Guidance on modelling the concentration and deposition of ammonia emitted from intensive farming

Executive summary

A two-stage approach is recommended to model dispersion and deposition of ammonia emitted from intensive farming sources. The proposed empirical approach allows both the concentration dependency of the deposition velocity and the ammonia depletion of the plume to be taken into account.

1 Introduction

1.1 To determine applications for permits under the Environmental Permitting Regime information is needed on the potential environmental impact of the installation being considered. Often the only way in which the exposure of a sensitive receptor such as a wildlife site to a pollutant can be assessed, is through the use of air dispersion modelling.

1.2 This document provides guidance on the approach to be applied for assessing the exposure of receptors such as wildlife sites to ammonia from intensive livestock farms. It is important that dispersion models are set up correctly to represent the situation being considered and therefore it will generally be necessary to employ experienced consultants to undertake this work. This guidance is aimed primarily at these consultants and supplements existing modelling guidance already available on the Environment Agency's website (http://www.environment-agency.gov.uk/business/regulation/38791.aspx), for example, on the choice of model, use of meteorological data and information to be included in modelling studies.

2 Model set up

Emission source type

2.1 In order to model the dispersion of ammonia from intensive livestock farming it is important that the characteristics of the source, such as, pollutant emission rate, temperature and velocity of exhaust gases, number and configuration of housing or manure storage facilities are properly represented in the model.

2.2 If annual average emission factors are used in the modelling it will generally be an adequate approximation to assume that releases occur evenly over the year. However, it will be necessary to apportion them correctly between different sources on the farm, particularly if there are significant differences in emissions with location or over time. Although ammonia in its pure form is lighter than air it is emitted as a minor constituent of air vented from the house and will disperse in a similar manner to the air within which it is carried. If the dispersion model permits the density of the release to be specified this should be set to that for air rather than ammonia alone.

2.3 The type of housing present on the farm will significantly affect the dispersion characteristics and it will be important that these are correctly represented in the model. Housing types will vary widely between farms, from sheds with high velocity roof fans to free-range operations with minimal housing in the field. There may even be a variety of different housing types on the same farm. The modeller will need to think carefully how these are to be represented in the model and the chosen approach should be properly justified in the modelling report. The following paragraphs provide some suggestions as to how typical housing types may be represented in a model.

2.4 Sheds with roof vents should be modelled as a series of elevated point sources with appropriate release characteristics (volumetric flow, temperature etc.). Modellers should identify the mode of operation of fans. Some units may use variable speed fans which result in a reduced exit velocity at low fan speeds compared with 'on/off' type fans. Where there are a large number of vents they may need to be combined into a smaller number of composite sources distributed to represent the release scenario. It should be noted that when an effective diameter is used which is much larger than the actual physical diameter, the calculation of the plume rise may be inaccurate. The use of an effective stack diameter may also have an impact on stack tip downwash modelling. It is suggested that the stack diameter and exit velocity for an individual stack is used to represent the combined sources. However, the mass emission rate should be increased to represent the composite source. Sensitivity analysis needs to be carried out if necessary.

2.5 Some sheds may have tunnel ventilation with fans in the gable ends. If the line of gable ends is long or the shed is wide they can be modelled as a low level line source to account for the building downwash effect. Otherwise, they can be modelled as a series of point sources with zero efflux velocity and including building downwash effects.

2.6 Naturally ventilated sheds typically may be considered as 'leaky boxes' and modelled as volume sources. However, some sheds may be designed with side inlets and a roof exit. In which case they may be modelled as a low level line source or a series of point sources and including building downwash effects.

2.7 Site vents. These vents direct the air flow to ground level and should be modelled as either a series of ground level point sources or a line source of appropriate length with the exit velocity setting to "zero".

2.8 For free-range animals, the appropriate emission factor will need to be apportioned between the free-range area and any housing in proportion to the time the animals spend in each location. The national Inventory of Ammonia Emissions from

Agriculture[1] assumes that 20% of droppings will occur outside the house. Also typically, birds remain close to housing and it would generally be inappropriate to assume that they roam over the whole area available to them. A conservative modelling assumption would be to assume that all emissions arise from the housing. However, where alternative assumptions are made these will need to be properly justified in the modelling report.

<u>Meteorological data and terrain impact</u>

2.9 The model should be run using 5 years of meteorological data from the nearest appropriate meteorological station. Each year of meteorological data should be run separately and the highest predicted annual average from the 5 years used as the basis of the assessment.

2.10 The effects of terrain should also be considered where slopes greater than about 1:10 occur within the area being considered.

3 Approach to model ammonia dispersion and deposition

3.1 At a particular wildlife site the concentration of ammonia in the air may exert direct effects on the vegetation or indirectly through deposition on the ground. The United Nations Economic Commission for Europe[2] have set environmental criteria known as critical levels for the protection of vegetation from direct effects and critical loads to protect against the indirect effects of deposition of pollutants. The critical level or load for the site will vary depending on the sensitivity of the vegetation. Generally for ammonia, if the critical level for a wildlife site is met this will provide sufficient protection in relation to the effects of deposition. However, occasionally where a higher critical level is appropriate to protect vegetation against direct effects of ammonia but soils are particularly sensitive, this may not be the case. Therefore, the deposition of ammonia should be estimated for comparison with appropriate critical loads for acidity and nutrient nitrogen where the critical level for the site is set to protect higher vegetation (3 $\mu g/m^3$).

3.2 The scientific literature suggests that the dry deposition velocity of ammonia is concentration dependent and is significantly reduced at high concentrations, i.e., from 0.02 – 0.03 m/s at ambient concentration down to about 0.003 m/s at a long-term average over 80 $\mu g/m^3$ [3, 4]. When the concentration dependence of the deposition velocity is taken into account, the reported cumulative depletion ratio (the ratio of ammonia deposited to the total emitted) was about 10% at 500 to 1000 m downwind[3, 5].

[1] Inventory of Ammonia Emissions from UK Agriculture 2007. Defra, 2008.
[2] http://www.unece.org/env/lrtap/WorkingGroups/wge/mapping.htm
[3] Walker J, Spence P, Kimbrough S and Robarge W, 2008. Inferential model estimates of ammonia dry deposition in the vicinity of a swine production facility. Atmospheric Environment 42, 3407-3418.
[4] Cape JN, Jones MR, Leith ID, Sheppard LJ, van Dijk N, Sutton MA, Fowler D, Estimate of annual NH3 dry deposition to a fumigated ombrotrophic bog using concentration-dependant deposition velocities. Atmospheric Environment 42 (2008) 6637-6646.
[5] Fowler D, Pitcairn CER, Sutton MA, Flechard C, Loubet B, Coyle M, Munro RC 1998: The mass budget of atmospheric ammonia in woodland within 1km of livestock buildings. Environmental Pollution 102, S1 (1998) 343-348.

3.3 ADMS and AERMOD are two air dispersion models commonly used in ammonia dispersion from poultry/pig farms for regulatory application. Both ADMS and AERMOD contain a deposition module for calculating the hourly dry deposition flux under the assumption that the dry deposition velocity is independent of the pollutant concentration. The modules may not be fit for purpose in modeling ammonia from intensive farming emissions.

3.4 Until the models deal adequately with this issue we recommend a two-stage approach;

<u>Stage one</u>

i) Use an appropriate dispersion model to predict the annual average ammonia concentration in air with the deposition module switched off. Where necessary the effects of building downwash and terrain (if the slope is greater than 1:10) should also be considered.

ii) Once the modeling run is completed, process the concentration field using the following equation to calculate the ammonia dry deposition flux,

$$F = V_d \times C$$

where
- C is predicted ammonia annual mean concentration (μg/m^3)
- V_d is ammonia dry deposition velocity, V_d = 0.02 m/s for grassland and 0.03 m/s for forest/woodland.
- F is deposition flux (μg NH_3 m^{-2} s^{-1}), which can be converted to the unit of kg N ha^{-1} year^{-1} by multiplying a factor of 259.7.

iii) If there are insufficient computing resources available to process the complete concentration field as described above, the dispersion model can be used to provide concentration values at specific locations across the wildlife site (including the point of maximum ground level concentration) and the deposition flux estimated at these points.

<u>Example</u>

Deposition velocities for two types of habitat can be used:

0.02 m s^{-1} for short semi-natural vegetation
0.03 m s^{-1} for tall vegetation and woodland

Monitoring/modelling data on the edge of an ombrotrophic bog gives a concentration of 0.8 μg NH_3 m^{-3}

0.8 μg m^{-3} x 0.02 m s^{-1} = 0.0160 μg m^{-2} s^{-1}

0.0160 μg m^{-2} s^{-1} x 31,536,000 s x 10,000 m^2 = 5,045,760,320 μg ha^{-1} y^{-1}

Divide by 10^9 to get kg ha = 5.05 kg NH_3 ha^{-1} y^{-1}

Correct NH_3 to N:

5.05 kg NH_3 ha^{-1} x 0.82 = 4.16 kg N ha^{-1} y^{-1}

or 0.8 µg m^{-3} x 0.02 m s^{-1} = 0.0160 µg m^{-2} s^{-1}
0.0160 µg m^{-2} s^{-1} × 259.7 = **4.16 kg N ha^{-1} y^{-1}**

iv) If the predictions from Stage one indicate that the thresholds used in the assessment will be exceeded, then go to Stage two.

<u>Stage two</u>

i) When Stage one predictions, without the inclusion of ammonia deposition, indicate that the relevant assessment thresholds are exceeded, appropriate concentration dependent deposition velocities covering the range of predicted concentrations (including background) need to be selected from Table 1. These can then be included into the model using the spatially varying deposition feature in the ADMS 4.2 (Section 4 of the ADMS manual) and the model re-run. Table 1 presents a summarised relationship between ammonia dry deposition velocity and long term ground level concentration based on information from a number of studies[3, 4, 5, 6, 7].

Table 1. Recommend ammonia dry deposition velocity at different long term average concentration to be used in an impact assessment.

NH3 conc (farm contribution + background) (µg/m^3)	**< 10**	**10 - 20**	**20 - 30**	**30 – 80**	**> 80**
Deposition velocity (m/s)	0.02 - 0.03*	0.015	0.01	0.005	0.003

* 0.02 m/s for short vegetation, and 0.03 m/s for tall vegetation.

ii) Information on the annual ammonia background concentration can be found on the APIS website (http://www.apis.ac.uk/index.html) or through the government's UK Deposition Portal (http://www.uk-pollutantdeposition.ceh.ac.uk/node/203).

[6] Leith ID, Sheppard LJ, Fowler D, Cape JN, Jones M, Crossley A, Hargreaves KJ, Sim Tang Y, Theobald M, Sutton MR 2004 Quantifying Dry NH3 Deposition to an Ombotrophic Bog from an automated NH3 field release system. Water, Air and Soil Pollution 2004 207-218.

[7] Sutton M A, Pitcairn CER and Flowler D (1993) the exchange of ammonia between the atmosphere and plant communities. Advances in Ecological Research Vol. 24.

Generally, background concentrations of ammonia over much of the UK are less than 4 µg/m^3 but it is particularly important they are included where the farm contribution is low.

3.5 Wet deposition of ammonia is not significant compared to dry deposition close to the source[8, 9]. It is recommended that wet deposition of ammonia emitted at poultry/pig farm is not considered in the assessment.

3.6 Consultants may adopt an alternative approach to estimating ammonia concentration and deposition to that recommended above but this will need to be properly justified in the modelling report.

4 Uncertainty in the recommended approach

4.1 Modelling uncertainty may arise from a number of different sources: atmospheric turbulence, the model itself which describes the transport of pollutants through the atmosphere and input data, such as meteorological information, surface roughness, particularly estimates of emission rates.

4.2 The overall uncertainty in a model prediction of air concentration will depend strongly on the situation being modelled and the model being applied but is typically within 50% of measured values for the annual average concentration. Estimating the deposition of ammonia adds significant additional uncertainty.

4.3 Stage one of the recommended approach is likely to be conservative in concentration or deposition flux because the depletion process is not considered. The papers by Walker et al (2008)[3] and Fowler et al (1998)[5] suggest that the accumulated depletion is about 10% at 500 – 1000m from the source.

4.4 The recommended deposition velocities in Table 1 are based on the limited data available. There is currently insufficient information to do an uncertainty analysis. However, the proposed empirical approach does allow both the concentration dependency of the deposition velocity and the ammonia depletion of the plume to be taken into account. The use of the long term average concentration also avoids the complexity encountered in short term (i.e., hourly) modelling.

4.5 The recommended method does not consider ammonia wet deposition from a farm, although this is generally considered to be small. The UNECE Expert Workshop on ammonia suggested that between 0.25%-2% of NH_3 might be scavenged by wet-deposition up to 1000 m downwind from sources[9].

[8] Modelling of the atmospheric transport and deposition of ammonia at a national and regional scale
W.A.J. van Pul (RIVM, NL), O. Hertel (NERI, DK), T. Dore (CEH, UK), M. Vieno (IAES, UK), J.A. van Jaarsveld (MNP, NL), R. Bergström (SMHI, S), M. Schaap (TNO, NL), H. Fagerli (EMEP) Version 29/11. UNECE Expert Workshop on Ammonia, Edinburgh 4-6 December 2006.

[9] Ammonia deposition near hot spots: processes, models and monitoring methods, Benjamin LOUBET, Willem A.H. ASMAN, Mark THEOBALD, Ole HERTEL, Sim Y. TANG, Paul ROBIN, Mélynda HASSOUNA, Ulrich DÄMMGEN, Sophie GENERMONT, Pierre CELLIER and Mark A. SUTTON. UNECE Expert Workshop on Ammonia, Edinburgh 4-6 December 2006,

4.6 The recommended method for modelling ammonia dispersion and deposition is based on the current understanding of the ammonia deposition and best available information. However, we will review and revise the method in the light of new information and the development of modelling techniques as they become available.