS

6.1. Ammonia

Ammonia emission maps were derived for the UK, for inclusion in the 2009 version of the NAEI for agriculture (SNAP Codes 10.1, 10.3 and 10.5), natural sources (SNAP Code 11.3 and 11.7), waste disposal (SNAP Code 9.4), sewage works and sewage sludge spreading (SNAP Code 9.10), solvents (SNAP Code 6.4) and other miscellaneous sources for the UK.

The non-agricultural sources listed above were spatially distributed using a combination of population census data, landcover data, information on landfill sites and sewage works from the Environment Agency, SEPA and others, mammal distribution data from the Biological Records Centre (BRC) etc.

Agricultural emission sources (livestock manures, fertilisers) were distributed using the CEH/University of Edinburgh AENEID model, which incorporates agricultural census data, landcover data, agricultural practice information (e.g., fertiliser application rates, stocking densities) and emission source strength data from the NARSES UK NH_3 Emissions Inventory (Misselbrook *et al*. 2010).

6.2. Methane and nitrous oxide

New CH_4 and N_2O emission maps were derived for the UK for inclusion in the GHGI for 2009 for agriculture (SNAP Code 10), natural sources (SNAP Code 11), waste disposal and sewage sludge spreading (SNAP Code 9) for the UK.

Agricultural emission sources (livestock manures and enteric fermentation, soils) were distributed using the greenhouse gas version of the CEH/University of Edinburgh AENEID model, with emission source strength data from the CH_4 and N_2O emission inventories for the UK by Rothamstead Research, North Wyke (Cardenas *et al*. 2010). The non-agricultural sources listed above were spatially distributed using a combination of population census data, landcover data, and data from the Environment Agency, SEPA and others on landfill sites.

6.3. Spatial resolution

All maps were submitted for inclusion into the NAEI and GHGI at a 1 km grid resolution for the first time. For emission sources with strict data licensing agreements of input data (i.e., all agricultural emissions) and those with large uncertainties in the input data (e.g., sewage sludge, biomass burning, land fill) the 1 km grid is a nominal resolution (explained in detail in Section 3.1). For all other sources without such restrictions, emission maps were provided at a true 1 km grid resolution.

ACKNOWLEDGEMENTS

The authors are grateful to Defra, who are funding this work as part of the National Atmospheric Emissions Inventory (NAEI) and Greenhouse Gas Inventory (GHGI) project, and to the Biological Records Centre (CEH Monks Wood) for wild mammal distribution data from records compiled by the Mammal Society, to the JNCC for data from the Seabird 2000 survey, the British Deer Society, the Game Conservancy Trust, and others.

REFERENCES

BSFP (2010): *The British Survey of Fertiliser Practice. Fertiliser use on farm crops for crop year 2009*. Defra, London. 100pp.

Cardenas L., Gilhespy S. and Misselbrook T. (2010) Inventory of UK emissions of methane and nitrous oxide from agricultural sources for the year 2009. MS EXCEL spreadsheet. Rothamstead Research, North Wyke, Devon, UK.

Dragosits U., Hallsworth S. and Sutton M.S. (2010) Ammonia emissions from UK non-agricultural sources in 2008: contribution to the National Atmospheric Emission Inventory. CEH Report. Centre for Ecology & Hydrology, Edinburgh Research Station, Bush Estate, Penicuik. 15pp.

Dragosits U. and Sutton M.S. (2011a) Ammonia emissions from UK non-agricultural sources in 2009: contribution to the National Atmospheric Emission Inventory. CEH Report. Centre for Ecology & Hydrology, Edinburgh Research Station, Bush Estate, Penicuik. 15pp.

Dragosits U. and Sutton M.A. (2011b) The spatial distribution of ammonia, methane and nitrous oxide emissions from agriculture in the UK 2009. CEH Report Centre for Ecology & Hydrology, Edinburgh Research Station, Bush Estate, Penicuik. 13pp.

Dragosits U., Sutton M.A., Place C.J. and Bayley A.A. (1998) Modelling the Spatial Distribution of Agricultural Ammonia Emissions in the UK, Environmental Pollution 102(S1) p.195-203

Hargreaves K.J. and Fowler D. (1998) Quantifying the effects of water table and soil temperature on the emission of methane from peat wetland at the field scale. *Atmospheric Environment* **32**, 3275-3282.

Hellsten S., Dragosits U., Place C.J., Vieno M., Dore A.J., Misselbrook T.H., Tang Y.S. and Sutton M.A. (2008) Modelling the spatial distribution of ammonia emissions in the UK. *Environmental Pollution* **154**, 370-379.

Hunt J.F. (2003) Impacts of Wild Deer in Scotland - How Fares the Public Interest? Report for WWF Scotland and RSPB Scotland, August 2003 (www.rspb.org.uk).

Misselbrook T.H., Chadwick D.R., Gilhespy S.L., Chambers B.J., Smith K.A., Williams J. and Dragosits U. (2010) Inventory of ammonia emissions from UK agriculture 2009. Defra Contract Report (AC0112). Rothamstead Research, North Wyke, Devon. 34 pp.

SEPA (2010) Landfill Allowance Scheme (online). Scottish Environmental Protection Agency, Stirling, UK. http://www.sepa.org.uk/waste/waste_data/waste_data_reports/landfill_allowance_scheme.aspx.

Stone I., Gilbert E.J. and Pocock R. (2010) Survey of the UK organics recycling industry 2008/09. UK Organics Recycling Survey 2008/-9 – final report. Association for Organics Reycycling, Wellingborough, Northamptonshire. 84p.

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.

Sutton M.A., Dragosits U., Dore A.J., McDonald A.G., Tang Y.S., van Dijk N., Bantock T., Hargreaves K.J., Skiba U., Fowler D., Misselbrook T., Brown L. and Hobbs P. (2004) The potential to use trace-gas changes following the 2001 outbreak of Foot and Mouth Disease in Great Britain to reduce the uncertainties in agricultural emissions abatement. J. Environ. Science and Policy 7, p. 177-194.

Sutton M.A., Dragosits U., Simmons I., Tang Y.S., Hellsten S., Love L., Vieno M., Skiba U., di Marco C., Storeton-West R.L., Fowler D., Williams J., North P., Hobbs P. and Misselbrook T. (2006) Monitoring & modelling trace-gas changes following the 2001 outbreak of Foot & Mouth Disease to reduce the uncertainties in agricultural emissions abatement. Environmental Science & Policy 9, 407-422.

Wilson L.J., Bacon P.J., Bull J., Dragosits U., Blackall T.D., Dunn T.E., Hamer K.C., Sutton M.A. and Wanless S. (2004a) Modelling the spatial distribution of ammonia emissions from seabirds. *Environmental Pollution* **131**, 173-185.

Wilson L.J., Bacon P.J., Bull J., Dragosits U., McDonald A., Blackall T.D., Dunn T.E., Hamer K.C., Sutton M.A. and Wanless S. (2004b) The spatial distribution of ammonia emitted from seabirds and its contribution to atmospheric nitrogen deposition in the UK. *Water Air and Soil Pollution: Focus* **4**, 287-296.

APPENDIX A - NARSES CATEGORIES

Cattle
1 Dairy cows & heifers
2 Dairy heifers in calf, 2 years +
3 Dairy heifers in calf, <2 years
4 Beef cows & heifers
5 Beef heifers in calf, 2yrs +
6 Beef heifers in calf, <2 years
7 Bulls >2yrs
8 Bulls 1-2yrs
9 Other cattle, 2yrs +
10 Other cattle, 1-2yrs
11 Other cattle, <1yr

Sheep
12 Sheep
13 Lambs, under 1 year old

Pigs
14 Sows in pig & other sows
15 Gilts in pig & barren sows
16 Gilts > 50kg not yet in pig
17 Boars
18 Other pigs, 110kg and over
19 Other pigs, 80-110kg
20 Other pigs, 50-80kg
21 Other pigs, 20-50kg
22 Other pigs, under 20kg

Poultry
23 Layers
24 Breeding birds
25 Broilers
26 Pullets
27 Turkeys
28 Other poultry

Other livestock
29 Horses
30 Goats
31 Deer

Crops
32 Set-aside land
33 Wheat
34 Winter Barley
35 Spring Barley
36 Sugar beet
37 Oilseed rape
38 Potatoes
39 Other cereals
40 Other root crops
41 Other crops
42 Vegetables for human consumption
43 (Soft) Fruit
44 Bulbs, flowers and nursery stock
45 Grassland less than 5 years old
46 Permanent grassland