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knowledge brokers
for a resilient Scotland

SCAIL-Agriculture update

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Terms and Definitions:

Term	Definition
ACNV	Automatically Controlled Natural Ventilation
ADMS	Advanced Dispersion Modelling System
AGANET	Acid Gas and Aerosol Network
APIS	UK Air Pollution Information System
ARD	Alberta Agriculture and Rural Development
ASSI	Area of Special Scientific Interest
CBED	Concentration Based Estimated Deposition
CEH	Centre for Ecology and Hydrology
CL	Critical Load
CLMinN	Minimum Critical Load for Nitrogen
CLMaxN	Maximum Critical Load for Nitrogen
CLMaxS	Maximum Critical Load for Sulphur
CLRTAP	(UNECE) Convention on Long-Range Transboundary Air Pollution
DEFRA	Department for the Environment, Food and Rural Affairs
EA	Environment Agency
EMEP	European Monitoring and Evaluation Programme
EMS	Earthen-liquid Manure Storage facilities
EPA	Environmental Protection Agency (Republic of Ireland)
FAC2	Fraction of model predictions within a factor of two of observed values
FB	Fractional Bias

Term	Definition
FRAME	Fine Resolution Atmospheric Multi-pollutant Exchange model
GIS	Geographic Information System
HNO_3	Nitric Acid
IED	Industrial Emissions Directive
IPC	Integrated Pollution Control (prior to IPPC and IED)
IPPC	Integrated Pollution Prevention and Control
JNCC	Joint Nature Conservation Committee
LNR	Local Nature Reserve
MG	Geometric Mean bias
MMF	Mobile Monitoring Facility
NAMN	National Ammonia Monitoring Network
NH_3	Ammonia
NH_4	Ammonium
NHA	Natural Heritage Area
NIEA	Northern Ireland Environment Agency
NMSE	Normalised Mean Square Error
NNR	National Nature Reserve
NO_X	Oxides of Nitrogen
NO_3	Nitrate
NPWS	National Parks and Wildlife Service
NRW	Natural Resources Wales
OU_E	European Odour Unit
PEC	Predicted Environmental Concentration
PC	Process Contribution
$PM_{2.5}$	Airborne Particulate Matter (diameter of less than 2.5 micrometres)
PM_{10}	Airborne Particulate Matter (diameter of less than 10 micrometres)
Ramsar	The Convention on Wetlands of International Importance (Ramsar Convention)
SAC	Special Area of Conservation
SCAIL	Simple Calculation of Atmospheric Impact Limits
SEPA	Scottish Environmental Protection Agency
SNH(i)	Scottish Natural Heritage (information)
SO_2	Sulphur Dioxide
SO_4	Sulphate
SPA	Special Protection Area
SRCL	Site Relevant Critical Loads
SSSI	Site of Special Scientific Interest
UCD	University College Dublin
UNECE	United Nations Economic Commission for Europe
UoA	University of Alberta
US EPA	United States Environmental Protection Agency
VG	Geometric Variance

1. Background

1.1. The need to update SCAIL-Agriculture

Emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3) and their subsequent deposition to sensitive sites impose a major environmental burden both nationally and internationally (Bobbink *et al*., 1998; Pearce and van der Wal, 2002). At a local scale the deposition of these pollutants can result in eutrophication of sensitive ecosystems and the acidification of soil. As part of the Habitats Directive, environmental regulators have a duty to consider the potential impacts of emissions from regulated industrial installations on designated European Sites.

The SCAIL-Agriculture model was first developed by the Centre for Ecology and Hydrology (CEH) for the Environment Agency (EA). The model was subsequently modified for the Scottish Executive to provide a screening model that could help the Scottish Environmental Protection Agency (SEPA) assess permit applications (v2.0) (Theobald *et al*., 2009). The model is used by environmental regulators throughout the UK to assess the impacts of agricultural installations on designated habitats including Habitats Directive sites and designated sites under National Legislation (SSSIs /ASSIs/NNRs). The objective is to screen environmental permit applications from farm units and to assess impacts from agricultural developments applying for planning permission to determine if there is the possibility of adverse impacts. Should such impacts be found then this would indicate that more detailed dispersion and deposition modelling is required.

SCAIL-Agriculture produces an estimate of the nitrogen deposition (and ammonia concentrations) at a certain distance downwind of the source, using a 'deposition velocity' specific to the habitat of interest. The model also estimates the potential for critical load exceedance at the nearest edge of the habitat, taking into account the background deposition at that location and the critical load of the habitat. To do this, the model uses both UK Critical Load/Level maps and habitat information held within the Air Pollution Information System .

A similar model, SCAIL-Combustion was developed for assessing the impact of combustion sources on habitats sites to assist in the initial stages of an Appropriate Assessment for designated habitats as set out in the Habitats Directive. This tool uses the AERMOD atmospheric dispersion model to highlight potential exceedances of Critical Loads/Levels. It also incorporates information on current background levels (information held in APIS) and site information from Scottish Natural Heritage information (SNHi) and the Joint Nature Conservation Committee (JNCC).

Intensive agriculture is now included within Integrated Pollution Prevention and Control (IPPC) and subsequently the Industrial Emissions Directive (IED). Intensive agricultural installations are now required to demonstrate compliance with air quality assessment levels (for the protection of human health and the environment) and to demonstrate appropriate odour control. The emission of fine particulate matter (PM_{10}[1]) is of primary concern when considering air quality assessment levels.

This current project has provided an update to the SCAIL-Agriculture screening model. The tool has been designed to specifically deal with emissions from pig and poultry buildings and has been developed to evaluate the following emissions:

- *Impact of NH_3 emissions on habitats sites;*
- *Impact of PM_{10} emissions on human health; and,*
- *Impact of odour emissions on nearby receptors.*

[1] PM_{10} is defined as airborne particulate matter with a 50% cutpoint aerodynamic diameter of less than 10 micrometres.

1.2. Requirements for SCAIL-Agriculture revised tool

As with the previous SCAIL-Agriculture screening tool, the revised tool is focused on the concentration and deposition of NH_3 and assess the potential for Critical Level and Critical Load exceedance at designated sites through the utilisation of information held within APIS. However, the tool also estimates atmospheric concentrations of PM_{10} and odour at human health receptors within the vicinity of intensive pig and poultry units.

As part of the update, the tool has been recompiled to incorporate the latest version of AERMOD and also incorporate the effects of buildings upon dispersion. AERMOD is one of the "next generation" Gaussian plume atmospheric dispersion models and is typically applied for regulatory air dispersion modelling assessments. A particular objective for this project was to enable the revised SCAIL-Agriculture model to better replicate the modelling required as part of regulatory assessment.

In addition, the revised tool includes an automatic look-up for designated sites within a user specified distance of the farms and includes a web-based mapping tool used to display geographical information. Up-to-date background concentrations and deposition data are included in the tool that enables a comprehensive assessment of the atmospheric impacts of regulated intensive agricultural installations.

The project delivers software that provides a robust, user-friendly, desk-based screening tool to:

1. *Estimate atmospheric concentrations and deposition rates associated with emissions of ammonia from intensive pig and poultry units.*
2. *Complete the first phase of an Appropriate Assessment as set out within the Habitats Directive and for the assessment of licence applications.*
3. *Follow procedures set within regulatory guidance (EPA, EA-Natural Resources Wales NRW , SEPA and NIEA).*
4. *Create a system that can be used by regulators who work for any of the regulatory bodies in the United Kingdom and Republic of Ireland (EPA, EA-NRW, SEPA and NIEA).*
5. *Generate an output file that includes relevant information on the model parameters, pollutants and receptor sensitivity that can be used for licence justification.*

Methodologies applied in the Sniffer project UKPIR15 (SCAIL-Combustion, see Sniffer, 2010a) have been utilised in order to streamline the development process for the revised and expanded SCAIL-Agriculture screening tool, further details are provided later in this report. The outcomes from the project have delivered a tool that:

- *Incorporates the features in SCAIL-Combustion that are relevant to modelling emissions and dispersion of NH_3, PM_{10} and odour from intensive pig and poultry facilities across the UK.*
- *Can be expanded in the future to include screening for $PM_{2.5}$ (particles with a diameter of 2.5 micrometres or less) or other discrete components of the aerosol (such as bio-aerosol components) if the EU/UK establishes thresholds for them.*
- *Incorporates local wind and atmospheric stability data.*
- *Allows the user to input multiple facilities and multiple emission sources.*
- *Provides output for both designated sites and human health receptors.*
- *Applies an appropriate source configuration, e.g. point, volume or area, taking into account the characteristics of the source.*
- *Incorporates the effects of building downwash upon the dispersion of pollutants where possible.*
- *Eliminates double counting when incorporating background information.*
- *Incorporates information from web-based information sources, e.g. APIS, to obtain critical load and habitat information.*
- *Includes a full revision of the SCAIL-Agriculture User Guide to facilitate understanding and use.*

Based on user input regarding the location, type and size of the facility (and other readily-available information) the tool achieves the following design objectives:

For Ammonia:

- *Automatically locate designated habitats sites within a user specified distance of the unit.*
- *Identify those habitats sites and their designations.*
- *Allow the user to input additional sites which are not currently designated.*
- *Assess the designated sites in terms of the most sensitive habitat type.*
- *Give current background levels of NH_3 concentration and deposition of nitrogen and acidity at each designated site.*
- *Model concentration, deposition and hence determine potential exceedance of appropriate critical levels/critical loads at the closest boundary of each identified designated site.*

For PM_{10}:

- *Include emission factors for the most common types of pig and poultry livestock housing and rearing systems.*
- *Allow for input of one or more human health receptors.*
- *Give current background levels of ambient PM_{10} at those sites.*
- *Model concentration and hence determine potential exceedance of the appropriate air quality standard at the human health receptor.*

For Odour:

- *Include emission factors for the most common types of pig and poultry livestock housing and rearing systems.*
- *Allow for input of one or more human health receptors.*
- *Model concentration and hence determine potential exceedance of the appropriate odour threshold at the human health receptor.*

2. Development of Revised SCAIL-Agriculture

The revised SCAIL-Agriculture tool has been updated applying the techniques developed in the SCAIL-Combustion model "UKPIR15" whilst preserving elements of the look, feel and functionality of the previous version of SCAIL-Agriculture. The project has delivered a tool that closely resembles the SCAIL-Combustion model though applies the relevant parameters and assumptions that are required for modelling agricultural pig and poultry sources (*e.g.* Bealey *et al*., 2009). Where possible the current tool has utilised existing methods and data owned by Sniffer within the SCAIL-Combustion tool. In particular the tool performs the following functions:

Emissions

- *Incorporate methods to derive source terms (in grams per second or odour units* (OU_E) *per second) from livestock numbers and types based on the latest emission factors available from national inventories, EA/ SEPA and Irish EPA guidance.*
- *Treat point, volume and area source releases and include guidance on appropriate efflux parameter ranges (ventilation rates, surface area etc.).*
- *Dispersion*
- *Use the AERMOD model and incorporate appropriate dispersion modelling methodologies for treating releases of NH_3, PM_{10} and odour following EA, SEPA and EPA Ireland guidance. The model treats multiple sites (termed "Installations") and also multiple emission points within the same farm.*
- *Allow multiple receptor points. These are habitats sites for NH_3 and "relevant exposure locations" for PM_{10} and odour. The tool incorporates an automated "look up" for identifying all habitat sites within a user-specified distance of the emission sources.*
- *Use the meteorological dataset developed for SCAIL-Combustion updated to include sites in the Republic of Ireland.*
- *Calculate "Process Contributions" for each of the Installations detailing the annual average air concentrations of NH_3; nitrogen and acidity deposition fluxes; PM_{10} as the annual average or a percentile of the daily concentration distribution and odour concentrations as the 98^{th} percentiles of hourly values.*

Effects

- *Process contributions calculated using the AERMOD model are combined with relevant background data on ammonia air concentrations, PM_{10} air concentrations, nitrogen deposition flux and acid deposition flux obtained from the Air Pollution Information System and national scale modelling and mapping exercises.*
- *The tool compares the PM_{10} results with relevant air quality standards for human health; the NH_3 concentrations with critical levels; and nitrogen and acid deposition with habitat specific critical loads.*
- *Odour concentrations at the 98^{th} percentile of hourly means are compared to the relevant benchmark levels*.

Validation

- *The dispersion and deposition schemes that are included in the tool are validated against datasets that are available from national and international research studies. Full details of the validation of the tool are provided later in this report.*

Reporting

- *The tool provides output that can be imported into a spreadsheet package (e.g. Excel) as well as a template AERMOD input file which could be used for further detailed modelling.*
- *There is a full user guide for the model, as well as an online tutorial.*
- *The tool will include an updated on-line help system.*

Initially a feasibility study was carried out to outline the specification for the updates to the SCAIL-Agriculture tool and determine the most appropriate methods to implement the required improvements.

Specific issues that were considered in the feasibility study include:

- *Emission rates*
- *Methods to model point, area and volume sources and their location*
- *Methods to include local building influences*
- *Issues related to modelling ammonia deposition and plume depletion*
- *GIS methods for the automation of habitat data identification*
- *Critical loads, levels and links with the GIS system*
- *Availability of data on background concentrations (NH_3 and PM_{10}) and deposition (nitrogen and acidity)*
- *Methods for including components of PM_{10} (e.g. physical size fractions or chemical constituents)*
- *Methods for determining impacts of odour emissions, especially in complex situations e.g. for fluctuating emissions (such as manure spreading, which happens periodically) and multiple odour sources.*
- *Odour impact of slurry spreading and percentiles*
- *Expectations of the users of the tool (e.g. complexity vs. ease of use)*
- *Licensing requirements for the data sources*

2.1. Emission rates

2.1.1. Ammonia

Emission rates for NH_3 have been taken from the previous SCAIL-Agriculture tool and are shown in Appendix A.

2.1.2. Odour

For odour emissions, a review has been carried out in order to identify the most appropriate and up-to-date emissions factors.

Whilst a large amount of data is available on generic odour emissions from both pig and poultry farming sources, the data have not been collected on a sufficiently systematic basis to reproduce all of the emission data subdivisions within the current SCAIL agriculture database. However because of the nature of odour emissions and the type of tool required, the following approach to data identification has been undertaken.

Whilst odour production is an intrinsic feature of animal husbandry, the more intense odours tend to arise from anaerobic processes within waste. These often arise as a result of management practice by allowing undisturbed accumulation of litter to progress to the anaerobic phase. Conversely management practices which reduce this propensity result in lower levels of odour generation and nuisance. Since this is a chemical process, ambient temperature will also affect the rate of these reactions. Superimposed upon these generalisations are on-going changes in farming practice driven by legislation both on animal welfare and emission control and by the use of innovation such as the use of anaerobic digesters to deal with organic waste.

A priori, the main modifier on emission rate will be the approach to housing and management of the animals. Production methods which maintain relatively low moisture content within the litter (for example by managing the availability of water) result in lower odour emissions. Similarly, housing methods which remove manure before it can accumulate tend to reduce the odour emissions from housing (though may increase emissions from manure storage).

Ranges of emission rates derived from literature are shown in Appendix B, which has an identical structure to the SCAIL-Agriculture ammonia emission database, showing the relative sparseness of the data. Odour emission rates from housing types tend to be derived by estimation of odour concentrations within the building by sampling and use of odour panels. This concentration is then multiplied by the building ventilation rate to give an emission rate per building which is then divided by the number of animals housed to give an emission rate per animal. The main disadvantage of this method (unless building ventilation rates are derived by some form of dilution technique) is that it fails to capture fugitive emissions from the buildings and so will underestimate the true emission rate to some degree.

Pigs

For pigs, typical practice is to house livestock within slatted floor systems with under floor manure storage. Odour emissions tend to be reduced by managing the water content of the manure and by reducing the overall surface area of exposure of the under floor store.

Housing units tend to have a range of types of animal from sows, and farrowers through to weaners, growers and finishers. Odour emissions increase with animal mass, but the numbers within a housing unit tend to be dominated by the finishers, and hence the average animal weight within each unit is relatively high and constant, so the odour emission rate is assumed to be constant throughout the year.

An Irish EPA study (Eire EPA, 2001) summarised three European studies (Ogink, 1997, Van Langenhove, 2001 and Pierson, 1995) of odour emissions resulting from a variety of housing types. These were supplemented by emission data from Hayes *et al.* (2004, 2006b) for a variety of pig housing types within Ireland. Overall there are insufficient data to draw conclusions of the benefits of different types of housing on odour emission rates, other than there appears to be a ~25 % reduction in emissions resulting from a reduced exposure area of under floor manure storage.

Poultry

For broiler production, birds are grown to an age of 30 – 40 days (depending upon market type) with odour emissions increasing markedly in the last few days of this growth pattern (Clarkson and Misselbrook, 1991). Odour emissions are most marked in the latter stages of the growth cycle and also at the end of the cycle when the houses are cleaned out (for production methods which result in accumulation of litter in the house).

Single houses would show a marked peak in odour emissions every 6 weeks or so if individual batches follow a single life cycle – it is assumed emissions are averaged from the facility as a whole as facilities typically have a number of individual “houses” which tend to be at different stages of maturation.
Layers have a more averaged emission rate as they tend to be more mature birds of similar age and mass.

Several international studies were identified which published data on odour emission rates from poultry farming. For broilers, Hayes *et al.* (2006a), and Jiang and Sands (2000) derived emission rates for broilers. Once again there is insufficient data to derive differences in emission rate from different housing types.

For layers, Hayes *et al.* (2006a), and Navaratnasamy and Feddes (2004) produced single data points for deep ventilated pit housing and for manure removal by conveyor belt. This shows an expected reduction in odour emission rate, but as only two data sets are present it is difficult to draw conclusions.

Lubac and Aubert (2001) showed a 3-fold increase in odour emission rate with age of Muscovy ducks, and several studies were identified showing a large range of odour emissions for turkeys. Conservative emission values were taken from Hayes *et al.* (2006a).

Manure storage

For chickens, modern methods tend to remove chicken manure from the farm directly upon removal from the housing, for example to composting locations, preventing the build-up in on-site stores. If stored on-site the material tends to be stored within farmyard manure piles rather than within slurry stores, and broadcasting in fields is mainly in the relatively dry phase. Emission rates from manure for a variety of poultry are available from Navaratnasamy and Feddes (2004).

For pigs, manure can be removed from the farm for further treatment, but if not, it tends to be retained within large slurry stores or lagoons. Emission rates are taken from Edeogu (2001) for circular stores and from Zhang (2005) and Bicudo (2001) for lagoons. Odour emissions can be reduced by covering these stores using a degree of advanced technological solutions (English and Fleming, 2006). Slurry broadcast in fields is an acknowledged source of nuisance, with some degree of amelioration of effect resulting from injection of the slurry directly below the soil surface using tined application methods.

Proposed approach

The SCAIL-Agriculture odour module is a screening tool. As such, reflecting the relative paucity of data compared to ammonia emissions, the appropriate level of modelling detail will be to use a simplified emission rate from livestock housing and from manure storage.

Individual animal emission rates can be selected from the available data and are a conservative value, reflecting rates for mature animals. A reduction (25%) in emission rate is allowed for housing types which reduce emission rates (reduced emitting areas for pigs, manure removal systems for poultry). These values are then scaled by the numbers of animals in the specified housing to give an overall emission rate from the building.

Manure storage can be either as farmyard manure heaps for hens or in slurry stores or lagoons for pigs. Reductions from the raw emission rates can be made for covers of differing degrees of technology (50% for straw, 90% for engineered covers). A 50% reduction in emission rate is also allowed for removal of manure from farms to other locations. Emission rates are per unit area per second, and are scaled by the area of the storage facility.

Emission factors for odour related to manure spreading were determined from the respective ammonia emission factors by applying a factor of 1.7E+06 Ou/ g NH_3 based on data from Pain *et al.* (1988).

A summary of emission factors derived from the literature for odour are shown in Appendix B. The proposed emission rates which can be calculated from these data and modifiers to be used in this study are shown in Table 2-A. These are then used as the basis for the “Emission Factor” column in Table B - 1. Where a value does not have an emission rate derivable from the literature, a calculated value from Table 2-A is used. Reduction factors are applied to the base emission rates. For example, for a housing system for pigs that results in a lower area of exposure, the base emission rate is reduced by 25%.

Table 2-A: Ranges of odour emission rates derived from literature

Livestock type	Housing emission rate (ou s^{-1} $animal^{-1}$)	Housing reduction modifier	Manure storage emission rate (ou m^{-2} s^{-1})	Storage reduction modifier
Pigs	26 (average of FSF finishers in Table D-1)	25% for low emission area (Judgement of PSF finishers in Table D-1, conservative choice of 25% rather than 40% actual.)	20 (Average of Zhang *et al*. 2005 and Bicudo *et al*. 2001 values) Also average of values given in Hudson *et al.* (2007)	50% for low tech (*e.g.* straw cover) 50% for removal from yard 90% for high-tech system (English and Fleming, 2006)
Broilers	0.5 (Conservative worst case from data presented- except ADAS max value)	-	77 (Navaratnasamy and Feddes, 2004)	-
Layers	1.4 (highest value from Hayes *et al*., 2006a)	25% for manure removal system (judgement comparing belt removal system to deep pit but a conservative estimate of 25% rather than 50%)	61 (Navaratnasamy and Feddes, 2004)	-
Turkeys	6.55 (From Hayes *et al*. 2006a)	-	20 (Navaratnasamy and Feddes, 2004)	-
Ducks	6 (Lubac *et al*., 2005)	-	20 (assumed same as turkey)	-

2.1.3. PM_{10}

Emission factors for PM_{10} were determined from a review of the available literature. Overall, the information from the EA Guidance note on Intensive Agriculture (Jan 2012) EA (2012) was found to be representative of a wide range of poultry types. A conversion factor of 1/3 was applied to convert dust emissions to PM_{10} emissions in line with information in the EA guidance document. A summary of the relevant information is presented in Table 2-B. Emissions from pig production were taken from Takai *et al.* (1998), assuming that PM_{10} was analogous to respirable dust and applying typical liveweights of 150 kg for sows, 60.3 kg for fatteners and 20 kg for weaners (Table 2-C).

It should be noted that emissions of PM_{10} were not included for either stored manure or for slurry spreading.

A summary of emission factors for PM_{10} are shown in Appendix C.

Table 2-B: PM_{10} emission factors for poultry from EA (2012).

Type	kg dust/animal place/year	kg PM_{10}/animal place/year
Layers, perchery or aviary	0.1	0.033
Layers, cage	0.05	0.017
Broilers	0.1	0.033
Turkeys (male)	0.9	0.300
Turkeys (female)	0.5	0.167
Ducks	0.2	0.067
Pullets	0.1	0.033

Table 2-C: PM_{10} emission factors for pigs from Takai *et al.* (1998).

Type	mg respirable dust/ 500Kg L.w./ hr	kg PM_{10}/animal place/year
Sows litter	49	0.129
Sows slats	13	0.034
Weaners slats	60	0.021
Fatteners litter	73	0.077
Fatteners slats	133	0.141

2.2. Modelling methods

There are various methods available to model aerial dispersion from agricultural sources, and within these models there are a variety of ways to configure the source itself, such as point, area and volume sources. As the updates to the SCAIL-Agriculture tool are based on the improvements that were recently made to the SCAIL-Combustion tool, AERMOD has been used to model the dispersion from the agricultural sources in question. This model was successfully used in the SCAIL-Combustion tool and has been well validated for regulatory applications. AERMOD allows the use of a variety of source configurations, although there are some important limitations on how these may be applied.

Point sources are the simplest type of source available in AERMOD and are used to represent emissions from distinct locations such as stacks or vents. Point sources are the only source type that can be applied in conjunction with buildings. For the purposes of modelling agricultural sources associated with pig and poultry units, point sources would be applicable to model forced-ventilation buildings with either roof or wall fans. This would also then require the effects of the associated building on aerial dispersion to be modelled. The basic information needed to model a point source includes:

- *point emission rate in g/s or* OU_E*/s,*
- *release height above ground in metres,*
- *stack gas exit temperature in degrees K,*
- *stack gas exit velocity in m/s, and*
- *stack inside diameter in metres*

Emission rates for the agricultural process being considered have been determined using the latest data available for pig and poultry units, as discussed in Section 2.1. The release height both above ground and in relation to the rest of the building may affect subsequent dispersion of aerial emissions. For forced ventilation it is also important to understand the gas exit velocity through the stack or vent, which has been determined by the fan speed of the ventilation system. Typical ventilation rates for farm buildings expressed on a per animal basis are shown in Table 2-D.

Table 2-D: Typical ventilation rates for agricultural buildings from Seedorf *et al.* (1998).

Type	Winter (m^3/s per animal)	Summer (m^3/s per animal)	Average (m^3/s per animal)
Pig, Sows on litter	0.031	0.058	0.044
Pig, Sows on slats	0.018	0.023	0.020
Pig, Weaners on slats	0.0025	0.0033	0.0029
Pig, Fatteners on litter	0.013	0.023	0.018
Pig, Fatteners on slats	0.0056	0.014	0.010
Poultry, Layers (Aviary)	0.00056	0.0014	0.0010
Poultry, Layers (Caged)	0.00056	0.00083	0.00069
Poultry, Broilers (litter)	0.00028	0.00056	0.00042

The stack diameter will also affect the dispersion of material being emitted. For the types of agricultural unit being considered in the SCAIL-Agriculture tool, the temperature of the emission is unlikely to be important as emissions will generally be close to ambient temperature. AERMOD includes a modelling option that will adjust the exit temperature for each hour to match the ambient temperature plus 5°C. This has been applied herein, although the results are unlikely to be sensitive to the assumption of release temperature.

Area sources can be specified in AERMOD in terms of their shape and size, and represent a low-level, or ground-level diffuse source with no plume rise. For agricultural sources associated with pig and poultry units, area sources are applicable to slurry spreading, free-range animals, hard-standings or manure storage tank releases. The area sources that are used in SCAIL-Agriculture are circular sources and are located by their centre-point. The basic data needed to model an area source include:

- *area emission rate in g/(s-m^2) or* OU_E *m^{-2} s^{-1}*
- *release height above ground in metres(this was set to zero as only ground level sources were modelled).*
- *radius of the source, in m.*

The emission rate for the area source is an emission rate per unit area, which is different from the point and volume source emission rates, which are total emissions for the source in units per second.
Volume sources are also used as a source configuration in AERMOD. Volume sources would be applicable to modelling naturally ventilated buildings or sheds considered as “leaky boxes” (Environment Agency, 2010). The basic information needed to configure a volume source includes:

- *volume emission rate in g/s or* OU_E*/s*
- *release height (centre of volume) above ground, in metres*
- *initial lateral dimension of the volume in metres*
- *initial vertical dimension of the volume in metres*

All three source configurations (point, area and volume) are available to the user of the SCAIL-Agriculture tool as farms may incorporate numerous sources of different dimensions.

2.2.1. Modelling buildings

Buildings near to a source may influence the aerial dispersion of emissions by creating eddies in the airstream and by potentially inducing downwash in the building wake, which can cause local areas of high concentrations of pollutants. Methods available to include local building influences include those outlined in Table 2-E. A short description of the positive and negative aspects of each method in relation to the SCAIL-Agriculture update is also given in Table 2-E.

Table 2-E: Methods available to model buildings

Method	Positives	Negatives
Compile the BPIP-PRIME model to allow the direct incorporation of data through the interface.	Allows complete use of building configurations and deals with site complexity.	Expensive to code, test and implement. Unlikely that users will have the building information required.
Derive a simple implementation of the BPIP-PRIME model specific to agricultural buildings.	Allows a limited set of modelling parameters to be derived appropriate for specific building types.	Requires coding and testing. Unlikely to be able to account for groups of buildings. User may not have building information available.
Derive simple building types allowing the user to select the closest approximation from a list.	Accounts for main building effects, does not require detailed input data, likely to be slightly overpredictive in the near field for building groups. Ease of use.	May be too simplistic, may overpredict concentrations in the near-field.

A simple scheme based on an idealised building type has been used in the tool as this option provides a level of detail that is sufficient to take buildings into account, without overcomplicating the system from the user's perspective. Where a farm has several buildings close together then the user of the tool should consider treating them as one "effective" building.

SCAIL-Agriculture will not include terrain (topographical) effects due to the limitations in the availability and ease of use of such data for screening purposes. Complex terrain effects would be expected where terrain gradients of 1:10 or greater apply (Hill *et al.,* 2007). Intensive agricultural installations that would be included in the Industrial Emissions Directive would be likely to require detailed modelling to account for the influence of complex terrain.

2.2.2. Modelling deposition and plume depletion

Ammonia deposition in the near field may account for around 5-10 % of the emission from a poultry farm (Pitcairn *et al.,* 1998; Hill 2000, Walker *et al.,* 2008). Deposition has been accounted for in the SCAIL-Agriculture tool by following the EA Stage 1 guidance (EA, 2010), which is applicable to a screening tool. This method estimates deposition at a specified location downwind of the source by using a habitat-specific deposition velocity, which is multiplied by the modelled air concentration at the relevant downwind location. Using this method, local deposition is only calculated at the site of interest. The deposition velocities applied in the tool are shown in Table 2-F.

Table 2-F: Deposition velocities applied in SCAIL-Agriculture

Habitat	Deposition Velocity
Woodland	0.03 m/s
All other surface types	0.02 m/s

In addition, plume depletion due to dry deposition has not been included in the tool. Ignoring plume depletion due to dry deposition of ammonia could lead to an overprediction of local air concentrations by approximately 10 %, and hence overestimation of dry deposition. The overestimation of dry deposition may increase with distance from the source, due to calculating deposition from the undepleted plume, and again the overestimation may be approximately 10 %.

Nitrogen deposition flux and acid deposition flux resulting from the emissions of NH_3 will be calculated at the site of interest and background rates for these processes will be obtained from APIS.

Wet deposition of ammonia has been ignored due to the dominance of local ammonia dry deposition. Deposition has not been considered for PM_{10} as it is the air concentrations that are of concern for human health.

Atmospheric chemistry has not been considered in the tool due to the low chemical conversion of NH_3 at the local scale being considered (*e.g.* within 10 km of the source) and hence over a relatively short timescale (*e.g.* typically less than 1 hour atmospheric transport time).

2.2.3. GIS methods

Habitat data in the form of GIS datasets have been obtained from the relevant agencies as detailed below. The following designations or their equivalents have been included in the tool:

- *Sites of Special Scientific Interest (SSSI) and Areas of Special Scientific Interest (ASSI) in Northern Ireland*
- *Special Area of Conservation (SAC)*
- *Special Protection Area (SPA)*
- *Natural Heritage Areas (NHA)*

The datasets were obtained from the following agencies:

- *Scottish Natural Heritage (SNH)*
- *Natural England*
- *Countryside Council for Wales*
- *Northern Ireland Environment Agency*
- *National Parks & Wildlife Service (NPWS) in Ireland*

A direct live data link between the tool and the data repositories of the various agencies would have been the most efficient model. However, this was not implemented due to potential technical complexities in data formatting and access. The system will have to rely on data which has been manually downloaded from the agency websites. The process to update the designations information will be made as simple as possible. The frequency of these updates will need to be specified and could be stated on the website. The habitat datasets in question do not change frequently, therefore the fact that the data is based on a download will not present a major issue.

Once the data and licensing were in place, the datasets were converted into the correct format and coordinate system for use in an Oracle database and displayed on Google Maps. Oracle was selected for use in GIS analysis in this online tool because of its comprehensive search functionality and ease of integration within the web-based user interface.

Once a location is selected the tool will return a list of habitat sites within a user-specified radius. This output is integrated with the outputs from the rest of the tool and the APIS system. The locations of the habitats sites are displayed via Google Maps.

It is important to note that RAMSAR sites are not included within the automated site lookup functionality and, if required, need to be added by the user manually as "user specified sites". Information on RAMSAR sites can be obtained from the JNCC.

2.2.4. Critical loads and levels and links with the GIS system

For each designated site (SAC, SPA, A/SSSI or NHA in Ireland) there are key habitats or species features that have been listed as part of the site designation. These listed features (habitats and species) also require links between themselves and the relevant critical loads for nutrient nitrogen and acidity.

For the UK, the process of linking designated features to their respective critical loads of nitrogen deposition and acidity has already been done (Sniffer ER04, 2011) and this dataset has been linked into the SCAIL system as a look-up table. In order to simplify the selection of multiple habitats or species, SCAIL-Agriculture returns the feature at that site that is most sensitive to nutrient nitrogen or acidity.

For Ireland, habitats which are already present in the linkages database have been used for designated sites, but some habitats and bird species particular to Ireland have had new linkages made and have been added to the database.

For calculating ammonia exceedances, designated habitats and features for the UK or Ireland have not been allocated to a particular critical level for ammonia. There are currently only two critical level values for habitats, namely 1 µg m^{-3} for lichens and bryophytes and 3 µg m^{-3} for other vegetation. For the SCAIL-Agriculture tool it was decided to include results for both critical levels and to allow the user to decide which was relevant.

For non-designated sites (*e.g.* LNRs or other non-designated habitats) a look-up table for a generic set of habitats has been developed based on the previous version of SCAIL-Agriculture.

For nutrient nitrogen critical loads, the same linkages have been applied to each designated feature in Ireland as were applied for UK sites. The acidity critical loads that have been used were derived from a project by the EPA in Ireland as part of their national reporting to the Coordination Centre for Effects for use by the Working Group on Effects of the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP).

2.2.5. Background air concentration and deposition data

For ammonia, nitrogen and acid deposition, background maps of concentrations and depositions for the UK and Northern Ireland are already set up in the APIS system and have been used for assessing UK designations. These datasets include[2]:

- *Nitrogen Deposition: 3-year average (2010-2012); 5km resolution*
- *Acid Deposition: 3-year average (2010-2012); 5km resolution*
- *NH_3: 3-year average (2010-2012); 5km resolution*

The methodology that was applied is as follows. Total N and S deposition was calculated for a 5 km x 5 km grid square as the sum of wet, dry, cloud droplet and aerosol deposition. In general most of the deposition is from rain (wet) or gases (dry). The basis of the method is to start from national measurement site concentration data and derive a concentration map for each pollutant - these are SO_2, NO_2, HNO_3, NH_3, SO_4, NO_3 and NH_4. Deposition is then the product of the concentration map and a process to deliver the pollutant from the atmosphere to the landscape. Wet deposition uses rainfall modified to account for the orographic enhancement of both rainfall volume and rain ion concentrations. Dry deposition uses a modified big leaf model which basically estimates the transfer

[2] The APIS datasets are updated as new deposition data becomes available.

rates from the atmosphere to the canopy surface and then the uptake by various mechanisms within the plant canopy.

Cloud droplet and aerosol deposition use a simpler version of the same mechanistic structure as dry deposition. Where it is beneficial, *e.g.* for NO_2 and NH_3 concentrations, extra model information from the emissions inventory is used to improve the spatial pattern of the concentration maps. The deposition is modelled to each land-use separately so the differences between moorland and woodland are related to the physics of the canopy structures and the biology of the plants in that typical land use.

For Ireland deposition maps are presented on a 5 km × 5 km grid (based on the Irish grid); dry oxidised sulphur and nitrogen deposition to forest and semi-natural ecosystems were produced from observation (based on recent wet deposition for sulphate and longer-term wet deposition for nitrogen). These data were supplemented with EMEP oxidised nitrogen and sulphur deposition obtained from the EMEP chemical transport model developed at Meteorological Synthesizing Centre-West (URL: webdab.emep.int/Unified_Model_Results).

In Ireland ammonia concentrations were based on air concentrations during the period 1999–2000 calculated from the interpolation of annual average data from a monitoring network of 40 stations.

Background air concentrations of PM_{10} for Great Britain (1 km GB grid) and Northern Ireland (1 km Irish Grid) were included from the most recent base year that modelled background data are available (2010). These data are available from the DEFRA website (http://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html).

For Ireland, background air concentrations of PM_{10} were taken from the FRAME model and were based on a 5km grid resolution. The background data for the most recent year that modelled background data are available (2007) were incorporated into the SCAIL-Agriculture tool.

Background odour concentrations are not included as these are not typically required as part of an odour assessment due to the intermittent nature of odour episodes.

2.2.6. PM_{10} components and human health limits

Particulate matter (PM), especially small particles less than 10 µm in diameter (PM_{10}) and fine particles less than 2.5 µm in diameter ($PM_{2.5}$), have been shown to have adverse effects on human health. Hence, in Europe there are standards for concentrations of PM_{10} and $PM_{2.5}$ in air that must be met. The standards for the UK and Ireland for concentrations of PM_{10} and $PM_{2.5}$ are shown in Table 2-G. The revised SCAIL-Agriculture tool incorporates a method to estimate PM_{10} concentrations at receptors (typically the nearest human residences to the farm), and to assess the contribution of the farm to this concentration.

Emission factors for $PM_{2.5}$ are less readily available, however there is evidence to suggest that concentrations of PM_{10} and $PM_{2.5}$ are closely linked, therefore the ratio between the two size fractions can be used to estimate concentrations of $PM_{2.5}$. Recent reports have shown that throughout Europe the ratio between $PM_{2.5}$ and PM_{10} ranged from 0.42 to 0.78 and more specifically in North-western Europe (including the UK and Ireland) the ratio was 0.5 to 0.7 in rural areas and 0.6 in urban areas (Sniffer, 2010b). Another recent study in Scotland showed that the mean $PM_{2.5}$ to PM_{10} ratio for sites studied in Scotland is 0.66 (Stevenson *et al.*, 2009), which is consistent with the study for the whole of Europe. The annual mean concentration of $PM_{2.5}$ can therefore be estimated from the concentration of PM_{10} modelled using SCAIL-Agriculture by applying an appropriate scaling factor.

Table 2-G: Relevant air quality standards for $PM_{2.5}$ and PM_{10}.

Region	Pollutant	Time Period	Standard Conc. (µg m-3)	Number of exceedances permitted	Date to be achieved by
England, Wales, N.Ireland and Republic of Ireland	$PM_{2.5}$	Annual mean	25	0	2020
	PM_{10}	24-hour mean	50	35	2005
		Annual mean	40	0	2005
Scotland	$PM_{2.5}$	Annual mean	12	0	2020
	PM_{10}	24-hour mean	50	7	2005
		Annual mean	18	0	2005

Percentiles of the daily average PM_{10} concentration are required in order to demonstrate compliance with the short-term (24-hour mean) air quality objectives for the UK and Ireland. In England, Wales and Ireland the 90th percentile of daily average concentrations is required and in Scotland the 98th percentile is required. These percentiles equate to 35 permissible exceedances of the 24-hour average objective in England, Wales and Ireland and 7 permissible exceedances in Scotland (in any one year). The 90th and 98th percentiles of 24-hour mean concentrations were calculated by outputting the 36th and 8th highest concentrations from AERMOD. An option was included in the tool to allow the user to define the PM_{10} metric that is output.

A comparative empirical approach to the number of exceedances was initially evaluated using the method from TG(09)(Defra, 2009) though was not implemented. This method is as follows:

No. 24-hour mean exceedances = -18.5 + 0.00145 x annual mean^3 + (206/annual mean)

However, it should be borne in mind that this formula breaks down for low annual mean concentrations. Therefore an additional argument would need to be incorporated which highlights that no exceedances of the 24-hour average objective are expected using this method when annual mean concentrations are below a defined concentration (approximately 16 µg m^{-3}). Figure 2-A shows the relationship between annual mean PM_{10} concentrations and the expected number of exceedances of the 24-hour mean objective using the formula from TG(09) (Defra, 2009).

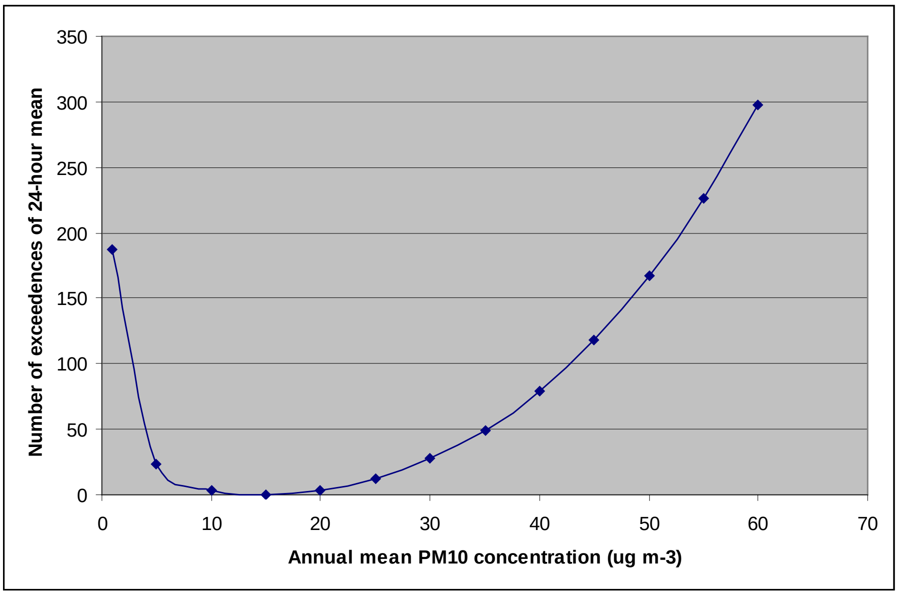

Figure 2-A: Relationship between annual mean PM_{10} concentrations and the expected number of exceedances of the 24-hour mean objective

The chemical composition of PM_{10} is often complicated and difficult to define without carrying out detailed monitoring and analysis of air samples. It is envisaged that more often than not, the user of the SCAIL-Agriculture tool will not have any detailed information regarding the chemical composition of the particulate matter being released by an intensive farm unit. In addition, it is assumed that in most cases the potential health effects of the particulate matter itself will be of more concern than the chemical toxicity of the particles as the particles are very small. From the sources in question, there should not be any substances present which would be particularly toxic in such small quantities, otherwise it is likely that they would already have been identified for separate investigation. With this in mind, it is envisaged that it will not be necessary to include an option in the tool for the user to specify the chemical composition of the particles being released.

If the user needs to calculate the air concentration of specific chemical pollutants in addition to PM_{10} and NH_3, then emissions should be calculated external to SCAIL-Agriculture and inputted along with a description in the relevant comments box. However, it should be borne in mind that background concentrations and information on environmental assessment levels will still relate to PM_{10}.

2.2.7. Methods for determining impacts of odour emissions

Benchmark levels that can be used to indicate the likelihood of unacceptable odour pollution are provided in the Environment Agency H4 Odour Management guidance document (Environment Agency, 2011). Very similar target and limit values are used by the Environmental Protection Agency Ireland (Harreveld, 2000). A benchmark level of 3 ou_E m^{-3}, measured as the 98th percentile of hourly means, was used in the SCAIL-Agriculture tool to decide whether a pig or poultry unit could result in unacceptable levels of odour. In the Environment Agency H4 guidance, 3 ou_E m^{-3} (as the 98th percentile of hourly means) is the benchmark level for moderately offensive odours, which includes odours from intensive livestock rearing. In the EPA Ireland framework, 3 ou_E m^{-3} (as the 98th percentile of hourly means) is the limit value for odour from new pig production units. The EPA Ireland framework also includes a limit of 6 ou_E m^{-3} (as the 98th percentile of hourly means) for odour from existing pig production units. No distinction is made between new and existing livestock units in the SCAIL-Agriculture tool as this will be used simply as a benchmark for screening whether further consideration of odour needs to take place.

Odour concentrations calculated as the 98th percentile of hourly means (the 176th highest value) are estimated using the AERMOD dispersion model within the SCAIL-Agriculture tool, however, some consideration must be taken of complex situations for which there may be large uncertainties in the model predictions.

Odour from slurry or manure spreading typically arises from the products of anaerobic chemical processes resulting from storage conditions. The process of broadcasting facilitates the release of these chemical into the atmosphere causing downwind odour nuisance. However, the effects are relatively short-lived. Broadcasting rapidly introduces aerobic conditions to the slurry, slowing down the production of the key odoriferous products. This is seen in the rapid reduction in odours reported (*e.g.* Misselbrook *et al.*, 1997), with odours not being detected 24 hours after application. Thus the usual remediation method for slurry spreading, ploughing-in within 24 hours, does not reduce the odour nuisance significantly. However, amelioration by direct injection into the soil does result in much lower odour impact (Agnew, 2010).

As AERMOD is designed to model the dispersion of continuous emissions to air, the prediction of odour concentrations from slurry or manure spreading in isolation would not be accurately modelled using the continuous emission factors and annual meteorology that is available within SCAIL-Agriculture. Where impacts of slurry spreading operations in isolation from other farm sources are required, then an alternative methodology should be applied that applies short-term meteorological and emissions data relevant to the conditions that prevail during the broadcasting.

Modelling of odour from multiple sources is another complex situation that may increase uncertainty in the modelled odour concentrations (Pullen and Vawda, 2007). A study by Hoff and Bundy (2003) used a Gaussian dispersion model to estimate odour concentrations from multiple swine production sources. The study concludes that the model can be used for screening applications such as evaluation of site selection, evaluation of odour control technologies, and evaluation of the impacts of expanding existing facilities. It is therefore considered that the AERMOD model will be adequate for the screening application of SCAIL-Agriculture for multiple odour sources. The modelling of low- or ground-level odour sources and buildings in SCAIL-Agriculture is discussed in Sections 2.2.1, 4.4.5 and 4.4.6.

The applicability of meteorological data for a typical meteorological year to the calculation of short term (98th percentile of hourly mean) concentrations has been considered. It is considered that the use of typical meteorological year data will be appropriate in the calculation of 98th percentile of hourly average concentrations as the meteorological data used are hourly sequential data. It is not feasible to use or obtain meteorological data for averaging periods of less than 1 hour for use in the SCAIL-Agriculture tool as this would result in long model run-times and high cost in terms of obtaining and processing the meteorological data. In addition, Pullen and Vawda (2007) state that dispersion models are currently only practical for predicting ensemble mean concentrations and that fluctuation modelling is not yet adequately validated.

The treatment of periods of low wind speed (calms) by AERMOD has also been considered as it is known that high concentrations of odour can occur during stable conditions with low wind speeds, when dispersion is poor (Pullen and Vawda, 2007). AERMOD uses the guideline method recommended by the US EPA (detailed in Appendix W of the U.S. Code of Federal Regulations Part 40 , page 29). This method employs a calms processing feature whereby all concentrations for a calm hour are set to zero and the subsequent short-term averaging is calculated using fewer hours than the given period to eliminate the artificial lowering of concentration that a calm hour would give. The calms processing routine uses no fewer than 75% of a given averaging period number of hours. For example, for a 24-hour average, AERMOD will calculate a “24-hour average” on as few as 18 hours. If 6 hours within that 24-hour period are calm, AERMOD will ignore those 6 values and divide the total concentration from that day by 18. The resulting calculation will be labelled the 24-hour average. If more than 6 hours are calm, then the additional zero concentrations will be factored into the average. This procedure is adopted because the basic calculation performed by AERMOD involves the inverse of the wind speed, hence calm winds cannot be processed by the model as it would result in a division by zero error.

Due to the nature of the meteorological conditions in the UK and Ireland, it is unlikely that the typical meteorological year data that are proposed to be included in the SCAIL-Agriculture tool will include extended periods of calm conditions. It is expected that uncertainties in modelling odour concentrations will increase in low wind speeds, however the use of a 98th percentile value will account for some of this variability and uncertainty in model predictions. Further discussion of the meteorological data to be used in SCAIL-Agriculture is provided in Sections 2.2.10 and 4.1.

2.2.8. Expectations of the user

The system has simple input parameters that are consistent with the information that farms need to supply as part of their permit application. To the user, the look and feel of the tool is designed to be similar to the SCAIL-Combustion tool. The tool is designed to be easy for the user to navigate without necessarily having specialist knowledge of aerial dispersion or atmospheric chemistry, especially if they are already familiar with the SCAIL-Combustion tool. However, in designing the tool it is possible for "expert users" to adapt the modelling methodologies to allow more complicated processes to be included or to apply alternative emission factors. An example would be the option for the user to include an emission of a "user defined" pollutant and apply the point source model in SCAIL-Agriculture to consider plant such as on-farm anaerobic digesters.

The simplicity of the tool means that assumptions and default data are included, for example the use of two default habitat-dependent deposition velocities and typical meteorological year data as opposed to real meteorological data. The drawback of increasing simplicity is that the tool becomes less realistic, however where assumptions and defaults are included in the tool they are derived from the latest guidance and research where possible. The benefits of having a simple system are believed to outweigh the disadvantages, as in many cases more realistic or complex input data may not be available. In addition, the SCAIL-Agriculture model is a screening tool to indicate whether more detailed modelling needs to be carried out; hence it is not designed to replace more detailed dispersion modelling.

2.2.9. Licensing requirements

Habitat data in the form of GIS datasets were obtained from the relevant agencies along with their consent for their datasets being integrated within the SCAIL-Agriculture tool.

The Google Maps interface is used for the display of location information in SCAIL-Agriculture. This tool is freely available and its implementation within SCAIL-Agriculture does not require any third party access to the underlying datasets.

There are no licensing issues associated with the aerial dispersion element of the tool as the system uses data already available through various agencies involved in the project or data and methods that are already used in SCAIL-Combustion or are publicly-available. As applied in SCAIL-Combustion the meteorological database will only be used for running the AERMOD model and it will not be possible for users to download meteorological datasets, thus removing any potential licensing issues.

2.2.10. Meteorological data

Meteorological data for the UK was obtained from the existing SCAIL-Combustion tool (Sniffer, 2010a, Section 3.1, pages 5 -13). This tool uses statistically-selected meteorological data for 30 meteorological stations throughout the UK. The statistical methods identify a "typical" year of meteorological data that is representative of the weather at the particular location in question, derived from five-years of continuously measured meteorological data. This work has already been carried out for the UK for the SCAIL-Combustion tool. The nearest meteorological station to the emission point is selected by the screening tool.

Meteorological data were obtained from 11 sites in the Republic of Ireland and the same approach was applied to define "typical meteorological years" for incorporation of the data into SCAIL-Agriculture. The locations for which meteorological data are available in Ireland are shown in Figure 2-B.

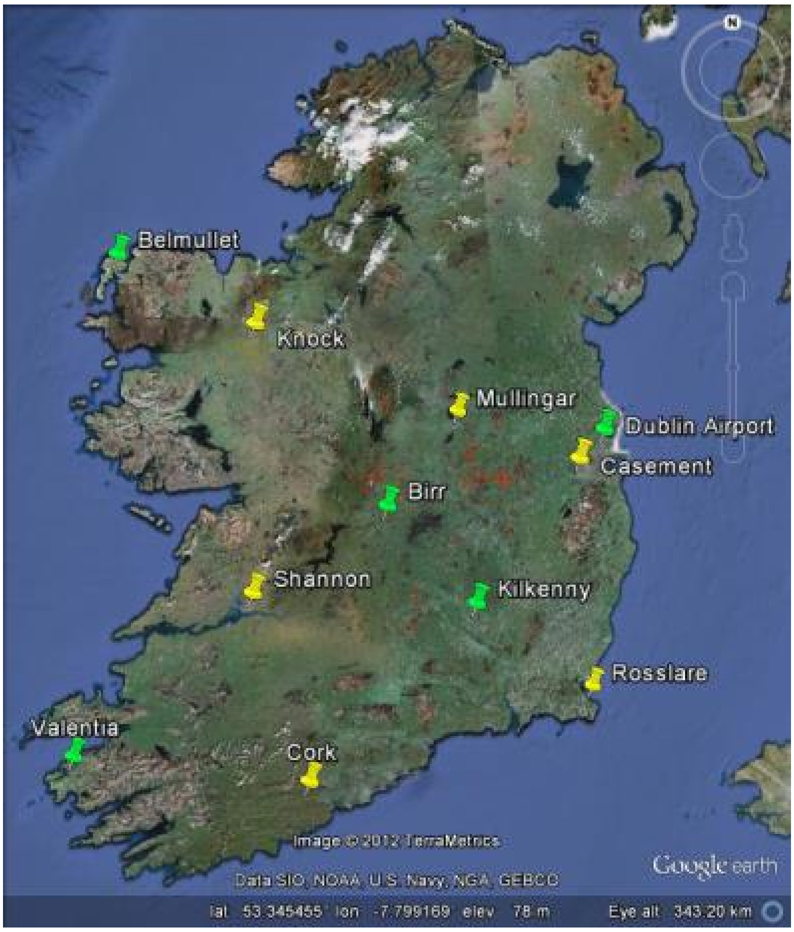

Figure 2-B: Location of meteorological stations in Ireland

3. Architectural design

3.1. Data Input

The data input page is shown in Appendix D. The assessments conducted using SCAIL-Agriculture follow a linear process and can be divided into several logical blocks. The following is a descriptive summary of the requirements of each block. A comprehensive user guide for SCAIL-Agriculture can be found on the website and should be referred to for details of how to use the tool.

At the top of the data input page the user has the ability to select either the 'User Guide', the 'SCAIL-Agriculture Report' (*i.e*. this project report) or a link to the appropriate EPA/SEPA/EA/NIEA contacts if further information is required. The user is able to click the "?" buttons to show simple guidance notes on how to input data. The "X" buttons allow the user to delete incorrect data entries.

3.1.1. Project Details

The project details section is used to provide background notes and a description for the assessment. The user must also select whether the screening tool should be run with conservative or realistic meteorological data. No other inputs are required for this section.

3.1.2. Location Details

This section allows the user to select whether the assessment is performed for sites in England, Scotland, Wales, Northern Ireland or the Republic of Ireland. This provides information to the tool with regards to the appropriate air quality objectives to apply to the assessment and defines the grid system required for the GIS element of the tool.

3.1.3. Installation Details

The term "Installation" is used to describe the economic entity (or farm) for which it is required to carry out an assessment. An "Installation" may well be comprised of a number of emission sources. The location of the first "Installation" that is entered is a key requirement for other data flows as it will be used as the basis for the lookup of other geographical information such as the position of sensitive habitats, the acquisition of background information and meteorology data. Emissions from more than one installation can be modelled if, in the user's judgement, they are sufficiently close to each other or to a sensitive receptor that there is sufficient benefit in modelling the contribution from each facility. Multiple sources may be entered by selecting "Add Installation". However, the number of "Installations" which may be entered in a single assessment will be limited to 10.

In the "Installation Details" section the user will be asked to enter the following information:

- *Name*
- *Location*

The map tool allows the user to visualize the specified installation location on Google Maps to check that the location is correct. An installation can be dedicated to either pigs or poultry since units of the size requiring assessment and authorisation are usually too large to be of a mixed animal type, however different facilities in the same assessment can be of different animal types.

It should be noted that when running the model the output from all the sources within an installation is grouped and shown as a single contribution on the output page. Hence, expert users can use different "Installations" to group emissions and enable assessment of their contributions to the concentrations and depositions that are output.

3.1.4. Source Details

This section deals with the specification of emission sources within the facility. There are three types of emission source which may be configured; housing (force-ventilated or naturally ventilated), manure storage or land spreading. Emissions from more than one source may be modelled. Multiple sources may be entered by selecting “Add a source”. However, the number of sources which may be entered in a single assessment will be limited to 10 sources.

The user will be asked to enter the following information for each source:

- *Source name*
- *Source location*
- *Source type*

The source location should be the centre point of the building, manure storage facility or land spreading area. The “Verify location” option allows the user to use a mapping tool to confirm the location of the source(s).

(a) Estimating emissions

The user will be required to specify further information to estimate unit emission rates of NH_3, PM_{10} and odour from each source, as follows.

For housing:

- *Livestock type and associated housing type / livestock maintenance system*
- *Number of livestock*
- *Housing floor area*

For manure storage:

- *Manure storage type and cover type (for slurry storage only)*
- *Tonnes of fresh manure (not required for slurry)*
- *Area of storage*

Cover type is used to apply simple scaling factors to adjust the emissions from a manure storage area depending on whether the source incorporates methods to reduce emissions (*e.g.* covers to reduce emissions of odour and particulate matter).

For land spreading:

- *Land spreading type and feed type (if applicable)*
- *Tonnes of fresh manure (for poultry) or area of storage (for pigs)*
- *Field area of application*
- *Frequency of application*

The calculated emission rates are then presented for the user. The user can edit them if better information is available.

(b) Source configuration

The source type will determine the configuration of the source within AERMOD. Force-ventilated buildings will be modelled as point sources for which several additional input parameters are required as follows:

- *Building height (m)*
- *Fan location (roof or side of building)*
- *Number of fans*
- *Fan diameter (m)*
- *Fan flow rate (m^3/s)*

Fans are expected to be located either at roof level or on the side of the building. The user will also have the option to enter the number of fans and the fan diameter. If the fan diameter is not known or unspecified then a default fan diameter of 0.5 m is used. If the fans are located at roof level, the user will have an option to input a fan flow rate. If the fan flow rate is not specified then a default of 0 m^3/s should be used as this will result in higher concentrations being recorded in the output and is therefore appropriate for a screening model. For fans located on the side of a building the flow rate is automatically calculated within AERMOD to restrict plume rise as this is the USEPA's recognised method for treating horizontal releases and building effects at the same time.

The effect of building downwash on dispersion from force-ventilated buildings is modelled in AERMOD. This requires additional information on the building dimensions. The lateral dimensions (length and width) of the building are assumed to be identical (*i.e*. the building will be square) and determined by the size of the building footprint. Building length and width are therefore not required as input by the user and default surface areas based on livestock husbandry guidance can be applied where no information on building dimensions exist.

Naturally ventilated buildings are modelled as volume sources for which the lateral and vertical dimensions are required. The user will be expected to input the height of the building from which the vertical dimension of the volume source will be determined. The lateral dimensions will be determined by the size of the building footprint (again assuming that the building is square) and are therefore not required as input by the user. Note that the effect of buildings upon dispersion cannot be modelled explicitly for volume sources.

An area source is used to represent the surface of manure storage areas or areas where land spreading occurs. It is assumed that the surface is at ground level. The lateral dimensions of the source is determined by the area of storage or landspreading (assuming the area source is circular) as input by the user. It is noted that defaults of 400 m^2 and 10,000 m^2 were applied in the previous version of SCAIL-Agriculture for manure storage and landspreading areas. Expert users should note that the effects of buildings upon dispersion from area sources cannot be explicitly modelled.

3.1.5. Designated Site Details

Designated sites are areas identified or mapped out to enhance the conservation and protection of habitats. A designated site may contain multiple habitats. The first specified "Installation" location is used to draw upon information held in an Oracle Database to search for designated sites within a specified distance from the source.

It should be noted that if more than one installation is being assessed, the search will still be performed from the centre-point of Installation number 1, hence it is important that this installation represents the dominant source of emissions to air.

The mapping tool presents the relative positions of the designated sites for visual confirmation of location accuracy. In addition a table is shown detailing the following information: Site No.; Name; Distance(km); Designation; Easting; Northing.

The user can input a user-specified site, as information on some sites (*e.g.* Ramsar Sites) is not held within the Oracle Database. The impact on more than one site may be modelled by selecting "Add a site".

The user will be asked to enter the following information for each user-specified site:

- *Site name*
- *Site location*
- *Habitat type*

The user interface does not allow multiple habitats to be listed for a single user-specified site. Where there are multiple habitats present then additional receptors should be added at the same location.

Expert users can obtain information on background concentrations and deposition rates, along with information on critical loads and levels for automatically identified sites by creating a user specified site and entering the Easting and Northing manually.

3.1.6. Human Health Receptor Details

For PM_{10} and odour, the sensitive receptors are locations at which human impacts will be assessed and these must be specified by the user. The impact on more than one human health receptor may be modelled by selecting "Add a site". However, the number of human health receptors which may be entered in a single assessment is limited to 10 receptors.

In the "Human Health Receptor Details" section the user is asked to enter the following information:

- *Receptor name*
- *Receptor location*
- *The output that is required when modelling PM_{10} (annual average, 90^{th} percentile or 98^{th} percentile)*

The mapping tool presents the relative positions of farm and human health receptor sites for visual confirmation of location accuracy. The locations of the human health receptor can be modified in Google Maps and will automatically update in SCAIL-Agriculture. The user may view background concentrations at each human health receptor by clicking on the "Check Background Levels" option.

3.1.7. Run model

The final requirement of the user input is to initiate the calculation. The user also has the option to save the input at this stage, although this option is also available on the output page.

3.1.8. Save input

The current load/save routines in SCAIL-Combustion will be extended to cover new data specific to the configuration of SCAIL-Agriculture. The user may save the input at this stage but the user may wish to make modifications to the input based on the results. An option to save the input file is also provided on the results page. Data will be saved on the user's local system.

3.2. Results

The results page for SCAIL Agriculture is shown in Figure D-2 in Appendix D.

At the top of the results page the user will have the ability to select either the 'User Guide', the 'SCAIL-Agriculture Report' (*i.e*. this final project report) or a link to the appropriate EPA/SEPA/EA/NIEA contacts if further information is required. The user is able to click the "?" buttons to show a simple guidance notes on how to interpret the results.

3.2.1. Project Details

This section is a repetition of information entered by the user in the Project Details section of the input. This includes information regarding the project run mode.

3.2.2. Receptor Site Information

Results are displayed for a single designated site or human health receptor which the user may select from the drop down box in the Receptor Site Information section. The drop down box contains the list of designated sites and human health receptors in distance order for those that are automatically located by SCAIL-Agriculture with the closest sites first.

3.2.3. Facility/Source Details

This section displays the emission, concentration and deposition (if applicable) from each installation. Results for designated sites are displayed as air concentrations for NH_3 as well as deposition for nitrogen and acidity. Results for human health receptors are displayed as air concentrations for PM_{10} and odour.

3.2.4. Total Concentration, Deposition and Exceedances

This section displays the combined impact of all facilities included in the assessment. The combined impact is assessed against the relevant critical level, load, air quality standard or odour threshold. Exceedances are displayed as a positive value (in red text) or 'no exceedance' is displayed where no exceedances are identified. The "view ranges" option allows the user to view a range of critical loads applicable to habitat types within a designated site to determine if an appropriate critical load has been used in the calculation.

3.2.5. Notes

Any notes may be entered by the user in a comment box at the bottom of the results page. The notes should be specific to the designated site or human health receptor results currently displayed.

3.2.6. Back

There is an option to return to the data input page to add additional facilities and/or sources and run the assessment again. In this way the user can build an assessment by facility, or even by source, to gain an indication of source apportionment.

Please note that the back button on the web-browser should not be used as this may result in loss of data.

3.2.7. Save input

This option allows a user to save the input file used to run AERMOD and configure SCAIL-Agriculture, enabling the assessment to be rerun at a later date in SCAIL-Agriculture, or for the input data to be transferred to AERMOD for detailed modelling. Data will be saved on the user's local system.

3.2.8. Save results

This option saves the results in a comma separated file format similar to the format provided on the results page. Data will be saved on the user's local system.

4. Functional specification

Following on from the general description of the functionality in Section 3, several features can be identified which require further technical description.

4.1. Select meteorological data based on source location

This procedure will use the same procedures as applied within SCAIL-Combustion. Default datasets are already available for 30 meteorological stations around the UK. Eleven meteorological stations have been identified in the Republic of Ireland and are included as typical "meteorological years" to extend the current coverage.

4.2. Co-ordinate system

The tool is required to assess facilities in Britain, Northern Ireland and the Republic of Ireland and is therefore required to accommodate coordinates from 3 different coordinate systems; the British National Grid, the Irish National Grid and the Irish Transverse Mercator. The appropriate grid is determined by the specification of the country in the "Location Details" section of the input.

The user is required to enter a location either in the grid format appropriate to the coordinate system, *e.g.* NJ692258, or a full 12 digit grid reference, *e.g.* 345665,456755. The location can be verified by using the mapping tool, which will use the grid reference entered and present the location in Google Maps.

4.3. Mapping tool

Google Maps was selected as the web-based mapping tool used to display geographical information, because of its simple user-interface and its familiarity for many users. It also removes any potential issues in coordinate systems when crossing the boundary between two separate countries. The users of SCAIL-Agriculture are able to utilise the standard tools associated with Google Maps such as pan and zoom to verify the location of sources and receptors. In addition satellite imagery can be used to identify sources and receptors.

4.4. Calculating emissions

Emission factors are stored in an Oracle Database to provide robust data management and enable information to be updated as easily as possible. It should be noted that updates are expected to all emission factors databases as new scientific data becomes available. The tool also includes options to allow the user to modify the emission values predicted by the interface, although suitable comments should be included to justify any changes.

4.4.1. Animal housing

Emissions of NH_3, PM_{10} and odour from animal housing are estimated using a series of inputs to define the source. The flow chart in Figure 4-A describes the options available to the user leading to the choice of emission factor for each animal housing source. Emission factors for NH_3, PM_{10} and odour are available in units per animal or bird, therefore the combined emission for a whole building will be a product of the emission factor and the number of animals or birds in the building.

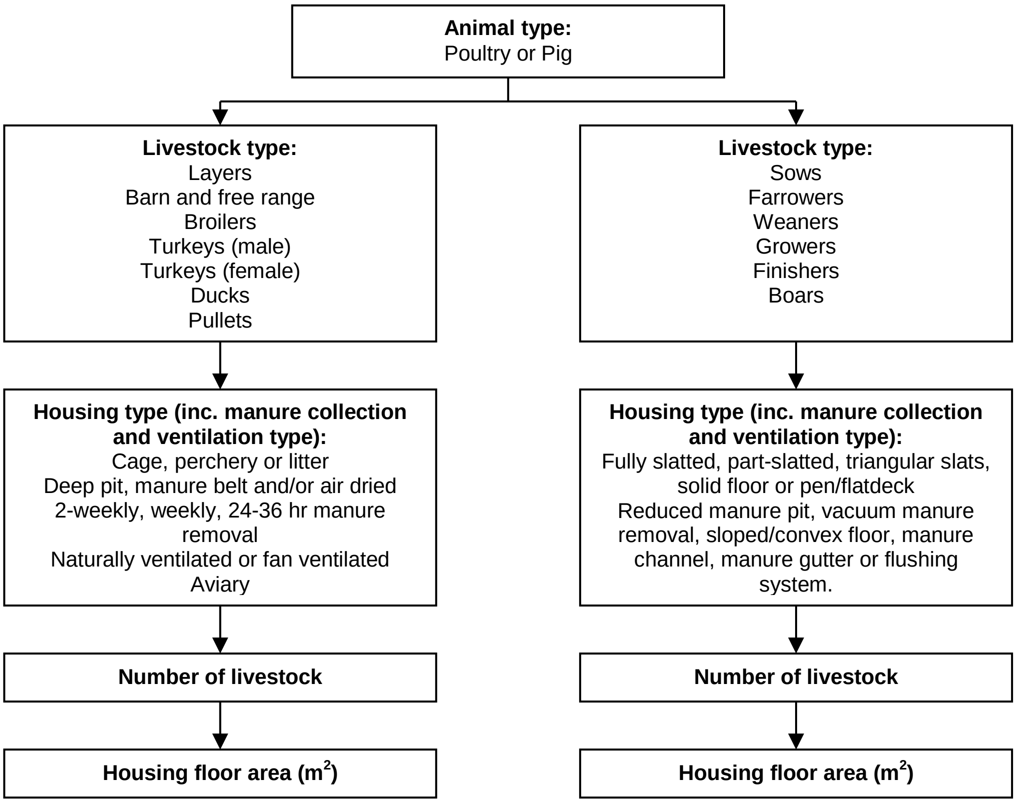

Figure 4-A: Input types to determine emissions from animal housing

4.4.2. Manure storage areas

For manure storage areas the emissions are based on the type of manure (or slurry) and the storage area. The flow chart in Figure 4-B describes the options available to the user leading to the choice of emission factor for each manure storage type. Manure (or slurry) emission factors for NH_3 and odour are available in units per m^2. No similar emission factors are available for PM_{10}; hence PM_{10} emissions from stored manures are not included. The emission factor determined by this storage type will be scaled depending on the total amount of manure (manure only) and the surface area of the manure or slurry storage area. A reduction in the emissions may be applied if covers are in place to reduce emissions. Odour emission reductions from the raw emission rates will be 50% for straw and 90% for engineered covers. A 50% reduction in odour emission rate is also proposed for the removal of manure from farms to other locations.

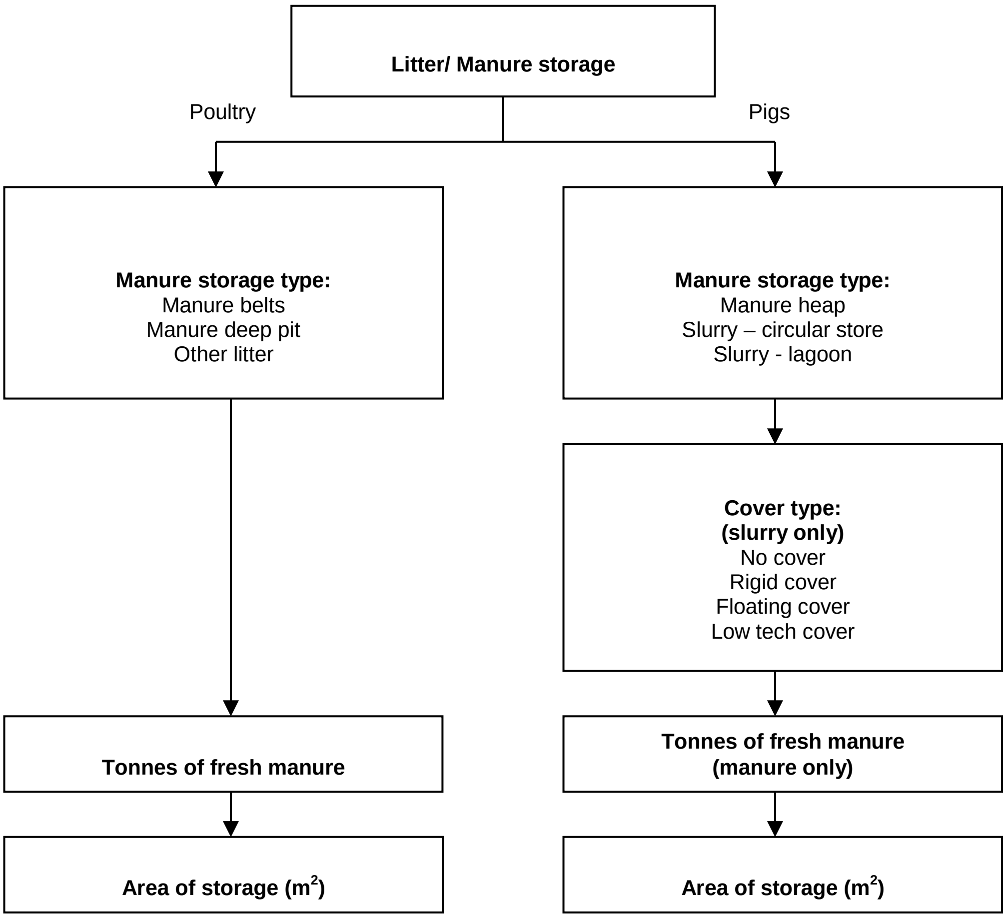

Figure 4-B: Input types to determine emissions from litter/manure storage

4.4.3. Land spreading

For land spreading, emissions will be based on the type of manure (pig or poultry, solid or slurry) and the application method (broadcasting, band-spreading or injection). The flow chart in Figure 4-C describes the options available to the user leading to the choice of emission factor for each land spreading type. Emission factors will be used for each type of manure and application method and will be scaled by the amount of manure spread and the field area of application. Emission factors for NH_3 are available as emissions per tonne of manure spread. Similar emission factors may be available for PM_{10} although these are yet to be determined.

For odours, the impact from manure spreading is short-term and would therefore not be well represented by the long-term emissions and meteorology included in SCAIL-Agriculture. Where such emissions are significant, or where only assessments of odour emissions from slurry spreading are required, then an alternative modelling methodology should be applied.

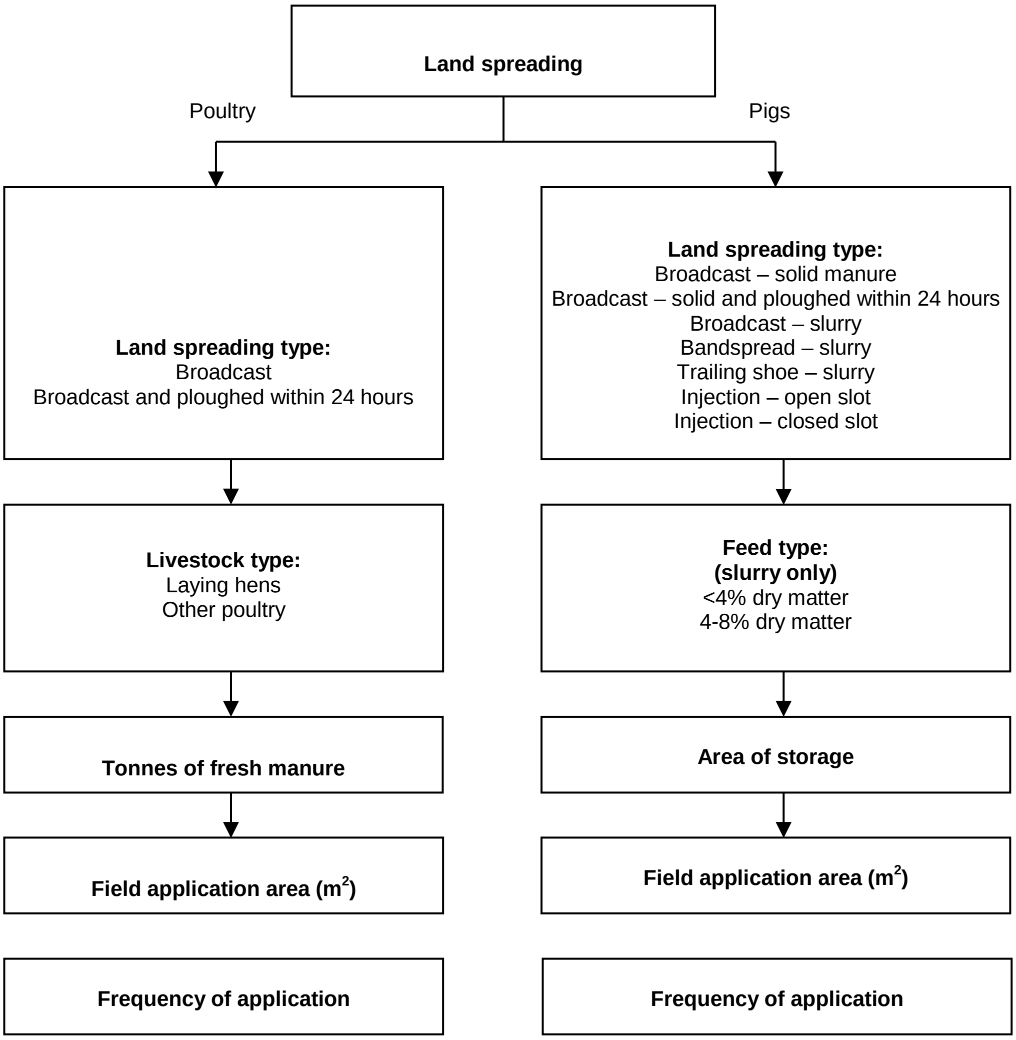

Figure 4-C: Input types to determine emissions from land spreading

4.4.4. Estimating housing dimensions

To model emissions from animal housing, information on the size and dimensions of the building will be required. Naturally-ventilated housing will be modelled as a volume source which requires the lateral and vertical dimensions of the building. Force-ventilated housing will be modelled as a point source. Although this does not explicitly require building dimensions, the effect of the building upon the dispersion of emissions from the point source will be modelled which does require building dimensions (length, width and height).

The location of the building will be defined by the location of the source as input by the user. The source location will be assumed to be the centre point of the building footprint. The building footprint is assumed to be of equal length and width, with dimensions based on the area defined by the user. The building height will be defined by the user but will be set at a default if the height is unknown.

As a guide, the animal welfare regulations (The Welfare of Farmed Animals (England) Regulations 2007) recommend minimum floor areas that must be provided for livestock. The recommended floor area can be multiplied by the number of animals to provide a minimum building area. For example, 2.25 m^2 of floor area is required per sow and a permit is required for farms with more than 750 sows, therefore the minimum floor area of a building would be 1688 m^2, which is roughly equivalent to a building 41 x 41 m. In reality, buildings will obviously be larger than this minimum requirement and the animals on a farm may be split between several buildings. Carney and Dodd (1998) studied a 450-sow unit for which the main animal housing building was 80 m by 80 m.

For poultry, the minimum area per caged hen is 0.75 m^2 and a permit is required for farms with more than 40,000 birds, therefore the minimum floor area would be 30,000 m^2. However, for poultry the cages are likely to be tiered, therefore this figure may be divided by three, if three tiers are used for example, and again birds may be housed in several buildings.

4.4.5. Modelling emissions from animal housing

Force-ventilated housing will be modelled as a point source assuming a single 'effective' fan at the centre of the building. The point source will be modelled at building height if fans are located on the roof or half building height if fans are located on the side of the building. The user is required to input information on the number of fans and an estimated diameter. From this information, the model will calculate an "effective" fan diameter based upon the combined cross sectional area of all fans. The user is also required to input a fan flow rate. If unknown, a default rate of zero should be used. The gas exit temperature will be assumed to be a constant value based on livestock husbandry guidance and will therefore not be required as input by the user.

Naturally-ventilated housing will be modelled as a volume source, the vertical and lateral dimensions of which are specified by the building footprint and the building height as specified by the user.

4.4.6. Modelling building downwash

In AERMOD, the effect of building downwash upon the dispersion of pollutants may only be modelled for point sources, therefore this limits the modelling of building downwash to force-ventilated livestock housing.

AERMOD includes building downwash effects for single "effective" buildings for each source on a directional basis in 10 degree increments proceeding in a clockwise direction. The model requires the building height (BH), building width (BW) and building length (BL) for the specific wind directions being considered. In addition the model requires along-flow (BAF) and across-flow (BXF) distances from the stack to the centre of the upwind face of the projected building. For most applications these parameters would be supplied by the BPIP pre-processor which in-turn requires input of detailed building dimensions and orientation from the user. As it is anticipated that such information will not be available to users of SCAIL-Agriculture, a simpler method for including building effects is required.

An initial simplification is that the model will only consider building effects arising from the building that the source is located on. For livestock housing this is justified as forced ventilated emissions are typically released with low momentum and buoyancy from roof or wall mounted fans. Emissions are then entrained and re-emitted from the wake cavity of the livestock housing. The length scales of the plume are increased to such an extent that entrainment in the wakes of additional buildings will have progressively less impact on atmospheric dispersion. On a practical scale it is also unlikely that users of SCAIL-Agriculture will have detailed information on the surrounding farm buildings.

We can then simplify the approach further as the height of the building remains a constant for all wind angles and can be set to a default of 7 m, which is typical of most low-lying agricultural buildings. The user can of course modify the building height should they have additional information.

The building footprint dimensions and orientation provide a more difficult problem. We assume that the user of the tool will not have detailed dimensions and that any consideration of such would be undertaken as part of a "detailed assessment" following the outcome of this initial screening. The user of the tool will however know the livestock numbers which can be used along with animal husbandry guidance to determine the floor area of a facility. If we assume that the building is square the width and length of the building can then be simply calculated as the square root of the area. The user will have the ability to enter a user defined building footprint area if known.

With regards to the location of the emission point, it is unlikely that this information will be available to the user and without detailed information on building dimensions and orientation such information would be of little objective use. We can therefore assume that the emission point is central to the building. It may seem counter intuitive to assume that wall mounted fans are centrally positioned, however by doing such we ensure that the releases will be fully entrained in the building wake and therefore should provide a realistic approximation of subsequent dispersion. It should also be noted that AERMOD cannot deal with horizontal releases and building effects simultaneously therefore we will assume a point source with negligible vertical efflux parameters for wall mounted fans. An assumption of a central location for the point source significantly simplifies the determination of the along-flow and across-flow distances from the stack to the centre of the upwind face of the projected building.

Further assumptions must be made to account for the unknown orientation of the building. A simple assumption to take is that the building is always orthogonal to the wind (as shown in Figure 4-D). As a consequence, building width, length and along-flow and across-flow distances are constant for all wind angles and can be simply determined as follows:

$$Building\ width\ and\ building\ length = \sqrt{building\ area}$$

$$Building\ along\ \ flow\ dist = \frac{\sqrt{building\ area}}{2}$$

$$Building\ across\ \ flow\ dist = 0$$

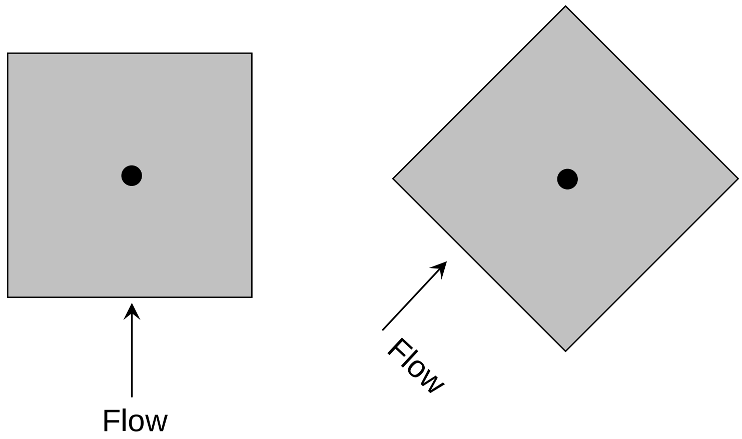

Figure 4-D: Rotational alignment of “effective buildings” for different incoming flows

In order to test the approximate method for including building effects a comparison was undertaken by applying AERMOD using the BPIP model. Two buildings were configured in AERMOD as follows:

- *A rectangular building 25 m (w) x 100 m (l) x 7 m (h)   (RECT)*
- *A square building 50 m (w) x 50 m (l) x 7 m (h) (SQUA)*
- *A simple square building configured using the rotational scheme of 50 m (w) x 50 m (l) x 7 m (h) (SIMPLE)*

All buildings have a floor area of 2500 m^2 and emissions were configured as a single roof mounted point source with a diameter of 1 m, an efflux velocity of 5 m/s and an ambient release temperature.
Tests were conducted using the Linton-on-Ouse dataset and by configuring receptors positioned as shown in Figure 4-E.

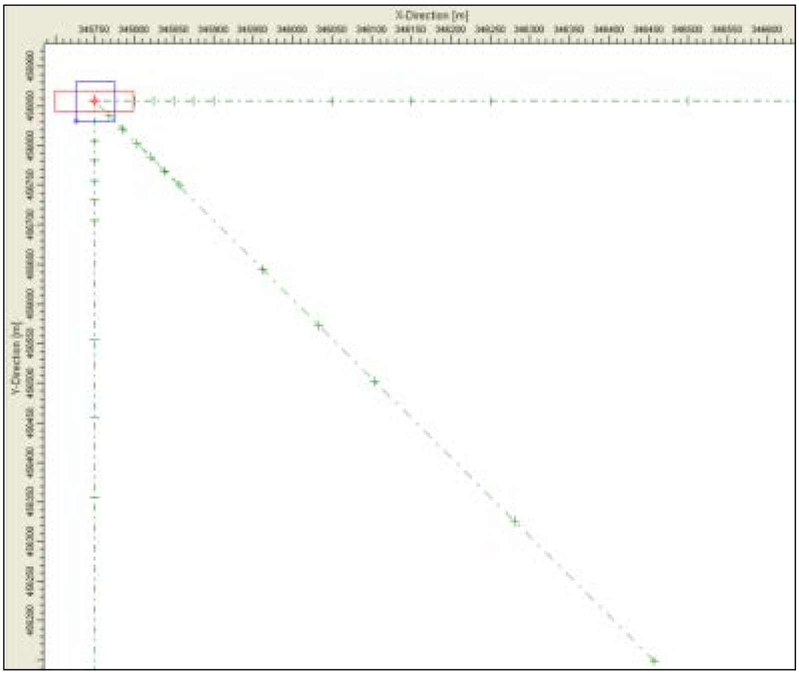

Figure 4-E: Buildings and receptor positions for the test of the building effects modelling methods. The point source is shown as a red cross and the receptors as green crosses.

The results of these tests are shown for the various averaging periods representative of the pollutants modelled in SCAIL-Agriculture in Figure 4-F, Figure 4-G and Figure 4-H. These results show that differences in concentration could occur in the near field (distances less than 100 m from the source). Within this region the largest differences occurred between rectangular and square buildings, though were typically much lower than a factor of two. Only slight differences were observed between the simple building parameterisation and the square building parameterised using BPIP therefore we propose to include the simple parameterisation in SCAIL-Agriculture.

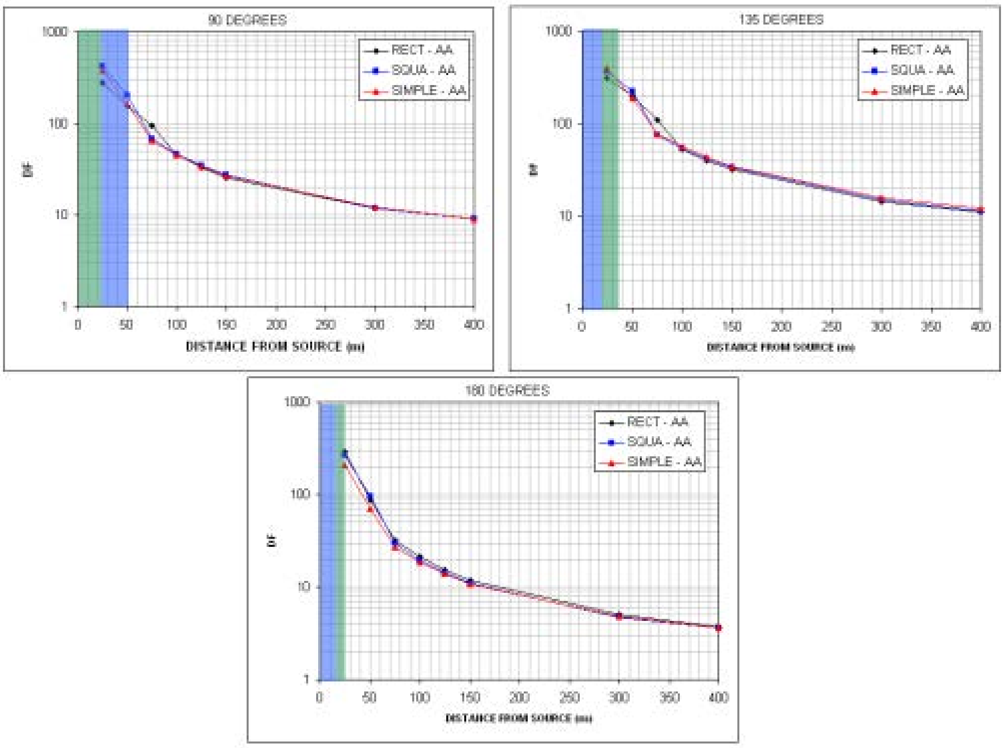

Figure 4-F: Comparison of annual average (AA) dispersion factors (DF in µs m^{-3}) for three different building configurations. Distance between the source and the downwind face of the square building are shown in green, whilst the equivalent distances for the rectangular building are shown in blue.

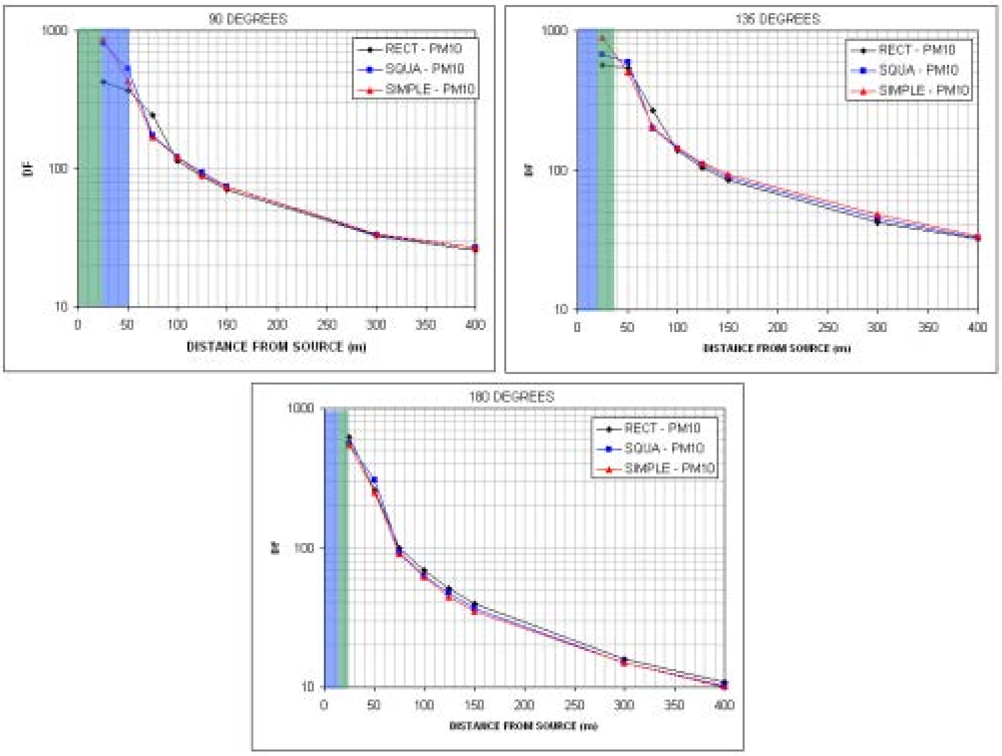

Figure 4-G: Comparison of 90th percentile of 24-hour averaged (PM_{10}) dispersion factors (DF in µs m^{-3}) for three different building configurations. Distance between the source and the downwind face of the square building are shown in green, whilst the equivalent distances for the rectangular building are shown in blue.

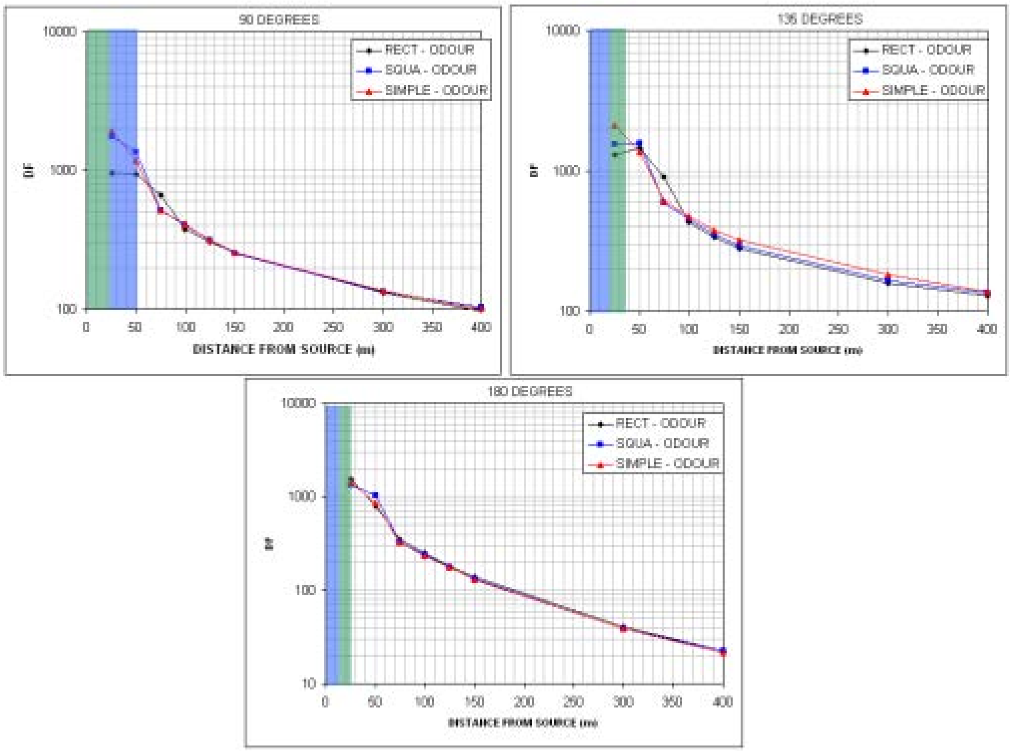

Figure 4-H: Comparison of 98th percentile of 1-hour averaged (odour) dispersion factors (DF in µs m-3) for three different building configurations. Distance between the source and the downwind face of the square building are shown in green, whilst the equivalent distances for the rectangular building are shown in blue.

4.5. Database of designated sites

Habitat data for SSSIs, ASSIs, SPAs, SACs and Ramsar sites in the form of GIS datasets is held by relevant agencies for England, Wales, Scotland, Northern Ireland and the Republic of Ireland. It was not possible to make a direct link between the tool and the data repositories of the various agencies due to potential technical complexities in data formatting and access. The information with respect to designated sites and their associated habitats, critical levels and critical loads was therefore stored in the aforementioned Oracle Database.

The data will need to be updated periodically as the various agencies issue new designations or update existing ones. A graphical representation of the designated sites selected for an assessment is available through the Google maps interface when the user clicks on “Verify receptor locations”.

4.6. Background data

The information with respect to background concentration and deposition data is also stored in the Oracle Database. Background maps of ammonia concentration and nitrogen and acid deposition are set up in the APIS system at a 5km resolution. Similar maps were set up using data from Ireland for inclusion. These data are transferred to the Oracle database to obtain background data for use with SCAIL-Agriculture. The background data for a specific designated site are given as the maximum possible value of any one of the 5km grid squares that cross the site boundary. In the APIS Site Relevant Critical Load (SRCL) tool the Concentration Based Estimated Deposition (CBED) 3-year average values are used to calculate the maximum values at each site by positioning a 5km grid of each pollutant over the site boundaries in GIS. CBED provide 5km maps of concentration and deposition across the UK from data based on the UK’s measurement networks: the Precipitation Network, NO_2 network, Acid Gas and Aerosol Network (AGANET) and the National Ammonia Monitoring Network (NAMN).

Background data for PM_{10} and $PM_{2.5}$ from the most recently available year are incorporated into the Oracle Database. Background odour concentrations are not included as they are not required due to the short term nature of odour episodes.

To avoid double counting, if the facility being modelled already exists, its contribution is subtracted from the background irrespective of the size of emission. This is achieved using a dry NH_3 emission map at 5km resolution. The ratio of emissions from the facility to the total emission in the 5km square will first be determined. The ratio will then be used to adjust the background concentration and deposition data. It should be noted that this approach is not completely robust as not all the emissions from a 5km square remain within the square and hence contribute to the background deposition. The background concentration and deposition may therefore be overestimated. However, it should also be noted that the background data is adjusted for dry deposition only (which often originates from very local sources) and not for wet deposition which would be more likely to originate from emissions outside the 5km square.

A situation may arise where an existing facility wishes to expand by adding emission sources. The consideration of background adjustments can only be made at the facility level and not at the source level therefore the new source must be input as a new facility.

It is considered unlikely that particulate matter from agricultural sources will be incorporated in the background data therefore there will not be any adjustment of the background contribution for existing sources for PM_{10}. Furthermore, the addition of background concentrations will not be considered for odour.

Background concentration and deposition data may be displayed for each designated site or human health receptor by clicking on the "Check Background Levels" option in the data input page.

4.7. Critical loads and levels

The following critical loads and levels will be calculated for the most sensitive habitat(s) within each designated site (within 10km):

- *Critical level for Ammonia*
- *Critical load for Nitrogen Deposition*
- *Critical load for Acid Deposition*

4.7.1. Ammonia Critical Level

Two ammonia critical levels are set at 1 and 3 $\mu g/m^3$ so the tool can easily compare ammonia concentrations to critical levels for all designated sites. It should be noted that if lichens and bryophytes (mosses) make up a key part of the designation then the more stringent critical level ($1 \mu g/m^3$) should be used.

4.7.2. Nitrogen Critical Loads

Nitrogen critical loads are based on a series of empirical nitrogen critical load classes set for a number of habitat types across the UK. It should be noted that the nitrogen critical load class for a habitat is not given by a single value, but is instead given a minimum and maximum value. For the purposes of SCAIL-Agriculture the most sensitive habitat, *i.e*. the one with the lowest minimum nitrogen critical load, is used to compare with the modelled nitrogen deposition.

The selection of habitat types available in the data input page for user-defined sites is a summary habitat whereby a single habitat may be divided into more specialised habitat types. For example, the habitat type "Bogs" may be classed as either "valley mires, poor fens and transition mires" or "raised and blanket bogs", both of which have minimum and maximum nitrogen critical loads. It is therefore possible that the lowest minimum nitrogen critical load may be selected for a habitat which is not applicable. The user may recalculate the exceedance based on a more relevant critical load if required although the option to change the habitat type will not be available within the tool; instead the calculation should be performed by the user and detailed in the notes section of the results page.

Work previously carried out under the Site Relevant Critical Loads (SRCL) tool for APIS has linked the various habitats within SACs and SSSIs to the relevant nitrogen critical load class(s). However NHAs, Local Nature Reserves, county wildlife sites and Ramsar sites have not been linked to specific habitat types and the same will be the case for user specified sites.

4.7.3. Acidity Critical Loads

Acidity critical loads are based on the soil type where the habitat is found, so the location of the habitat is used to find the relevant values for each habitat. The critical load function graph is used to compare the estimated acid deposition with the relevant critical load and to determine any critical load exceedance. Under the APIS SRCL tool, minimum and maximum critical loads for acidity have been calculated for each site. The values of CLMaxN, CLMinN and CLMaxS have been output for use in the SCAIL tool. Code to interpret the minimum and maximum critical load values to calculate a single value of critical load previously developed for another project has been included in the SCAIL-Agriculture tool. The most sensitive habitat (with the minimum critical load) at each site is compared with the acid deposition background value and the process contribution (PC) to determine any critical load exceedance.

4.8. Compiling AERMOD

The update to SCAIL-Agriculture makes extensive use of the functionality built into SCAIL-Combustion. Specific changes to SCAIL-Agriculture meant that the AERMOD executable was recompiled (AERMOD version 12060) using a Linux FORTRAN Compiler.

5. Model Validation

The development of any new model or the modification of an existing model must be subject to a process of validation and the updated SCAIL-Agriculture tool is no exception. This section outlines the validation process conducted to ensure that the updated screening tool provides realistic yet conservative results. The objectives of the validation process were:

- *To assess the ability of the updated SCAIL-Agriculture tool to provide realistic yet conservative estimates of atmospheric ammonia, PM_{10} and odour concentrations downwind of agricultural sources, using established quantitative methods;*
- *To assess the influence of input data uncertainty on the estimates of the updated SCAIL-Agriculture tool;*
- *To identify potential improvements to the tool and/or its application, if necessary.*

The starting point to the validation process was to carry out a literature review into the availability of ammonia emissions and deposition data, and the availability of odour emissions and monitoring data.

5.1. Ammonia data review

This section describes potential validation datasets, defines selection criteria and identifies those datasets that were used to validate the updated SCAIL-Agriculture tool, based on these criteria. Although the updated SCAIL-Agriculture tool will also be used to predict impacts of PM_{10} emissions on human health, this section focuses on impacts of ammonia. The updated tool does not assess the impacts on ecosystems from PM_{10} emissions. However, some of the potential validation datasets also contain measurements of PM_{10} and so there exists the possibility of validating both ammonia and PM_{10} predictions using the same datasets.

5.1.1. Aims of the validation exercise

Datasets were selected in order to validate the mean annual atmospheric ammonia concentrations predicted by SCAIL-Agriculture at several downwind locations for a range of source types and locations within the UK and the Republic of Ireland.

5.1.2. Previous validation studies

Although there exists a large body of literature describing validation studies for atmospheric dispersion models, very few studies have specifically focussed on the dispersion and deposition of ammonia emitted by agricultural sources. Many industrial sources of atmospheric pollutants are elevated above ground, have small emitting areas and often the emissions have high temperatures and exit velocities. By contrast, agricultural NH_3 emissions derive mainly from animal housing, and the storage and field-application of manures and slurries. Therefore emissions are close to ground-level, at near-ambient temperatures, at low or zero exit velocities and often over large areas. It is assumed that very little focus has been put on validating models for agricultural ammonia emissions, partly because of the lower level of emission regulations compared with industrial sources and partly because of the technical difficulties of measuring ammonia at near-ambient concentrations. However, some such studies have been carried out.

For example, Hill *et al.* (2001) used measurements of concentrations made around an intensive dairy farm in the UK to validate the buildings effects module of ADMS. The model estimated a mean concentration (averaged over the measurement locations downwind of the buildings) of 28.3 µg NH_3-N m^{-3}, which compared very favourably with the measured mean of 28.9 µg NH_3-N m^{-3}. Additionally, 85% of the modelled concentrations were within a factor of two of the measured values, with the periods of poor model-measurement agreement attributed to near-calm atmospheric conditions. By contrast, Baumann-Stanzer *et al.* (2008) compared measured concentrations of an SF_6 tracer (released from inside the source building) downwind of a pig farm in Germany with those estimated by ADMS and concluded that the model performed "unacceptably".

A more comprehensive validation study was carried out by Theobald *et al.* (2009) which involved the comparison of ammonia concentration predictions of several screening models (including SCAIL v1.1) with measured concentrations from eight field studies. None of the screening models performed "acceptably" in this study based on strict acceptability criteria (Chang and Hanna, 2004) developed for full atmospheric dispersion models (*i.e*. not screening models).

Theobald *et al.* (2009) also point out that very few measurements of ammonia dry deposition downwind of sources have been made and that those that have contain a large degree of scatter in their values. These two facts led the authors to conclude that validation of model dry deposition predictions is not feasible. The updated SCAIL-Agriculture tool uses a simple approach of ignoring plume depletion and applying a land-cover-specific dry deposition velocity to the undepleted plume (as recommended by the EA Stage 1 guidance (EA, 2010)) and, therefore, it is not necessary to validate deposition processes. However, a review of land-cover-specific dry deposition velocities was necessary to ensure that the most appropriate values are used in the tool.

5.1.3. Selection criteria

The criteria used to identify the final validation datasets have been grouped depending on their relation to a) the ammonia source; b) the dispersion domain; c) the measurements made; d) the meteorological data available and e) other relevant criteria. It is difficult to objectively assign weightings and priorities to the selection criteria although, as part of the selection process later, we suggest which criteria should be given higher priorities than the others.

(a) Source criteria

The characteristics of the ammonia source and its location within the landscape are important factors that determine the emission rate and the initial atmospheric dispersion of ammonia following emission. The following selection criteria were chosen:

- *Source specification: Ideally, parameters such as the source type (e.g. point, area, volume etc.) source height and source dimensions should be available;*
- *Emission rate: This must be well defined based on published emission factors for the animal type(s) or, preferably, based on measurements made at the emission source;*
- *Building effects: In order to assess the influence of nearby buildings, the building locations and dimensions should be available.*

(b) Dispersion domain criteria

The interaction between the source and other landscape elements has a strong influence on the dispersion and deposition of the ammonia downwind of the source and also determines the complexity of the model simulation. The related criteria are:

- *Land cover: The land cover within the modelling domain should be fairly uniform, preferably without the influence of built-up areas, which can complicate the dispersion processes due to additional turbulence and heat fluxes;*
- *Terrain: The topography of the modelling domain should be reasonably flat in order to avoid the use of complex model terrain algorithms;*
- *Source location: Ideally the source should be located in an area of fairly homogenous land cover and far from other sources, which could interfere with the measurements.*

(c) Measurement criteria

Suitable validation datasets must consist of measurements made using a reliable and accurate method and must be made in locations and conditions relevant to those of an impact assessment which will be required to be assessed by SCAIL-Agriculture. In order to represent conditions relevant to long-term impacts, the total measurement period should be at least several months in duration and preferably one year or more. The related criteria are:

- *Measurement method: Should be a robust and established method with sufficient accuracy and an estimation of uncertainty;*
- *Measurement distances: The measurements should be made over a wide range of distances from the source in order to characterise dispersion effects near to and far from sources;*
- *Sampling periods; multiple sampling periods should be used and the total measurement period duration should be as long as possible to capture seasonal variations (preferably one year or more);*
- *Background concentrations: Ideally these should be measured at an upwind location far from other sources but if these data are not available an estimate based on the lowest measured values can be used.*

(d) Meteorological data criteria

Site-relevant meteorological data are essential for accurate modelling of atmospheric dispersion. For non-UK or Ireland datasets it is also important that conditions are representative of those found in the UK or Ireland. The criteria that were chosen are:

- *Meteorological station location: Ideally, reliable on-site data of all the required meteorological variables should be available, but in their absence, data from a nearby meteorological station with similar climatic characteristics can be used;*
- *Representative of UK/Ireland conditions: For non-UK/Ireland datasets, it is important that conditions are representative of UK/Ireland conditions.*

(e) Other criteria

In addition to the grouped criteria listed above the following criteria were also assessed:

- *Data availability: Ideally, the original data from the dataset authors should be available although some information can also be obtained directly from publications;*
- *Data confidentiality: Although confidential datasets could be used in the validation exercise (e.g. by not publishing source coordinates), it would be a more transparent and auditable process if all data can be published;*
- *Wide range of situations covered: This is a global criterion to ensure that the widest possible range of situations (e.g. animal types, source types, land cover, meteorological conditions etc.) are covered in the validation process.*

5.1.4. Dataset summary

Potential datasets were identified through literature searches of peer-reviewed journals (both through Web of Science and Science Direct), searches for 'grey' literature (*e.g.* contract reports, impact assessments *etc*.), direct requests from monitoring bodies (*e.g.* Environment Agency) and personal experience and networks.

Literature searches were based on the following search terms: ammonia, concentration, measurements, monitoring, "livestock farms", dispersion, ADMS, AERMOD and Boolean combinations thereof.

As stated above, it is preferable to use validation datasets from the UK and Ireland, but the search was extended to international studies in case good quality, relevant studies could be identified.

(a) Summary of UK and Republic of Ireland datasets

Tables E-1 to E-3 in Appendix E provide a summary of the validation datasets identified from UK and Republic of Ireland studies (ordered alphabetically by study name). Of the 24 studies, ten focused on emissions from broilers (although some of the studies used the same source farms) (Table E-1). The other 14 studies focused on emissions from other poultry types, pigs, dairy cattle, mixed sources, slurry spreading and artificial releases (NH_3 from a cylinder). Sixteen of the studies were led or conducted by the Centre for Ecology and Hydrology (CEH) and five were carried out or commissioned by the Environment Agency (EA). The remaining three studies were done by the University of York, IGER and Teagasc/UCD. Despite a thorough search and correspondence with Ireland EPA and Prof. H-C. Hansson (ITE, Stockholm), it was only possible to obtain one potential validation dataset from the Republic of Ireland.

The measurement methods used depended on the organisation that conducted the study (Table E-2). CEH have used the passive ALPHA samplers (Tang *et al.*, 2001) for most of their assessment, whereas the Environment Agency have used their Mobile Monitoring Facility (MMF), allowing continuous (15 min. average) monitoring of NH_3 concentrations using a NO_x analyser fitted with an ammonia converter. The exception to this is the N*etc*en study commissioned by the EA, which used diffusion tubes prepared and analysed by Harwell Scientifics Ltd. Measurements were mostly made at a single site for the continuous measurements and up to 31 sites for passive sampler studies. The source-measurement distances used ranged from the edge of the source (ADEPT – Burrington Moor and Whim Moss) to a distance of more than 2.7 km (Bentwater). Continuous measurement campaigns ranged in duration from 2 weeks for the ADEPT – Burrington Moor experiment to more than 6 months for the Cubley study. For the passive sampler studies, exposure periods ranged from one day to eight weeks and total measurement period ranged from less than six months to more than 21 months. Seven of the studies specifically made measurements at an upwind location, or at a location sufficiently far from ammonia sources in order to estimate background NH_3 concentrations (Table E-3). For the other studies, the lowest measured value would have to be taken as an estimate of background values.

Fifteen of the 24 studies published an estimated or measured emission rate for the source (Table E-3). For model validation, an emission estimate would need to be calculated for the other 9 studies based on UK/Republic of Ireland emission factors. It should be noted that the use of emission factors to calculate source strength introduces considerable uncertainty into the model predictions and this should be taken into account in the validation process. Due to the nature of the emission sources, all of the identified studies have been carried out in rural areas, either with mixed land cover types or a single predominant type (grassland, woodland or moorland). About half of the studies recorded meteorological data at the location of the measurements; the other studies would need to rely on data from national meteorological networks in order to be used for model validation.

All datasets identified are either held by CEH or can be requested from the authors of the studies.

In addition to measurements of ammonia concentrations, some of the studies also measured other variables, which can add to the usefulness of the study as a validation dataset and should be taken into account during dataset selection. For example, the studies conducted by the Environment Agency at Newborough, Cubley and Salisbury also included measurements of PM_{10} (all three studies) and $PM_{2.5}$ (Cubley and Salisbury only), which provide potential validation datasets for PM concentrations as well. The Garvary Lodge study also included an ecological assessment of the moorland at several distances downwind of the source.

(b) Summary of international datasets

Tables E4 to E-6 in Appendix E provide a summary of the validation datasets identified from international studies. Fifteen potential validation datasets were identified for studies from Germany, Denmark, Poland, Spain, Italy, Portugal, USA and Canada. These studies include measurements made near a variety of different source types ranging in size from small farms (200 cows) to large feedlots (17,220 cows). In all but one of the studies, passive samplers were used for the measurements. The exception was the study by Staebler *et al*. (2009), who used a ground-based open path laser and an aeroplane-mounted NH_3 analyser. Passive sampler exposure periods ranged from one week to 44 days and total sampling periods ranged from two weeks to more than two years. For most of the studies an attempt has been made to estimate background concentrations either from upwind measurements or by taking the lowest measured value, but less than half of the studies have published an estimated or measured emission rate. Twelve of the studies recorded on-site meteorological data, one did not and two do not state whether they did or not. Data for about half of the studies identified are held by CEH whilst the data availability for the other studies is unknown.

5.1.5. Dataset selection

Table E-7 in Appendix E lists the pros and cons for each criteria group for the 24 UK and Republic of Ireland datasets. Although a quantitative weighting of the criteria is beyond the scope of this assessment, it is clear that some of the criteria should be given more consideration than others. In order to produce good estimates of atmospheric concentrations downwind of sources, it is important to have a good characterisation of the source and meteorological data representative of the dispersion domain. Studies in which dispersion modelling has already been carried out are, therefore, good candidates for validation. In addition to these priorities, it is also important to have extensive reliable measurements for the validation and so we suggest these three criteria groups (source, meteorology and measurements) should be given the highest consideration.

Weighing-up the pros and cons of Table E-7 in Appendix E and giving priority to these three criteria groups, we have ranked the studies in descending order of acceptability, as shown in Table 5-A below.

Table 5-A: Ranking of the UK and Ireland studies in order of acceptability for validation

Rank	Study name and reference	Source type	Reasons for ranking position
1	N. Ireland - Fan ventilated *Tang et al., 2005*	Broiler chickens	Building type, dimensions and emission points known, dispersion modelling carried out and seven-month monitoring period. The only disadvantages of this dataset are the lack of emission measurements and on-site meteorological data.
2	N. Ireland - Naturally ventilated *Tang et al., 2005*	Broiler chickens	Building type, dimensions and emission points known, dispersion modelling carried out and seven-month monitoring period. The only disadvantages of this dataset are the lack of emission measurements and on-site meteorological data.
3	Newborough (passive) *Donovan, 2005 (Netcen report)* Newborough (15 min) *Sheppard et al., 2003*	Broiler chickens	Many distances/directions covered by measurements, many measurement periods, 5.5 month total monitoring period, both studies complement each other and PM10 data also available. The only disadvantages of this dataset are the lack of source information and emission measurements.
4	Co. Wexford *Dowling (2010) PhD Thesis*	Dairy Cows / Sheep	Dataset for Ireland, long monitoring period (26 weeks) including emission measurements. Disadvantages are that measurements are made close to the buildings and that the source is relatively small and affected by adjacent buildings.

Rank	Study name and reference	Source type	Reasons for ranking position
5	NitroEurope – S. Scotland *Vogt et al. (in prep)*	Multiple sources (layers, free range / housed chickens)	Many distances/directions covered, many measurement periods, long total monitoring period (>20 months), little represented source types, dispersion modelling carried out, on-site met. data. The only disadvantages are that there are no source information or emission measurements and there are other potential sources nearby.
6	Pitcairn - Pigs *Pitcairn et al., 1998*	Pigs	Long measurement period (12 months) and a little represented source type. However, there is little source information available.
7	Garvary Lodge *Tang et al. Unpublished data*	Layers	Building type and emission points known, little represented land cover type (moorland) and downwind ecological assessment was carried out. Disadvantages are it is an over-represented source type and there are no on-site meteorology or emission measurements.
8	Bishop Burton *Skinner et al., 2006*	Multiple sources (pigs, sheep, dairy cattle and beef cattle)	Many distances/directions covered; many measurement periods, long monitoring period (12 months) and dispersion modelling carried out. The disadvantages are that the source is complex and there are no emission measurements or on-site meteorological data.
9	Pitcairn - Poultry 1 *Pitcairn et al., 1998*	Broiler chickens	Long measurement period (12 months) but it is an over-represented source type with very little source information.
10	Pitcairn - Poultry 2 *Pitcairn et al., 1998*	Broiler chickens	Long measurement period (12 months) but it is an over-represented source type with very little source information.
11	Pitcairn - Dairy *Pitcairn et al., 1998*	Dairy cows	Long measurement period (12 months) but it is a non-IPPC/ IED-regulated source type with very little source or location information.
12	Woodland chicken (2) *Braban et al. Unpublished data*	Layers	11 month total monitoring period and little represented source type. The main disadvantages are the lack of detailed source information and on-site meteorological data and interference from nearby sources
13	Woodland chicken *Braban et al. Unpublished data*	Breeder/Layers	11 month total monitoring period and little represented source types. The main disadvantages are the lack of detailed source information and on-site meteorological data

Rank	Study name and reference	Source type	Reasons for ranking position
14	Town Barton Farm *Hill et al., (2001)*	Dairy Cows	Emission rates well characterised and measurements were made at many locations/heights but it is a non-IPPC/ IED-regulated source type, the study was short and measurements were not made at more than 100 m from source.
15	Skiba - Broilers *Skiba et al., 2005*	Broiler chickens	Seven-month measurement period but it is an over-represented source type with very little source information.
16	LANAS *Theobald et al., 2004*	Broilers, ducks/geese	Twelve-month measurement period but little source information and there were other potential sources nearby.
17	ADEPT - Gleadthorpe *Sutton et al., 1997*	Poultry farm plus artificial release	Emission rate measured, continuous plus passive measurements; dispersion modelling carried out.
18	Whim moss *Leith et al., 2004*	Artificial release	Fifteen-month total monitoring period but it is for an artificial source and all measurements were made within 100 m of source.
19	AMBER *Theobald et al., 2001*	Artificial release	Fourteen-month total monitoring period but it is for an artificial source and all measurements were made within 100 m of source.
20	ADEPT - Burrington Moor *Sutton et al., 1998*	Slurry spreading	Very detailed measurements for a little-represented source but they were made over a very short period.
21	Salisbury *Bates (2010)*	Broiler chickens	State of the art continuous measurements but there is limited source information, it is an over-represented source type and the measurements were made only at one location and very close to source.
22	Cubley *EA Technical Report: NMA/TR/2009/05*	Broiler chickens	State of the art continuous measurements but there is limited source information, it is an over-represented source type and the measurements were made only at one location and very close to source.
23	Bentwater *EA report (no author given*	Ducks	State of the art continuous measurements and a little-represented source type but there is limited source information and the measurements were made only at one location.

Note: Datasets highlighted in grey are recommended for further consideration. Both Newborough studies have been counted as a single study because they were carried out at the same time with the same source.

Going down the study ranking, the first six studies provide a range of source types, study locations and measurement techniques and would provide a wide range of situations for model validation. Moving further down the ranking, source types, locations and measurement techniques are repeated and including these studies would not add much extra value to the validation exercise. For these reasons the six highest ranked UK and Republic of Ireland studies have been selected for the validation of the screening tool.

With regards to the international studies, they should only be included if they are representative of UK and Ireland conditions and provide situations that are not already included in the UK and Republic of Ireland studies. Firstly, the studies that were done in regions with climate significantly different to that of the UK and Republic of Ireland (Italy, Spain, Portugal, USA and Canada) should be discounted. Of the remaining studies, only the Danish study (Pedersen *et al.*, 2007) provides detailed information on source characteristics including measured emission rates and so this is the only international study that is recommended for use as a validation dataset.

The selected datasets for validation, therefore, are the first six studies in the above ranking (Table 5-A) plus the Danish study.

5.1.6. Dataset selection summary

The seven datasets selected for the validation of SCAIL-Agriculture cover the following parameters:

Emission sources:

- *Broiler chickens and laying hens in naturally and mechanically ventilated houses and free range*
- *Pigs in mechanically ventilated houses*

Measurement techniques:

- *Passive samplers (three types)*
- *Chemiluminescence analyser with NH3 converter*

Source-measurement distances:

- *Distances of 5 – 1000 m*

Monitoring periods:

- *12 weeks – 21 months*

In addition, the Newborough study also provides measurements for the validation of PM_{10} concentrations.

5.2. Odour literature and data review

Part of the update of SCAIL-Agriculture involved the development of an odour module that can be used to screen the impact of odours from pig and poultry facilities to determine whether the facility may need to carry out a full odour impact assessment. A full odour impact assessment may be required where the screening tool shows that the facility has the potential to cause unacceptable levels of odour at nearby sensitive receptor locations.

Literature and data reviews were conducted to identify whether suitable data exist to validate the odour module within the SCAIL-Agriculture tool. This section describes potential validation datasets, defines selection criteria and identifies those datasets that will be used to validate the updated SCAIL-Agriculture tool odour module, based on these criteria.

5.2.1. Aims of the validation exercise

Datasets were selected in order to validate the predictions of the odour module in the updated SCAIL-Agriculture tool at several downwind locations for a range of source types and locations within the UK and the Republic of Ireland.

5.2.2. Previous validation studies

Measurement of odour in the environment is generally conducted using people trained as "sniffers" who rate odour intensity using an odour intensity referencing scale. Field experiments to measure ambient odour are therefore often based on short-range studies over relatively short measurement periods of several hours as there is no monitoring equipment that can be left in the field to continuously measure odour. A few studies of odour over longer timescales and larger distances from the source have been carried out using residents who live close to livestock facilities (*e.g.* Guo *et al.*, 2001). Overall, there are relatively few studies of ambient odour close to livestock facilities and a lack of experimental data to validate dispersion models is recognised as a major obstacle in using dispersion models to predict odours from agricultural sources (Zhu *et al*., 2000; Curran *et al.*, 2007). Measurements of emissions of odour that are taken in conjunction with the field sniffer studies are also limited as usually the laboratories that measure odour concentration in samples are restricted by the number of samples that can be processed in the time required. Laboratory analysis of odour samples also relies on trained panellists for odour concentration measurements.

Several studies measuring odour from livestock facilities have been carried out in Ireland, Germany, North America and Canada, which may be applicable to the SCAIL-Agriculture odour module. The Ireland and Germany studies tend to focus on intensive pig units, however one of these studies (Carney and Dodd, 1989) does consider emissions from several types of sources within a pig production unit, including pig housing buildings, slurry stores and slurry spreading. The North American and Canadian studies also tend to focus on pig production; however some studies (*e.g.* Zhu *et al*., 2000) also include examples from poultry units including turkey and broiler chicken facilities.

In general, it is accepted that dispersion models are better at predicting mean concentrations of odour than short-term peak values. Dispersion models for odour are often configured to calculate hourly concentrations, however in reality the sensation of odour depends on a momentary concentration, not on a time-averaged value. Many studies have developed peak-to-mean ratios to overcome this issue and the current UK and Ireland regulations use a percentile value (98th percentile of hourly means) for the same purpose. The validation studies have shown that typical Gaussian dispersion models and "puff" dispersion models can be used to provide a reasonable estimation of ambient odour concentrations from livestock facilities. Environment Agency research into dispersion modelling for odour predictions (Pullen and Vawda, 2007) has pinpointed emissions factors as one of the key parameters in ensuring that model predictions are appropriate. The same research also highlights that uncertainties in modelling odours are increased when the source involves fluctuating emissions; low or ground-level sources in the presence of buildings; non-vertical or obstructed releases; and complex terrain.

5.2.3. Selection criteria

As in the ammonia dispersion studies, the criteria used to identify the final validation datasets for odour have been grouped depending on their relation to a) the odour source; b) the dispersion domain; c) the measurements made; d) the meteorological data available and e) other relevant criteria. It is difficult to objectively assign weightings and priorities to the selection criteria although, as part of the selection process, we suggest which criteria should be given higher priorities than the others.

The selection criteria are the same as those outlined for ammonia studies in Section 5.1.3, with the exception of background concentrations; therefore they are not repeated here. Background concentrations are not included as selection criteria for odour validation as the studies generally assume that background odours are negligible.

5.2.4. Dataset summary

Potential datasets were identified through literature searches of peer-reviewed journals (both through Web of Science and Science Direct), searches for 'grey' literature (*e.g.*, contract reports, impact assessments, conference papers *etc*.), direct requests from monitoring bodies (*e.g.*, Environment Agency) and personal experience and networks.

Literature searches were based on the following search terms: odour, measurement, monitoring, livestock, pigs, poultry, dispersion, ADMS, AERMOD and Boolean combinations thereof.

Although it is preferable to use validation datasets from the UK and Ireland, the search was extended to international studies in case good quality, relevant studies could be identified.

(a) Summary of validation datasets

Table F - 1 in Appendix F provides a summary of the validation datasets identified from UK, Republic of Ireland and international studies. Of the 10 studies, two were from Ireland, none were from the UK and the remaining 8 were from the USA, Canada and Germany. Most studies focused on emissions from pig units, with just one study including poultry farms and one using cattle feedlots.

The measurement methods for all studies used standard olfactometry methods (collecting an air sample that is subsequently assessed by a trained panel) to measure odour emissions and most studies used trained sniffers to measure ambient odour intensity downwind of the source. Two studies also used olfactometry to measure ambient odour concentrations downwind of the source. Background sources of odour were not specifically considered in any or the studies. Most of the studies measured meteorological variables on site. Most of the studies report measured ambient odours in terms of odour intensity, therefore methods would have to be used to convert these intensity measurements to odour concentrations for comparison with the output from the SCAIL-Agriculture tool. One study is written in German, therefore a translation may be required if the study is to be used for validation. In most cases, further information may need to be requested from the authors of the studies.

5.2.5. Dataset selection

Table F - 2 in Appendix F lists the pros and cons for each criteria group for the potential validation datasets. Although a quantitative weighting of the criteria is beyond the scope of this assessment, it is clear that some of the criteria should be given more consideration than others. As for the ammonia validation, in order to produce good estimates of odour concentrations downwind of sources, it is important to have a good characterisation of the source and meteorological data representative of the dispersion domain. Studies in which dispersion modelling has already been carried out are, therefore, good candidates for validation. In addition to these priorities, it is also important to have reliable measurements for the validation and so we suggest these three criteria groups (source, meteorology and measurements) should be given the highest consideration.

Weighing-up the pros and cons of Table F - 2 in Appendix F and giving priority to these three criteria groups, an attempt has been made to rank the studies in descending order of acceptability, as shown in Table 5-B below. It proved to be quite difficult to rank the studies as only two of them are directly relevant to the UK and Ireland and all studies will require further investigation in order to provide suitable validation datasets. Many of the studies only reported ambient odour intensity and these data will need to be converted to odour concentrations to compare them to the SCAIL-Agriculture output.

Table 5-B: Ranking of the UK, Ireland and international datasets in order of acceptability for validation

Rank	Study name and reference	Source type	Reasons for ranking position
1	Dublin Curran *et al.*,2007	Pig	Relevant to the UK and Ireland. Source data and meteorological data provided. Ambient odour concentrations reported, not just intensity. May be possible to get further details from authors.
2	Carney and Dodd, 1989	Pig (buildings, slurry store, spreading)	Only other UK/Ireland study. Odour concentrations at specific distances provided. Specific meteorological data including wind speeds not provided, but may be inferred. Further investigation may prove useful.
3	Minnesota Zhu *et al.*, 2000	Various inc. pig and poultry	Only study to include poultry. May be possible to get further details from authors. Ambient odour intensity reported, not concentration.
4	Saskatchwean Guo *et al.*, 2005	Pig	May be possible to get further details from authors. Ambient odour intensity reported, not concentration. Complex site over three locations.
4	Manitoba Zhang *et al.*, 2005 and Guo *et al.*, 2006	Pig	May be possible to get further details from authors. Ambient odour intensity reported, not concentration. Not necessarily relevant to UK/Ireland as most measurements in Cat. B conditions.
4	Alberta Qu *et al.*, 2006	Pig	Emission rates not obvious in paper, but may be possible to get further details from authors. Odour intensity vs. concentration relationship discussed. Not necessarily relevant to UK/Ireland.
4	Iowa Henry 2009	Pig	Emission rates not obvious in paper, but may be possible to get further details from author. Ambient odour intensity reported, not concentration.
4	Nebraska (slurry) Henry 2009	Pig slurry store	May be possible to get further details from author. Ambient odour intensity reported, not concentration. Measurements all very close to source (<200m).
5	Lohmeyer Keder *et al.*, 2005		This study may be useful if a translation of the paper can be found. At present few details are known about the study.
6	Nebraska (feedlot) Henry 2009	Cattle feedlot	Source is not relevant to pigs and poultry.

5.3. Model validation process

The SCAIL-Agriculture tool was run for each case study using the best estimates of model input data (see Appendix E for ammonia data) and the nearest SCAIL-Agriculture meteorological station (except for the Danish and odour case studies) to predict the concentration at each measurement location. These best estimates of model inputs were either the real values (where available) or based on expert judgement. The predicted concentrations (C_p) were then compared with the measured values (C_o) and the four following performance indicators were calculated for each dataset.

Fractional bias

$$FB = \frac{2(\overline{C_o} - \overline{C_p})}{(\overline{C_o} + \overline{C_p})}$$

Geometric mean bias

$$MG = \exp\left(\overline{\ln C_o} - \overline{\ln C_p}\right)$$

Normalised mean square error

$$NMSE = \frac{\overline{\left(C_o - C_p\right)^2}}{\overline{C_o}\;\overline{C_p}}$$

Geometric variance

$$VG = \exp\left[\overline{\left(\ln C_o - \ln C_p\right)^2}\right]$$

In addition we used a fifth metric, the fraction of model predictions within a factor of two of the observations (FAC2).

Chang and Hanna (2004) suggest ranges for five of the performance measure values that indicate acceptable model performance. The ranges suggested are:

- $-0.3<FB<0.3$
- $0.7<MG<1.3$
- $NMSE<1.5$
- $VG<4$ *and*
- $FAC2>50\%$.

Recent work on model performance evaluation by Hanna and Chang (2010) has recognised that, due to stochastic and turbulent processes, even an acceptable model may not meet all acceptability criteria for all experiments. As a result, they propose that an acceptable model is one that meets the criteria for at least half of the performance tests.

It should be noted that the objective of the simulations was to predict atmospheric concentrations as accurately as possible using the best estimates of model inputs. The model was not run in 'conservative' mode since the performance measures quantify the accuracy of model predictions with respect to the measured concentrations and so a conservative model (*i.e*. one which tends to overestimate concentrations) is likely to perform badly, by definition.

This report evaluates the predictions of SCAIL-Agriculture for ammonia (NH_3) in Section 5.4, Odour in Section 5.5 and PM_{10} in Section 5.6.

5.4. Validation of SCAIL-Agriculture for NH_3 concentrations

5.4.1. Summary of NH_3 validation datasets

Seven datasets were selected for validating the SCAIL-Agriculture tool for NH_3 concentrations. The County Wexford study originally selected has not been used due to insufficient data. The Garvary Lodge study has been included in its place. Table 5-C provides a brief overview of the selected datasets.

Table 5-C: Summary of ammonia sources and measurements made in the ammonia validation datasets

Dataset name	NH_3 source(s)	Measurements made	Reference (if available)
N. Ireland - Fan ventilated	Two broiler houses (68000 bird places in total) with roof ventilation	Mean ammonia concentrations at distances of 20-320 m from the sources. Measured by ALPHA samplers over a total of 30 weeks	*Tang et al., 2005*
N. Ireland - Naturally ventilated	Three naturally ventilated broiler houses (76000 bird places in total)	Mean ammonia concentrations at distances of 20-320 m from the sources. Measured by ALPHA samplers over a total of 30 weeks	*Tang et al., 2005*
Newborough	Six broiler houses (198700 bird places in total) with roof ventilation	Mean ammonia concentrations at distances of 36-847 m from the sources. Measured by diffusion tubes over a total of 119 days	*Donovan, 2005; Sheppard, 2003*
Scotland - poultry	Twenty four poultry houses (22 layers, 2 pullets)	Monthly ammonia concentrations for 1 year at 31 sites within 5 km x 5 km square around farm	*Vogt et al., (submitted to Atmos. Environment, Dec. 2012)*
Pitcairn – Pigs	Pig house (2000 animal places)	Mean ammonia concentrations in woodland at distances of 14-1000 m from the source. Measured by ALPHA samplers over a total of 12 months	*Pitcairn et al., 1998*
Garvary Lodge	Three layer chicken houses (Deep pit and belt cleaned; 65000 animal places in total) and two manure stores	Mean ammonia concentrations across a bog at distances of 70-590 m from the sources. Measured by ALPHA samplers over a total of 6 months	*Tang et al. Unpublished data*
Pedersen (Denmark)	Pig house (2688 fattening pigs and piglets) with roof ventilation	Mean ammonia concentrations at distances of 41-308 m from the source. Measured by diffusion tubes over a total of 12 weeks	*Pedersen et al., 2007*

In all simulations carried out using SCAIL-Agriculture for ammonia emissions, the developmental internet-based version of the model was used (*i.e.* each building source is represented by a single point source in the centre of a square building), unless stated otherwise. Where on-site emission data were not available, the ammonia emission factors recommended by the UK Environment Agency incorporated into SCAIL were used.

Figure 5-A shows the predicted concentrations plotted against the measured values for all of the validation datasets and Table 5-D lists the performance indicator values. This evaluation shows that SCAIL-Agriculture tends to underestimate concentrations for broiler farms (Newborough and Northern Ireland case studies) and overestimate them for layer farms (Garvary Lodge and Scottish Poultry case studies). The largest differences between individual modelled and measured concentrations were an underestimation by a factor of 7 (Newborough) and an overestimation by a factor of 16 (Scotland – Poultry) although more than 80% of the SCAIL-Agriculture predictions were within a factor of five of the measured values.

Overall the model meets the acceptability criteria for 12 of the 35 tests shown in Table 5-D (7 datasets × 5 performance measures). This suggests that the model is not acceptable, although it should be borne in mind that these performance criteria were designed for detailed atmospheric dispersion models with research-grade model inputs (*e.g.* on-site meteorological data, known emission rates *etc.*). A screening model using estimated and simplified inputs would not be expected to perform as well.

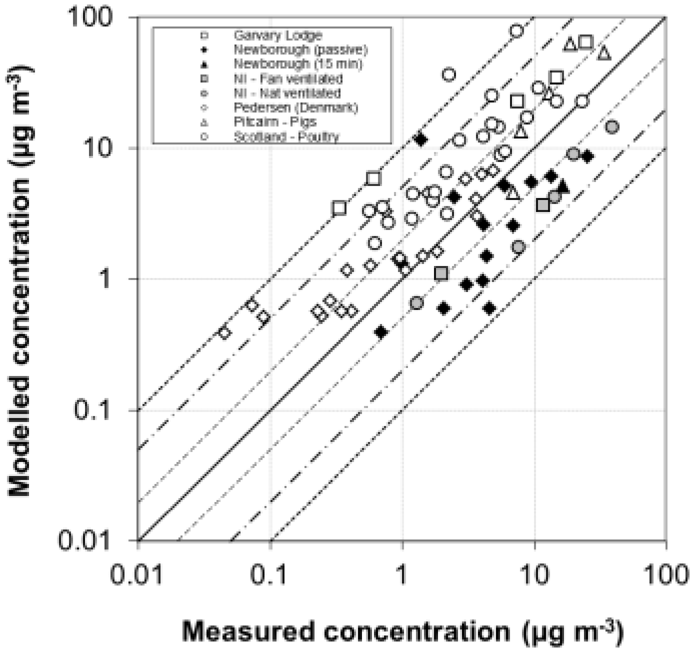

Figure 5-A: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values for the ammonia validation datasets. The solid line shows the 1:1 line and the dotted and dashed lines show the limits for predictions within a factor of two, five and ten of the measured values.

Table 5-D: Summary of the performance indicator values for the ammonia validation datasets. Shaded cells represent values that meet the acceptability criteria.

Dataset	FB	MG	NMSE	VG	FAC2
Newborough	0.7	2.1	1.3	2.9	50%
NI - Fan ventilated	1.0	2.4	2.0	2.3	50%
NI - Naturally ventilated	0.9	2.8	1.7	3.1	20%
Pitcairn - Pigs	-0.7	0.6	1.0	1.7	60%
Garvary Lodge	-0.9	0.2	1.8	15.1	0%
Pedersen - Denmark	-0.4	0.5	0.5	2.6	55%
Scotland - Poultry	-1.0	0.3	4.5	5.2	26%

Figure 5-B shows the factor of under- or over-estimation for each SCAIL-Agriculture prediction plotted against distance from the source (with the exception of the Scottish dataset, which has various sources

contributing at each receptor location). This plot shows that the model prediction error ranges from an underestimation by a factor of seven for the Newborough validation dataset to an overestimation by a factor of eleven for the Garvary Lodge dataset. Figure 5-B does not show a clear variation in model error with distance and so these data cannot be used to provide a robust estimate of the minimum distance to which SCAIL-Agriculture can be applied.

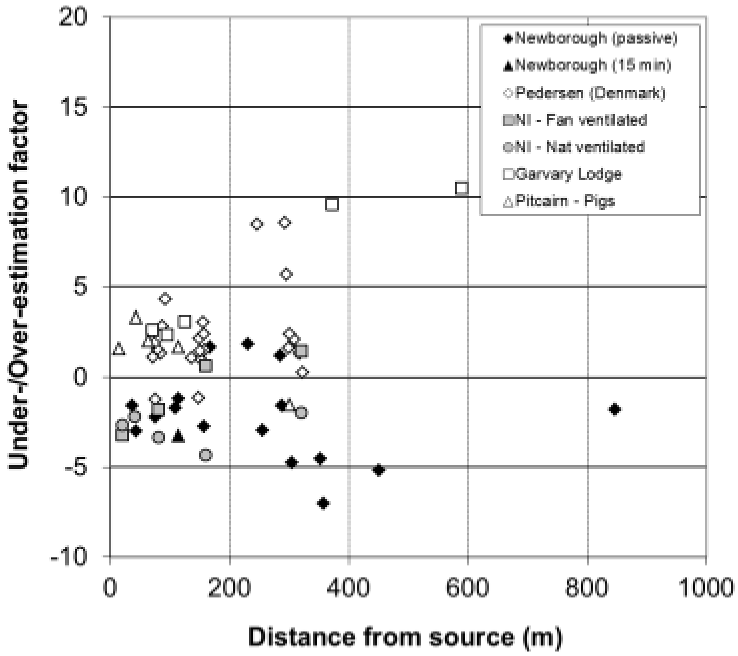

Figure 5-B: Factor of under- or over-estimation of the measured concentrations by SCAIL-Agriculture plotted against distance from the source for all validation datasets except the Scottish case study. Positive and negative values represent overestimation and underestimation, respectively.

5.4.2. Estimation of model prediction uncertainty due to uncertainty in model input data

In order to investigate possible reasons for not meeting the acceptability criteria, a simple uncertainty study was conducted for all of the datasets except the Pedersen and Scotland - Poultry case studies. This was done by individually setting model inputs to the lower and upper value of a realistic range for the uncertain parameters (*e.g.* source height where no information is available). Appendix G lists the inputs varied for each dataset and the uncertainty ranges used. A multi-parameter sensitivity analysis is beyond the scope of this report and so the prediction uncertainty range was taken as the minimum and maximum prediction at each measurement location from all of the simulations carried out.

Uncertainty in the measured concentrations was also estimated by assuming an analysis uncertainty of ±10% and a range of background concentrations from zero to the published background concentration or lowest measured value.

(a) Newborough

Model input data provided by AQMAU were used for the simulations. These data included all of the necessary source input data but exit velocities had to be modified for use in SCAIL-Agriculture due to the fact that the installations have both ridge fans (upwards emission) and gable fans (sideway emission). The exit velocity was estimated to be the effective velocity calculated from total air flow and fan area multiplied by 0.4 (the proportion of total air flow that exits through the ridge fans). The best estimates of the concentration predictions and the uncertainty range due to input parameter uncertainty are shown in Figure 5-C.

The best estimate concentrations range from an underestimation by a factor of 7 to an overestimation by a factor of 2, with the model underestimating at most of the sites. Mean model uncertainty is ±20%

(i.e. the mean lengths of the positive and negative error bars in Figure 5-C are 20% of the best estimate concentrations), mainly due to uncertainty in the emission factor used. This analysis shows that uncertainty in the model inputs is not sufficient to explain the model under-prediction for the majority of the measurement locations. This means that either the model is not suitable for this situation or the uncertainty in model inputs or measured concentrations has been underestimated. Normalising the predicted and measured concentrations by dividing the values of each dataset by the largest concentration allows the comparison of the measured and modelled concentration decrease with distance. As Figure 5-D shows, both measured and modelled concentrations show a similar decrease with distance although the modelled profile is more similar to a logarithmic decrease than the measured profile. This suggests that the underestimation by SCAIL-Agriculture shown in Figure 5-C is most likely due to errors in model inputs such as the emission rate although errors in the atmospheric dispersion predicted by the model or the non-representativeness of meteorological data may also contribute.

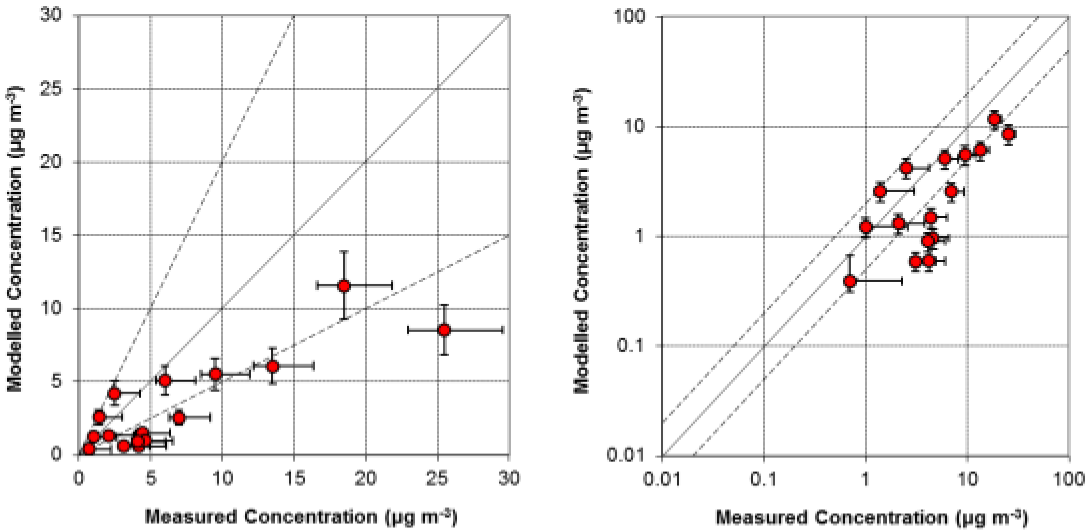

Figure 5-C: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values on linear (left) and logarithmic (right) axes for the Newborough validation dataset. Error bars show the estimates of uncertainty due to uncertainty in model input data (vertical) and measurement data (horizontal). The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

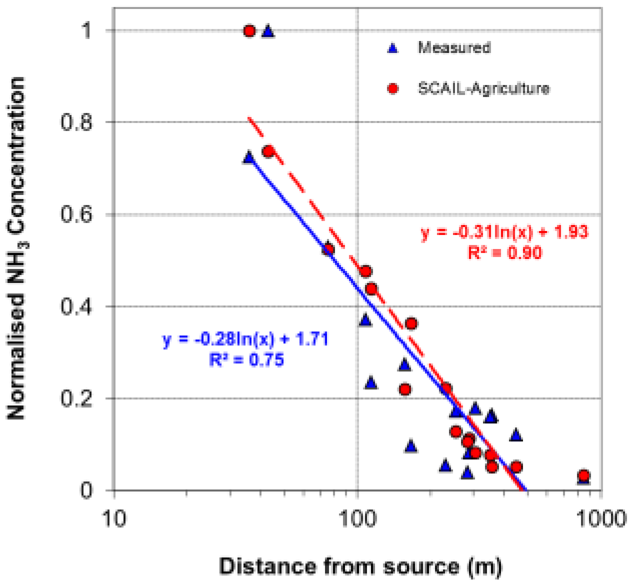

Figure 5-D: Normalised measured concentrations and best estimates predicted by SCAIL-Agriculture plotted against distance from the source for the Newborough validation dataset. Lines represent the fitted logarithmic curves. Note the logarithmic distance axis.

(b) Northern Ireland – Fan ventilated

The best estimates of the concentration predictions and the uncertainty range due to input parameter uncertainty are shown in Figure 5-E. The prediction uncertainty ranges (±20%) are similar to those of the Newborough dataset since the main uncertainty is the emission factor used. This analysis shows that uncertainty in the model inputs is not sufficient to explain the model under-prediction for the measurement locations where higher than background concentrations were measured. Plotting the normalised measured and modelled concentrations against distance shows that the modelled profile is more similar to a logarithmic decrease with distance than the measured profile (Figure 5-F), although the lower-than-background measured concentrations should be considered with caution.

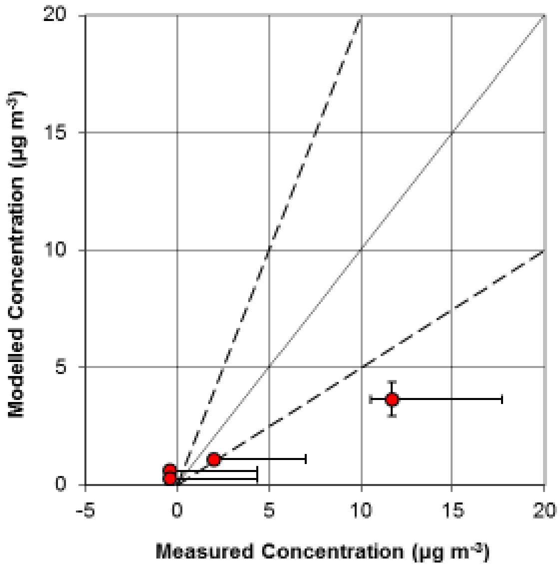

Figure 5-E: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values for the NI-Fan Ventilated validation dataset. Error bars show the estimates of uncertainty due to uncertainty in model input data (vertical) and measurement data (horizontal). The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

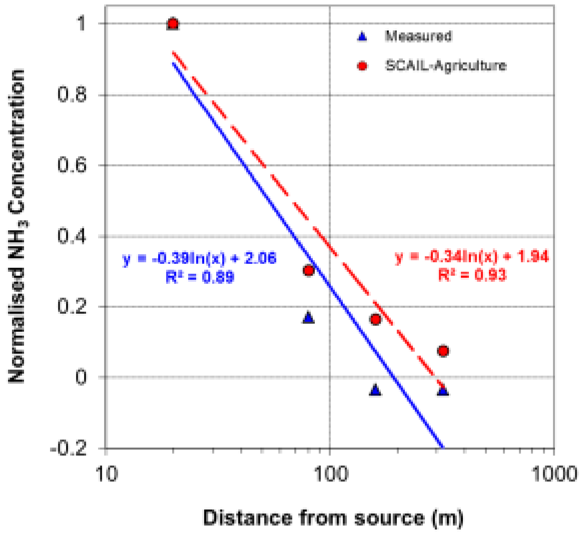

Figure 5-F: Normalised measured concentrations and best estimates predicted by SCAIL-Agriculture plotted against distance from the source for the NI-Fan Ventilated validation dataset. Lines represent the fitted logarithmic curves. Note the logarithmic distance axis.

(c) Northern Ireland – Naturally ventilated

Figure 5-G shows that the model also underestimates concentrations for this dataset (by a factor of 2-4). Mean model uncertainty is ±20% due to uncertainty in emission rates. This analysis shows that uncertainty in the model inputs is not sufficient to explain the model under-prediction. Figure 5-H shows that the normalised predicted and measured concentrations exhibit a similar logarithmic decrease with distance from the source.

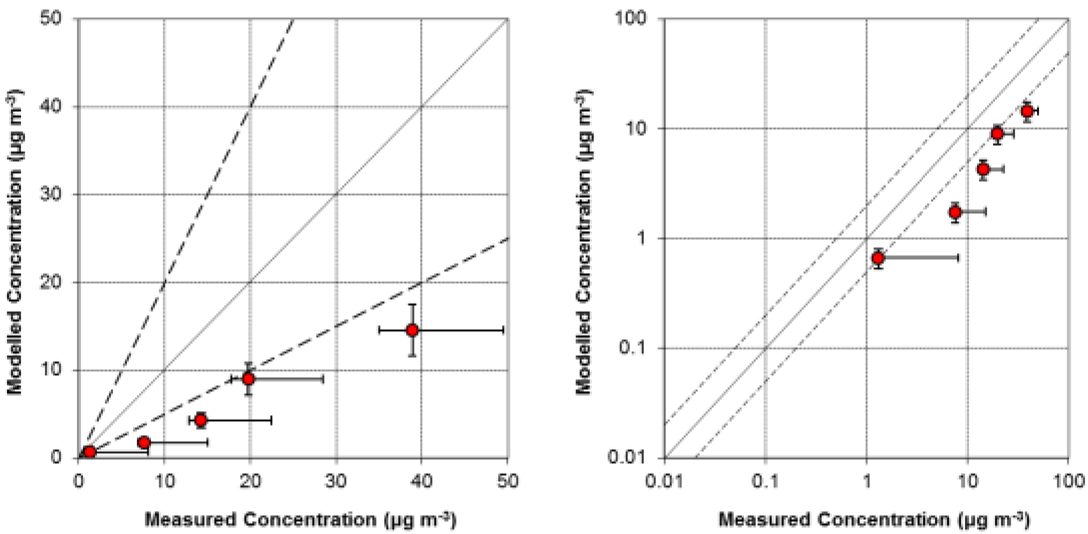

Figure 5-G: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values on linear (left) and logarithmic (right) axes for the NI-Naturally Ventilated validation dataset. Error bars show the estimates of uncertainty due to uncertainty in model input data (vertical) and measurement data (horizontal). The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

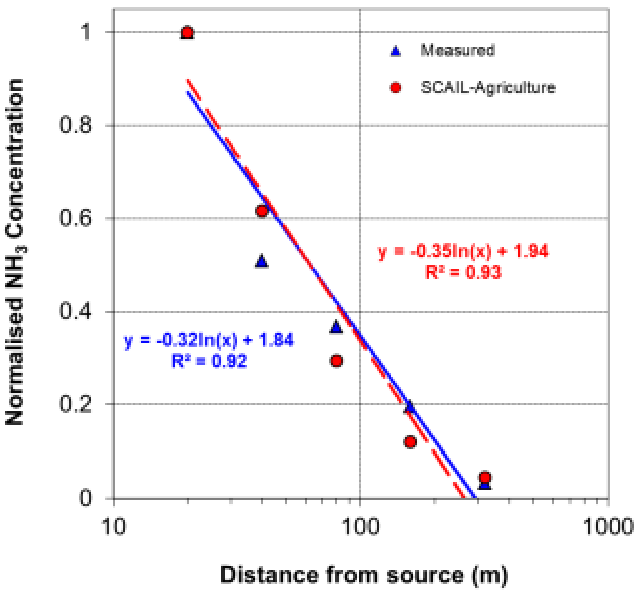

Figure 5-H: Normalised measured concentrations and best estimates predicted by SCAIL-Agriculture plotted against distance from the source for the NI-Naturally Ventilated validation dataset. Lines represent the fitted logarithmic curves. Note the logarithmic distance axis.

(d) Pitcairn - Pigs

Figure 5-I shows that SCAIL-Agriculture tends to overestimate concentrations for this dataset. Mean model uncertainty is +22% / -37%, due to uncertainty in emission rates and fan locations. This uncertainty, however, is not sufficient to explain the model over-prediction, which may be the result of the emission factor used. Another explanation could be the dispersion domain used since the measurements were made within a woodland, whereas the meteorological data used assumes an agricultural land cover (*e.g.* crops or grassland). This discrepancy would be expected to lead to an overestimation of concentrations. Since the final version of the model provides conservative concentration predictions, the assumption of agricultural land cover is justified. Figure 5-J shows that although both normalised measured and modelled concentrations deviate from a profile with a logarithmically decreasing concentration with distance, the overall concentration gradients are similar.

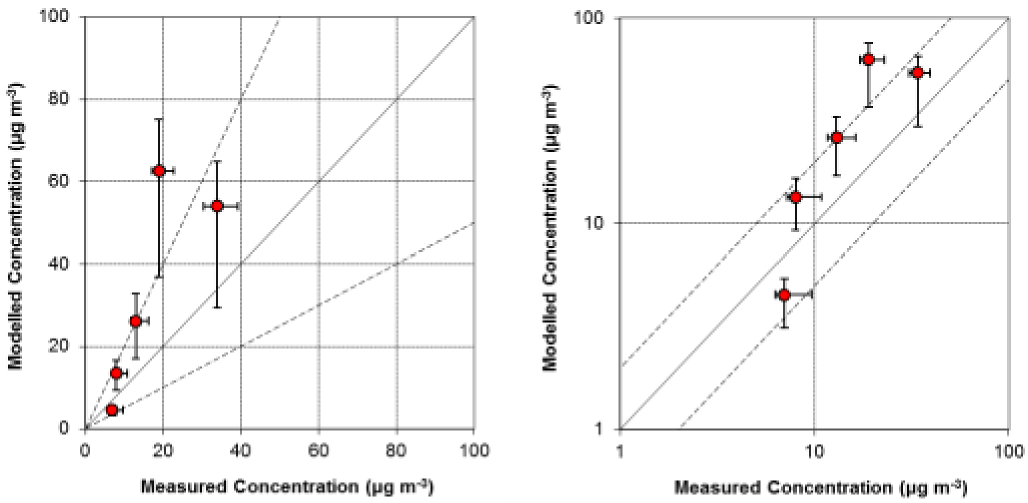

Figure 5-I: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values on linear (left) and logarithmic (right) axes for the Pitcairn - Pigs validation dataset. Error bars show the estimates of uncertainty due to uncertainty in model input data (vertical) and measurement data (horizontal). The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

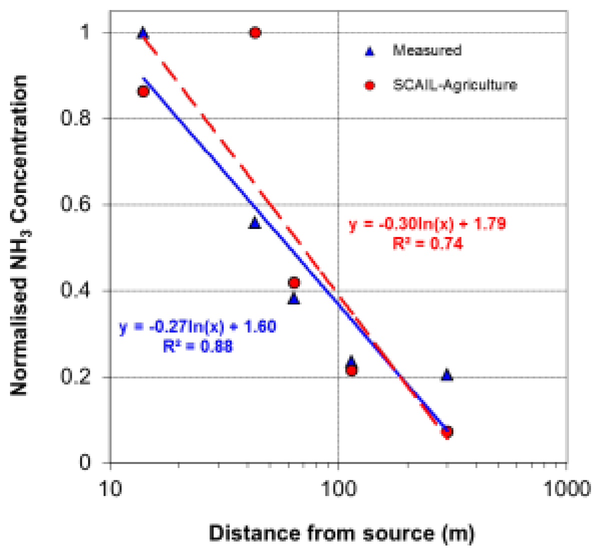

Figure 5-J: Normalised measured concentrations and best estimates predicted by SCAIL-Agriculture plotted against distance from the source for the Pitcairn - Pigs validation dataset. Lines represent the fitted logarithmic curves. Note the logarithmic distance axis.

(e) Scotland-Poultry

Although model uncertainty was not evaluated for the Scotland-Poultry case study, it is worthwhile investigating this case study in detail since it includes a large number of source and measurement locations. The modelling domain contains 24 poultry sources within a 3 x 2 km area and 31 measurement points within a 5 km square, within which the poultry installations are in the southern half. Measurements used were the annual average concentrations for 2008 and were averaged from monthly measurements. For the purposes of this study the area was considered as 2 installations: Installation 1 of 20 poultry house (see Figure 5-K:Installation 1 is a cluster of 5 on east side of area and 16 scattered houses to the west, and Installation 2 is a set of 4 houses on the west side of the area). SCAIL-Agriculture was operated in realistic mode, with the parameters summarised in the Appendix A. As can be seen from Figure 5-K, the area is a complex agricultural environment and as such has many agricultural activities in addition to the poultry houses. Validation was only carried out for Installation 1.

Figure 5-L shows the best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values for emissions from Installation 1. For this dataset it is not possible to compare the measured and modelled decreases in concentration with distance since each receptor location is influenced by more than one source.

For this case study, SCAIL-Agriculture did not meet any of the acceptability criteria (Table 5-D) due to over-prediction of concentrations by a factor of three, on average. One potential reason for this is the emission factors used by SCAIL. Housing emission factors in the area have been found to be significantly at variance to the national EFs used in SCAIL, partly due to local farm management practices and climatic conditions (Vogt *et al.*, 2013).

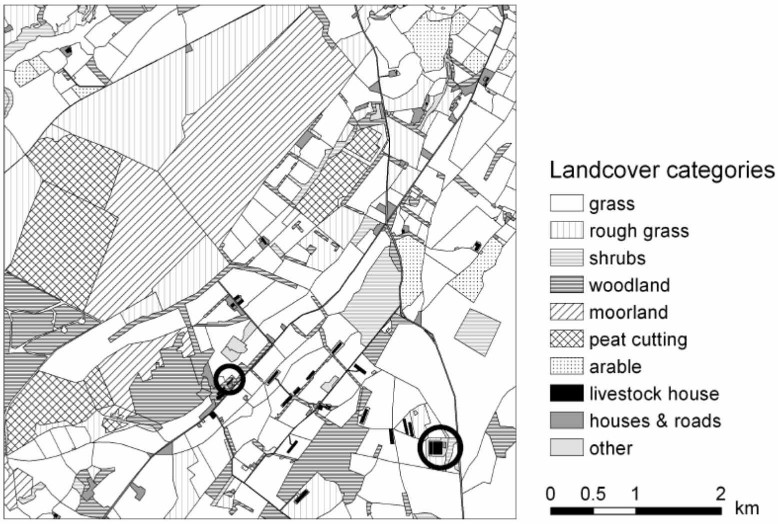

Figure 5-K: Scottish Poultry Installations 1 and 2. Poultry Houses marked in black. RH circle: 5 poultry houses on east side of main installation; LH circle: Installation 2.

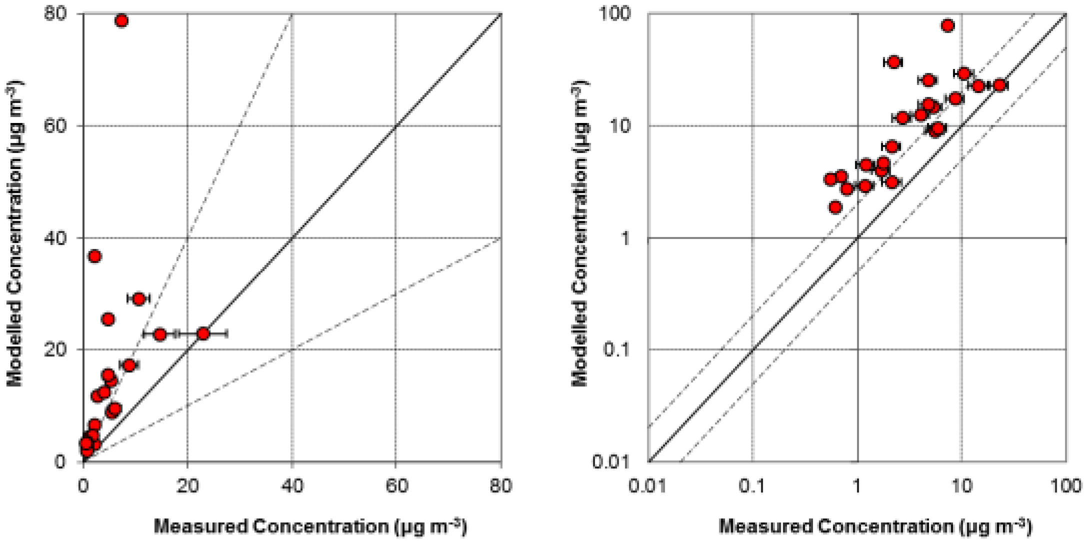

Figure 5-L: Best estimate concentrations predicted by SCAIL-Agriculture plotted against the measured values on linear (left) and logarithmic (right) axes for emissions from both installations of the Scotland - Poultry dataset. Error bars show the estimated uncertainty in the measured values. The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

5.4.3. Estimation of model prediction uncertainty due to simplification of model input data

SCAIL-Agriculture makes several simplifications to the input data provided in order to simplify the model data requirements and reduce model run time. It is possible that these simplifications introduce uncertainties into the model predictions and so it was necessary to evaluate these. This was conducted by using a dataset with detailed model input data and running AERMOD offline to compare the SCAIL-Agriculture predictions with those of the detailed AERMOD simulation. The best dataset for this is the Pedersen Danish pig farm case study since this dataset includes measurements of source emissions, exit temperatures and velocities as well as the exact locations of the sources and buildings.

In this case study the main simplifications made by SCAIL-Agriculture are the use of a single square building (of same floor area as the actual building) perpendicular to the wind direction, the assumption that the emission temperature is 5°C above ambient, the assumption of constant emission rates and exit velocities, the combination of the 11 sources into one single source in the centre of the building roof and the prediction of ground-level concentrations instead of those at the measurement height (2 m).

Figure 5-M shows the measured NH_3 concentrations and those modelled using SCAIL-Agriculture for each of the eight radial directions in which concentrations were measured.

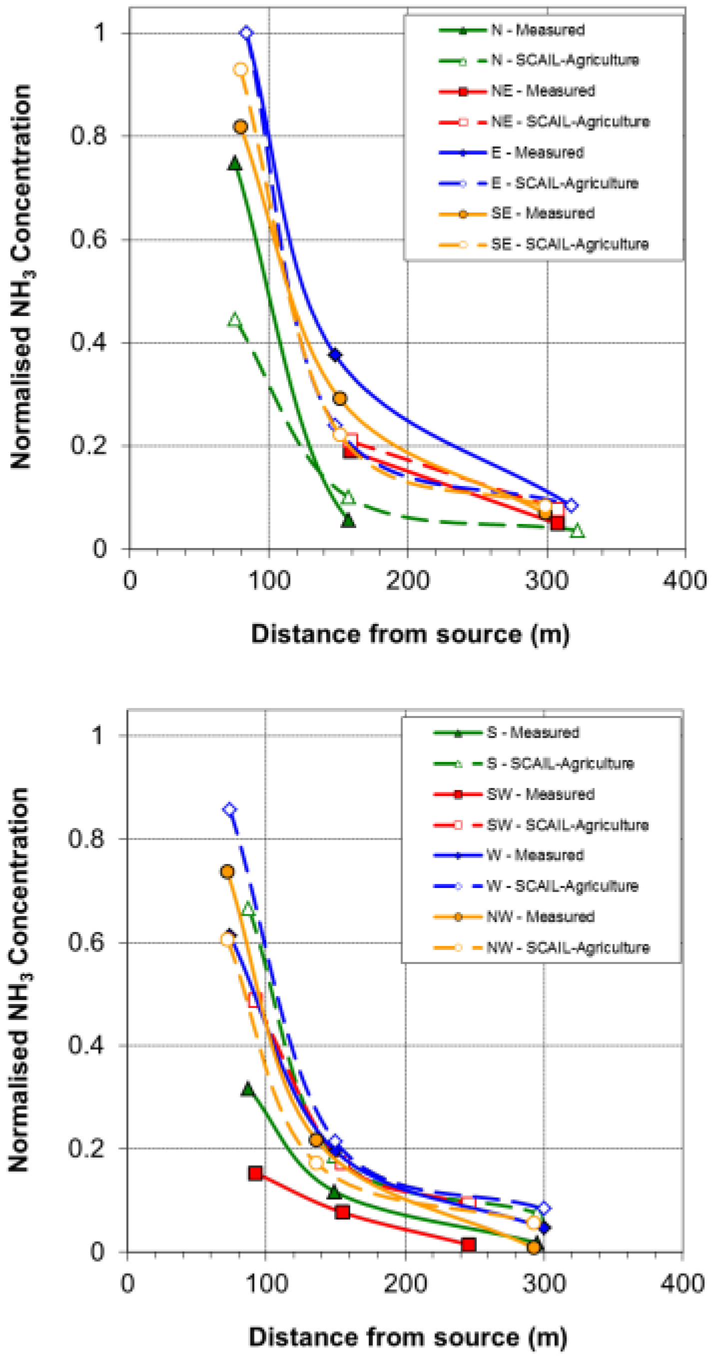

Figure 5-M: Concentrations predicted by SCAIL-Agriculture and the measured values plotted against distance from the source for the eight radial directions (top: N-SE; bottom: S-NW) for the Pedersen (Denmark) dataset.

In order to assess the effect that source simplification and other factors have on the concentrations estimated by SCAIL-Agriculture, additional simulations were carried out with the full AERMOD model (Table 5-E).

Table 5-E: Description of the different AERMOD model runs used to assess the influence of the simplification of building, source and receptor parameterisations.

Run	Building	Source	Receptor height	Effect on concentrations (relative to R1)	Comments
R1	Simplified	Simplified	Ground level	--	Identical to SCAIL-Agriculture simulation
R2	Actual dimensions	Simplified	Ground level	Reductions of up to 50% close to the source, small effect (<5%) further away	To assess the effect of simplifying the building
R3	Simplified	Temporally varying emission rate, exit velocity and release temperature (single central point source)	Ground level	Increases of up to 10% close to the source, smaller effect further away	To assess the effect of source parameters
R4	Simplified	Simplified	2 m	Reductions of up to 25% close to the source, small effect (<5%) further away	To assess effect of receptor height
R5	Actual dimensions	Measured exit velocity and temperature (all eleven point sources)	2 m	Reductions of up to 70% close to the source, smaller effect (up to 30%) further away	The AERMOD best estimate

Re-running the SCAIL-Agriculture simulation with the actual building dimensions (R2) decreased concentrations close to the source by up to 50% but affected the concentrations at distances of more than 100 m by less than 5% (relative to the SCAIL-Agriculture simulation, R1), (Figure 5-N). Rerunning the original simulation (R1) with the temporally varying measured values of source emission, exit velocity and exit temperature (R3) also increased the concentrations by up to 10% close to the source with smaller increases at distances of more than 100 m. Using the actual measurement height instead of ground level for the concentration predictions (R4) decreased concentrations close to the source by up to 25% but affected the concentrations at distances of more than 100 m by less than 5%.

Concentrations predicted by the detailed AERMOD simulation using the measured source emissions, exit temperatures and velocities as well as the exact locations of the sources, buildings and concentration measurements (R5) were up to 70% lower relative to the SCAIL-Agriculture simulation (R1) with the largest reductions within 100 m of the source. This reduction is probably the combined effect of using the real building dimensions and receptor heights. For this case study, therefore, the effect of the simplifications of model inputs in SCAIL-Agriculture (i.e. R1 vs R5) is an overestimation of concentrations by up to a factor of three within 100 m of the source and up to a factor of less than 1.5 further away.

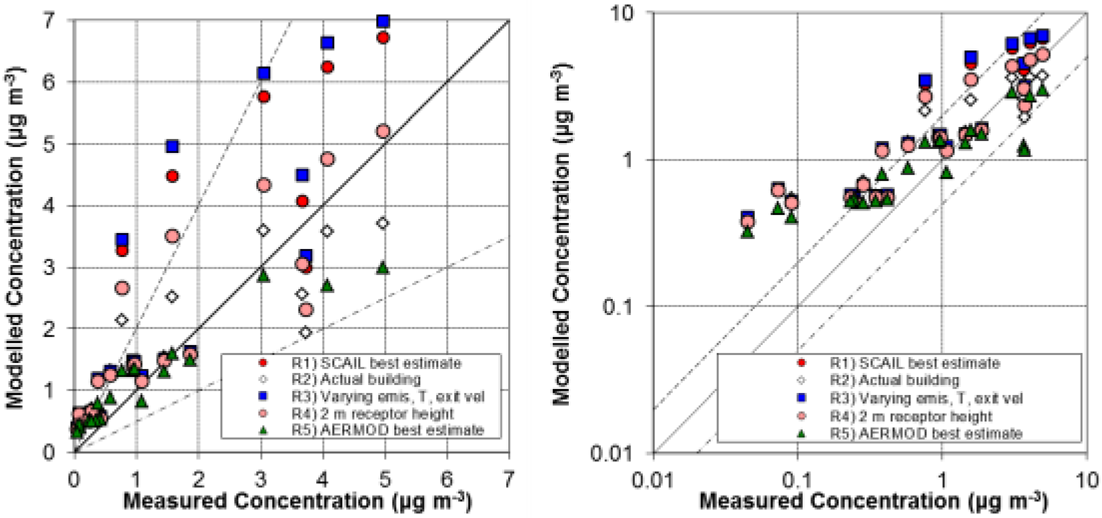

Figure 5-N: Concentrations predicted by SCAIL-Agriculture and the corresponding AERMOD simulations plotted against the measured values on linear (left) and logarithmic (right) axes for the Pedersen (Denmark) dataset. The solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

Table 5-F summarises the performance measure values for the simulations R1-R5. The original SCAIL-Agriculture parameterisation meets three out of the five acceptability criteria and model performance is improved using the real receptor height. Best model performance was from the detailed AERMOD simulation.

Table 5-F: Summary of the performance indicator values for the different model runs for the Pedersen (Denmark) dataset. Shaded cells represent values that meet the acceptability criteria.

Run / Parameterisation No.	FB	MG	NMSE	VG	FAC2
R1 **(SCAIL-Agriculture original parameterisation)**	-0.43	0.49	0.54	2.57	55%
R2 **(As R1 but with actual building dimensions)**	-0.11	0.57	0.27	2.36	59%
R3 **(As R1 but with temporally varying emission rate, exit velocity and release temperature)**	-0.48	0.47	0.66	2.72	50%
R4 **(As R1 but with a receptor height of 2 m)**	-0.26	0.54	0.28	2.38	55%
R5 **(AERMOD complete simulation)**	0.17	0.74	0.60	2.04	64%

5.4.4. Ammonia validation summary and recommendations

The performance analysis using the default emission factors shows that SCAIL-Agriculture does not meet the acceptability criteria. The model only meets 12 of the 35 acceptability tests (7 case studies × 5 criteria) though it must be borne in mind that these criteria were designed for research-grade experiments, not screening assessments. The reason for this performance is mainly due to an underestimation of ammonia concentrations for the broiler farm datasets and an overestimation for the layer farms, which suggests that the emission factors used in the model may not be truly representative.

Model prediction uncertainty depends on whether the input parameters are known or are estimated as well as the amount of simplification carried out by the model. If all model input parameters are known fairly accurately, the model prediction uncertainty will consist of the inherent uncertainty of

AERMOD plus uncertainty due to the simplification of model inputs. For the Pedersen (Denmark) dataset, inherent uncertainty of AERMOD (assuming that all model input is correct in the detailed simulation) ranges over ± a factor of two. Added to this in SCAIL-Agriculture is the uncertainty due to the simplification of model input data. For the Pedersen dataset, this uncertainty was estimated to be an overestimation of concentrations by up to 50%. Where input parameters are not known accurately (especially emission rates), the use of estimated values can lead to additional prediction uncertainties of at least ±20%.

From this analysis, a simple estimate of the uncertainty of SCAIL-Agriculture can be made for distances greater than 100 m from the source. Where input parameters are known accurately, the upper estimate of uncertainty for SCAIL-Agriculture is a factor of 2 × 1.5 (inherent model uncertainty combined with the maximum overestimation due to model simplification) = 3.0 (see Figure 5-O). A lower estimate of uncertainty for this parameterisation is a factor of 0.5 × 1 (inherent model uncertainty combined with the minimum overestimation due to model simplification) = 0.5. Where input parameters are not known accurately (*e.g.* emission rates), the use of estimated values can lead to a model prediction uncertainty of a factor of 0.4 to 3.6 (assuming that the largest uncertainty is in the emission factors (±20%)) i.e. predictions by SCAIL agriculture are in the range 40% to 360% of the real values. At distances less than 100 m from the source SCAIL-Agriculture could overestimate concentrations by up to a factor of seven and so is less suitable for predictions at these distances. It is possible that the emission factors used are wrong by more than 20%. If this is the case then the overall uncertainty of the model will be larger than that shown in Figure 5-O. Combining this simple uncertainty estimate with the results of the validation exercise, we conclude that SCAIL-Agriculture can predict atmospheric NH_3 concentrations within a factor five of the actual values for the majority of situations, for distances of more than 100 m from the source.

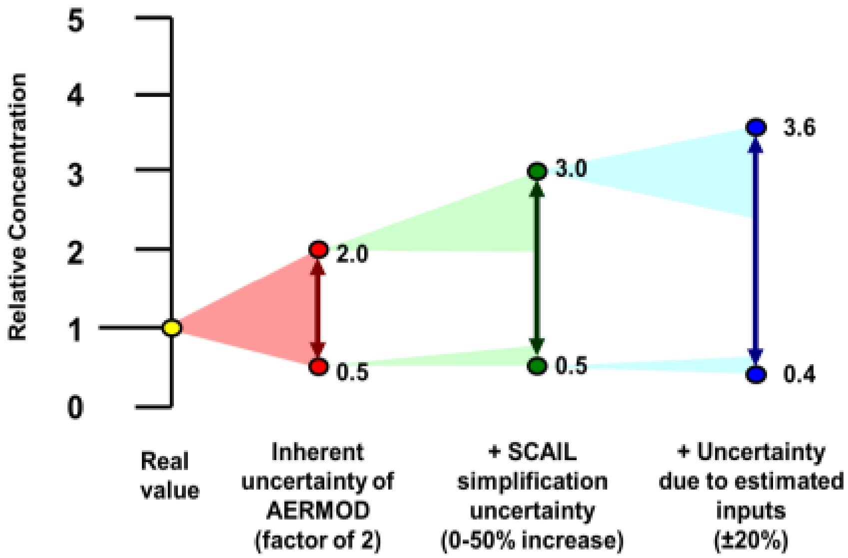

Figure 5-O: Schematic of the contributions to the uncertainty of SCAIL-Agriculture by the inherent uncertainty of AERMOD, the simplification of simulation parameters and the estimation of input parameters.

5.4.5. Comparison with previous version of SCAIL-Agriculture

Five of the seven validation datasets used in this study (Newborough, NI – Fan and Naturally Ventilated, Garvary Lodge and Pitcairn – Pigs) were also used for the validation of the previous version of SCAIL-Agriculture (Theobald *et al.*, 2009) and so it is possible to compare the performance of both versions of the model. Figure 5-P shows the concentrations predicted by the current and previous version of the model plotted against the measured concentrations for the five datasets. Although the current version of the model has a similar linear correlation with the measurements as the previous version, the slope of the linear regression of the current model is a substantial improvement on that of the previous version. This is not surprising since the current version of the model has a more complex representation of sources and buildings (the latter not included in the previous version). This improved model performance can also be seen in the values of the performance indicators (Table 5-G), all of which are an improvement for the current version of the model.

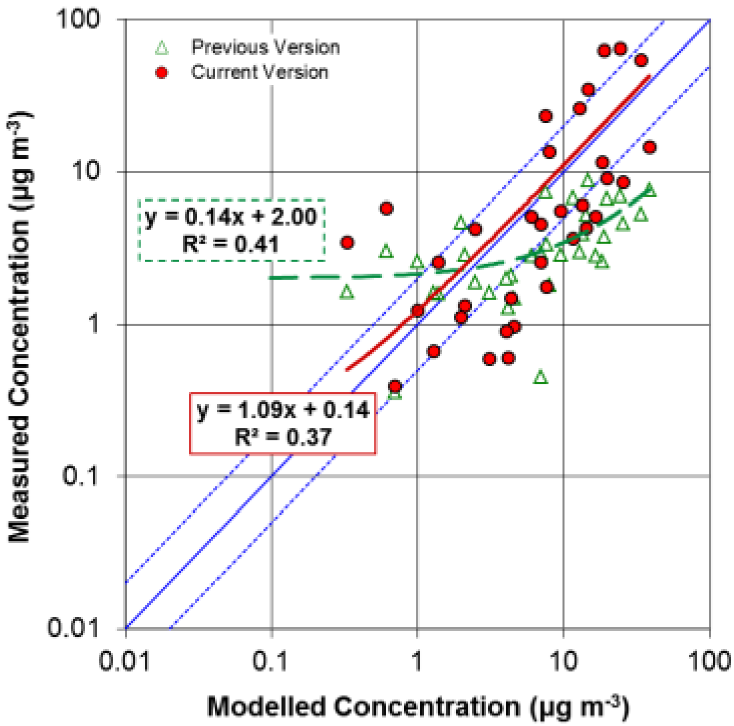

Figure 5-P: Best estimate concentrations predicted by SCAIL-Agriculture (circles) and the predictions of the previous version of SCAIL-Agriculture (triangles) plotted against the measured values for all corresponding ammonia validation datasets. Linear regressions for the predictions of the current version of the model (black solid line) and the previous version (black dashed line) are also shown. The blue solid line shows the 1:1 line and the dotted lines show the limits for predictions within a factor of two of the measured values.

Table 5-G: Summary of the performance indicator values for the concentration predictions by the current SCAIL-Agriculture and the predictions of the previous version of SCAIL-Agriculture for all corresponding ammonia validation datasets. Shaded cells represent values that meet the acceptability criteria.

	FB	MG	NMSE	VG	FAC2
Current model	-0.1	1.3	1.6	3.4	38%
Previous version	0.6	2.1	5.2	4.6	26%

5.5. Validation of SCAIL-Agriculture for Odour concentrations

Table 5-H lists identified datasets that could potentially be applied for odour validation. Suitable datasets were obtained from Dr Tom Curran at University College Dublin, and Alberta Agriculture and Rural Development (ARD) and University of Alberta (UofA) (Qu *et al.*, 2006) for use in the validation. It was not possible to obtain data from any of the other references listed below.

Table 5-H: Ranking of the UK, Ireland and international datasets in order of acceptability for validation

Rank	Study name and reference	Source type	Reasons for ranking position
1	Dublin Curran *et al*., 2007	Pig	Relevant to the UK and Ireland. Source data and meteorological data provided. Ambient odour concentrations reported, not just intensity. May be possible to get further details from authors.
2	Carney and Dodd, 1989	Pig (buildings, slurry store, spreading)	Only other UK/Ireland study. Odour concentrations at specific distances provided. Specific meteorological data including wind speeds not provided, but may be inferred. Further investigation may prove useful.
3	Minnesota Zhu *et al*., 2000	Various inc. pig and poultry	Only study to include poultry. May be possible to get further details from authors. Ambient odour intensity reported, not concentration.
4	Saskatchwean Guo *et al*., 2005	Pig	May be possible to get further details from authors. Ambient odour intensity reported, not concentration. Complex site over three locations
4	Manitoba Zhang *et al*. 2005 and Guo *et al*., 2006	Pig	May be possible to get further details from authors. Ambient odour intensity reported, not concentration. Not necessarily relevant to UK/Ireland as most measurements in Cat. B conditions.
4	Alberta Qu *et al*., 2006	Pig	Emission rates not obvious in paper, but further details were obtained from authors. Odour intensity vs. concentration relationship discussed. Results may not necessarily be relevant to UK/Ireland.
4	Iowa Henry 2009	Pig	Emission rates not obvious in paper, but may be possible to get further details from author. Ambient odour intensity reported, not concentration.
4	Nebraska (slurry) Henry 2009a	Pig slurry store	May be possible to get further details from author. Ambient odour intensity reported, not concentration. Measurements all very close to source (<200m).
5	Lohmeyer Keder *et al*., 2005		This study may be useful if a translation of the paper can be found. At present few details are known about the study.
6	Nebraska (feedlot) Henry 2009b	Cattle feedlot	Source is not relevant to pigs and poultry.

5.5.1. Ireland - Pigs

Field measurements took place at a 514-sow integrated pig unit in a rural area about 25 km northwest of Dublin airport. A shelter belt of trees existed along the access road to the south of the unit and also along the boundary fence to the east. Wheat was grown in the surrounding fields and was harvested in early September just before the field measurements began.

The operator of the site held an Integrated Pollution Control (IPC) licence, which was issued by the Environmental Protection Agency. Pig numbers are shown in Table 5-I alongside other parameters of the buildings. Measurements were made on two occasions of the odour emissions from a number of buildings on the site and were interpolated to provide an estimate of the overall emissions from the site. The vast majority of the buildings incorporated automatically controlled natural ventilation (ACNV) although the first stage weaning houses and a small number of farrowing units were mechanically ventilated.

Table 5-I: Source parameters for the pig farm. L: Length, W: Width, Emis1/2: emission measurements; D: Exit diameter of fans, NV: Naturally ventilated.

Source	L (m)	W (m)	Area (m^2)	Animals	Emis1 (OU s^{-1})	Emis2 (OU s^{-1})	D (m)	Flow (m^3/s)
BLD1	15.0	67.7	1014	394 sows 107 gilts	29257	39785	NV	NV
BLD2	10.4	57.6	596	96 farrow	4031	2997	NV	NV
BLD3	11.7	10.0	117	24 farrow	1272	1336	0.45	1.6
BLD4	15.8	14.8	233	1250 weaners	8270	5203	0.45	0.4
BLD5	9.2	42.0	385	720 weaners	6519	9860	NV	NV
BLD6	11.1	59.1	656	960 finishers	29105	25894	NV	NV
BLD7	10.5	58.9	622	960 finishers	29105	25894	NV	NV

The pig unit was well managed in terms of cleanliness of external yards. It was considered that the main odours were emanating from the pig housing on site. All the buildings had slatted floors with manure stored beneath. The unit had a large external overground slurry tank, which was empty during the test period. The depth of manure stored underneath the pig buildings at the time was also at a relatively low level because most of the slurry had been emptied during the summer season. The nearest farm building was approximately 800 m away; it was a cattle building and no animals were being housed during the period of measurements.

There are 9 buildings on the site configured as shown in Figure 5-Q.

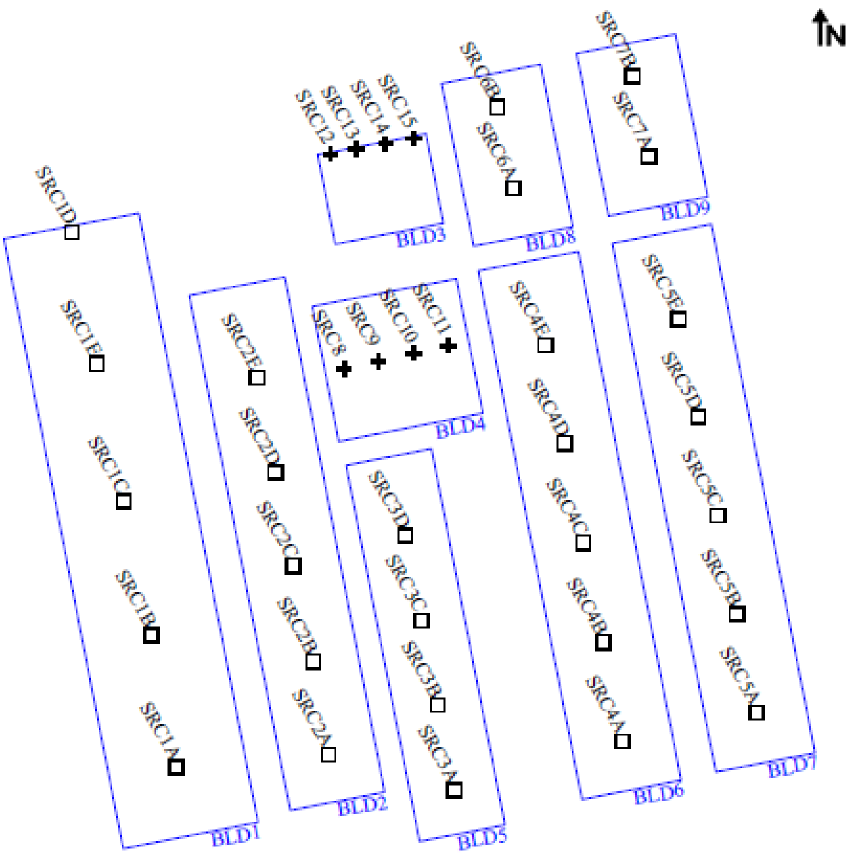

Figure 5-Q: Configuration of buildings on the pig farm used in the validation study.

Field measurements were collected using a panel of sniffers. Measurements were carried out in the afternoon on sampling days with a panel of sniffers positioned in a line, the approximate distances are shown in Table 5-J. VDI 3940 (1993) was used as a guideline to set up the experiment. The sensitivity of field panellists to n-butanol reference gas was also measured using a T07 olfactometer during the experimental period to ascertain where panel members fitted in the range between hypersensitivity and anosmia. It should be recognised that measurements collected by a sniffing panel will have a considerably higher uncertainty over validation.

Table 5-J also shows meteorological data that were measured locally during the experiments and boundary layer depths were modelled using the HIRLAM model. Atmospheric stability was taken as being category D (neutral) based on measurements from Dublin airport.

Table 5-J: Details of the sampling times measurement locations and meteorological conditions relevant to the odour validation. Data in grey were excluded as the sniffing panel were not downwind of the farm.

Date	Time	n. Samples @ distance	U (m s^{-1})	PHI (degrees)	T (K)	Boundary layer (m)
23/09	1637	6 @ 155 m 5 @ 205 m	5.6	316	288.4	1360
23/09	1700	6 @ 255 m 5 @ 305 m	5.7	328	288.0	1360
23/09	1717	6 @ 355 m 5 @ 405 m	6.7	309	288.1	1360
30/09	1615	5 @ 140 m 5 @ 190 m	4.8	279	287.9	1092
30/09	1638	5 @ 240 m 5 @ 290 m	4.0	272	287.6	939
30/09	1703	5 @ 340 m 5 @ 390 m	3.4	281	287.5	939
07/10	1615	5 @ 205 m 5 @ 255 m	1.6	312	287.4	1220
07/10	1631	5 @ 305 m 5 @ 355 m	3.0	332	287.3	506
07/10	1656	5 @ 405 m 5 @ 455 m	1.1	283	285.8	506

5.5.2. Results

SCAIL-Agriculture was run using emissions for the various animal types on the farm (assuming that gilts had the same emission factors as sows). The SCAIL emission calculations are shown alongside the measured/extrapolated emissions in Table 5-K. It is clear that SCAIL provides a similar overall emission estimation to that measured on the site although there are some significant variations, in particular buildings BLD 1 and BLD 5.

Table 5-K: SCAIL emission calculations for the pig farm.

Source	Emis1 (OU s^{-1})	Emis2 (OU s^{-1})	SCAIL (OU s^{-1})
BLD1	29257	39785	13026
BLD2	4031	2997	2496
BLD3	1272	1336	624
BLD4	8270	5203	5000
BLD5	6519	9860	2880
BLD6	29105	25894	24960
BLD7	29105	25894	24960
BLD8	12973	16979	12480
BLD9	12961	16979	12480

A comparison was made between the predictions of the SCAIL Tool and the field measurements as shown in Table 5-L. Two configurations of SCAIL were used, one treating the naturally ventilated buildings as volume sources (VOLUMES) and a second treating these sources as wall mounted point sources with low efflux velocities (POINTS). The SCAIL tool using the VOLUMES configuration meets three of the five acceptability criteria and was close to meeting the criteria for the two remaining metrics. When the POINTS configuration was applied the overpredictions of the tool increased. Despite only a fractional worsening of the performance of the tool, the acceptability criteria were only met for one of the five metrics when the POINTS configuration was applied. Scatter plots are shown in Figure 5-R.

A further comparison was made between the ISC and CALPUFF models and the predictions of SCAIL. ISC and CALPUFF were configured by UCD with the measured odour emission rates and building configurations. The SCAIL predictions were found to be comparable with those from the detailed modelling work and actually provided an improved performance for most metrics. It is likely that the improved performance of SCAIL relates to a reduced tendency towards overprediction due to the lower emission rates being predicted by the tool.

Table 5-L: Summary of the performance indicator values for the odour validation datasets. Shaded cells represent values that meet the acceptability criteria.

	FB	MG	NMSE	VG	FAC2
Dublin (SCAIL- VOLUMES)	-0.003	0.614	2.17	3.4	53%
Dublin (SCAIL- POINTS)	-0.168	0.586	2.04	4.01	48%
Dublin (ISC)	-0.6	0.408	1.91	10.9	36%
Dublin (CALPUFF)	-0.6	0.414	1.91	11.5	36%

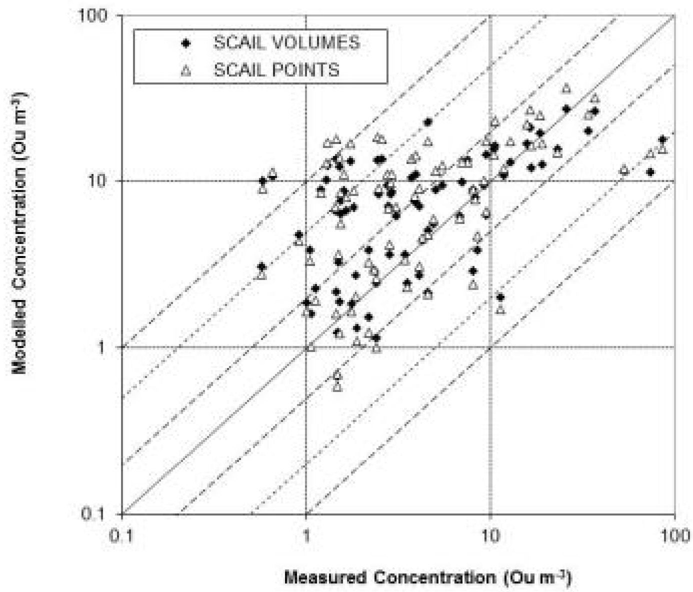

Figure 5-R: Odour concentrations for the Ireland validation set predicted by SCAIL-Agriculture for two configurations (modelling naturally ventilated sources as Volume sources: VOLUMES; or as Point sources: POINTS) plotted against the measured values for the odour validation dataset. The dotted lines show the limits for predictions within a factor of two, five and ten of the measured values whilst the solid line shows the 1:1 line.

5.5.3. Alberta - Pigs

Field measurements took place at an intensive pig unit in Alberta Canada. The site comprised of two pig houses and three associated earthen liquid manure storage facilities (EMS).

Details of the model configuration are shown in Table 5-M. Measurements were made on 11 occasions of the odour emissions from randomly selected exhaust fans in one of the two pig buildings on site and one of the three EMS, and were extrapolated to provide an estimate of the overall emissions from the site. A comparison of the measured odour emission and the emission predicted by SCAIL is shown in Table 5-M illustrating a good agreement between SCAIL and the measured emissions. Information was provided on the ventilation rates of the buildings although this did not cover all the emission points on the farm hence modelling in SCAIL was conducted using the volume source approach by selecting the naturally ventilated building option.

Table 5-M: Source parameters for the Alberta pig farm.

Source	Area (m^2)	Number of animals	Emis Meas. (OU s^{-1})	Emis SCAIL (OU s^{-1})
EMS 1	17218	-	4.39E+05	3.44E+05
EMS 2	2607	-	6.65E+04	5.21E+04
EMS 3 N	1226	-	6.25E+04	4.90E+04
EMS 3 S	233	-		
W Barn 1	1740	Approx. 2500	5.59E+04	8.41E+04
W Barn 2	2352	Approx. 2500		
E Barn 1	1229	Approx. 1600	4.19E+04	5.45E+04
E Barn S	1229	Approx. 1600		

Field measurements were collected using a panel of sniffers who were positioned downwind of the complex, Figure 5-S shows the positions used by the sniffing panel during all the experiments. Instantaneous odour intensities were recorded and averaged to provide an hourly estimation of odour intensity. Odour concentrations were calculated for each of the 24 hourly estimates of odour intensity using the relationship between intensity and concentration derived by ARD and UofA in a prior study. On site meteorological data were collected and analysed using AERMET to provide hourly sequential surface and profile files for inclusion into SCAIL.

The ISC model was run by ARD and UofA as a detailed modelling assessment using ground level area sources to simulate emissions from the buildings. These data were compared to the predictions of SCAIL.

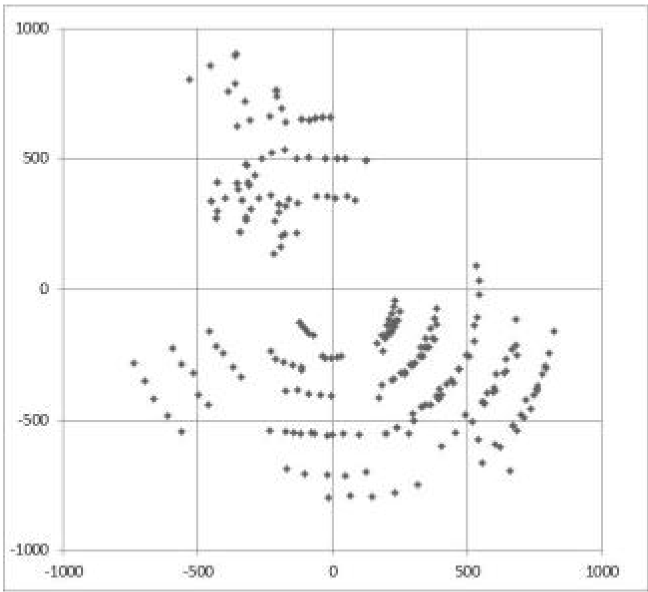

Figure 5-S: Positions used by the sniffing panel for the Alberta odour validation experiments (distances are shown in metres from the approximate centre of the installation).

5.5.4. Results

Table 5-N shows the model performance statistics for the SCAIL and ISC models illustrating that neither model met the model performance criteria. Both models underpredicted the odour concentrations observed in the field, with SCAIL underpredicting to a greater extent than ISC (Figure 5-T). This was likely to be due to the differences in the source configurations between SCAIL and ISC with SCAIL applying a volume source approximation and ISC modelling the buildings as ground level area sources. In addition, the modelling using ISC used the meteorological conditions averaged over the two 5 minute-averaged data points relevant to each set of field measurements whilst SCAIL applied hourly averaged meteorological data.

Table 5-N: Summary of the performance indicator values for the Alberta odour validation dataset. Shaded cells represent values that meet the acceptability criteria.

	FB	MG	NMSE	VG	FAC2
SCAIL	1.19	6.72	16.71	1988	23%
ISC (detailed modelling)	0.75	2.22	8.00	46	35%

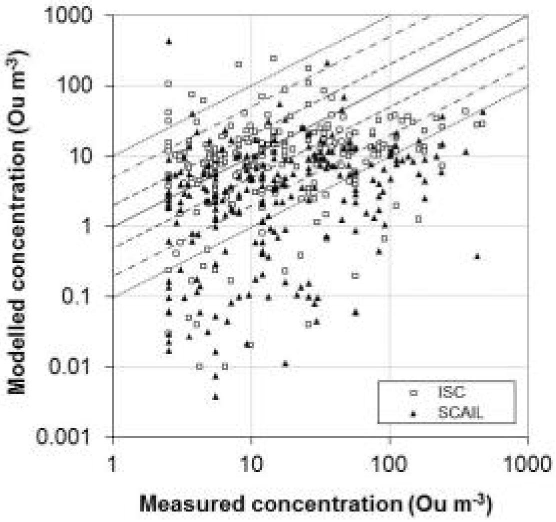

Figure 5-T: Odour concentrations for the Alberta validation set predicted by SCAIL-Agriculture and ISC. The dotted lines show the limits for predictions within a factor of two, five and ten of the measured values whilst the solid line shows the 1:1 line.

5.5.5. Conclusions from the odour validation

The SCAIL-Agriculture model was compared with measurement and modelling data collected through detailed studies conducted by University College Dublin, and ARD and UofA. One of the major sources of uncertainty in the modelling was identified to be the estimation of odour source terms. The overall emissions were comparable between SCAIL and the measurements made on site. However emissions from individual buildings could be in error by a factor of three or more.

Despite the expected considerable uncertainties in short term monitoring data collected by a panel of field “sniffers” the results of the validation for Ireland were encouraging and demonstrated that SCAIL-Agriculture met the majority of acceptability criteria set for “research grade” models. In addition, similar results were obtained from SCAIL when compared with detailed modelling using ISC and CALPUFF.

The model performance for the Alberta dataset was not as encouraging as found for Ireland. Neither model met the acceptability criteria set for “research grade” models with both SCAIL and ISC underpredicting concentrations measured in the field. A higher level of underprediction was found for SCAIL. Improvements to the predictions from SCAIL could be achieved through the use of sub-hourly meteorological data, however for this report it has not been possible to evaluate such data.

5.5.6. Validation of SCAIL-Agriculture for PM_{10} concentrations

Four datasets of PM_{10} concentrations measured near agricultural sources were identified for validating SCAIL-Agriculture. All the datasets used TEOM instruments located at between 15 m to 100 m from the poultry houses depending on the site. A summary of the PM_{10} monitoring data is shown in Table 5-O.
All the datasets related to intensive poultry broiler production with details of the farm sites being included in Table 5-P. The locations of the buildings and the monitoring points were estimated from Google Maps and from annotated aerial photography provided by the Department for the Environment Northern Ireland.

The results from SCAIL-Agriculture are shown in Table 5-Q and the comparison between the monitoring and modelling data is shown in Table 5-R. Overall SCAIL was found to meet the model evaluation acceptability criteria for PM_{10}. However, it should be noted that the variability between the monitoring and modelling datasets was typically between +/- 30 – 40 %.

Table 5-O: Summary of the PM_{10} monitoring data collected around poultry farm buildings.

Location	Source	Average PM_{10}	90^{th} %ile daily averages	Period	Distance to nearest building
Wales	Newborough	25.2	N/A	19/06/2003 - 15/10/2003	100 m
Northern Ireland	Augher	22.0	37	26/10/2005 - 15/12/ 2006	80 - 90 m
Northern Ireland	Eglish	20.6	34.1	21/11/2004 - 17/08/05	30 - 40 m
Northern Ireland	Brantray	16	31	28/12/2006 - 3/02/2008	15 m

Table 5-P: Metadata used for modelling poultry farm buildings.

Location	Source	Number of buildings	Total number of animals	Ventilation
Wales	Newborough	6	200,000 broilers	Forced
Northern Ireland	Augher	9	241,000 broilers	NV (assumed)
Northern Ireland	Eglish	7	195,000 broilers	NV (assumed)
Northern Ireland	Brantray	6	119,000 broilers	NV (assumed)

Table 5-Q: Summary of the PM_{10} modelling data produced by SCAIL Agriculture. PC = Process Contribution; PEC = Predicted Environmental Concentration (PC+ Background).

Location	Source	Average PM_{10}		90^{th} %ile daily averages	
		PC	PEC	PC	PEC
Wales	Newborough	7.00	32.52	Wales	Newborough
Northern Ireland	Augher	10.11	14.26	Northern Ireland	Augher
Northern Ireland	Eglish	17.58	22.31	Northern Ireland	Eglish
Northern Ireland	Brantray	14.51	18.96	Northern Ireland	Brantray

Table 5-R: Summary of the performance indicator values for the PM10 validation datasets. Shaded cells represent values that meet the acceptability criteria.

	FB	MG	NMSE	VG	FAC2
SCAIL (annual average)	-0.049	0.98	0.068	1.07	100
SCAIL (90^{th} %ile)	-0.230	0.81	0.127	1.12	100

5.6. Validation for Scottish Poultry Farm Sites

This section provides a summary of the validation exercise conducted for the SCAIL-Agriculture tool using monitored data collected from two farm sites. The full report is provided as Appendix H, which describes the bespoke monitoring conducted for the validation of the tool to ensure that the tool provides realistic yet conservative results.

A detailed set of model validation experiments were conducted at two farm sites (Whitelees and Glendevon Farms) in Central Scotland collecting odour, ammonia and airborne particulate data as well as recording on-site meteorological information. The following data were collected:

- *Continuous monitoring of meteorological data over a period of approximately three months at Whitelees and Glendevon Farms.*
- *Continuous monitoring of ammonia and airborne particulate concentrations was conducted over a period of approximately three months at Whitelees Farm.*
- *Monitoring of ammonia concentrations at nine locations around Whitelees and Glendevon Farms for a period of approximately three months using passive diffusion samplers (Alpha Samplers)*
- *Monitoring of ammonia, odour and PM_{10} emissions from the buildings at Whitelees and Glendevon Farms on two occasions.*
- *Monitoring ambient odour concentrations on transects at Whitelees and Glendevon Farms on two occasions.*

Measured emission data were relatively self-consistent between the two monitoring periods conducted at each farm. Measured emissions of ammonia were found to be higher than were predicted using the emission factors in SCAIL-Agriculture, whilst measurements of PM_{10} emission and odour emission were lower than those predicted using the emission factors in SCAIL-Agriculture.

Measured ambient concentrations of ammonia recorded using Alpha Samplers were found to agree well with the default configuration of SCAIL-Agriculture, with the model meeting all the acceptability criteria of Chang and Hanna (2004). In addition, a good agreement was found between SCAIL-Agriculture and a detailed AERMOD model of atmospheric dispersion from both farms. Ambient ammonia concentrations recorded using the continuous AiRRmonia monitor were also found to agree well with SCAIL Agriculture when configured using on-site meteorological data and measured emission rates, again meeting all the acceptability criteria of Chang and Hanna (2004).

Measured PM_{10} concentrations showed a relatively weak signal from Whitelees Farm, illustrating that other PM_{10} sources (either local or distant) were significant contributors. A filtering process was used to attempt to correct the measured data to remove these “background” contributions and a comparison of daily-averaged concentrations was made with the predictions of the SCAIL model. This comparison illustrated that, when configured with the default emissions parameters, SCAIL-Agriculture met 3 of the 5 model acceptability criteria of Chang and Hanna (2004).

Odour concentrations measured on transects by field “sniffers” around both farms were compared with the model predictions. It should be noted that there is a high level of inherent uncertainty associated with the comparison of data determined with the human nose over a short time period and the predictions of a numerical model configured with hourly averaged meteorological data. However, it was clear that, whilst only one of the five acceptability criteria of Chang and Hanna (2004) were met, the model (when configured using measured emissions data) provided realistic estimates of the magnitude of ambient concentrations and also their spatial distribution.

In conclusion the SCAIL-Agriculture model was found to broadly meet recognised acceptability criteria for the prediction of ammonia, PM_{10} and odour concentration arising from farm buildings. There are however a number of areas where further research could improve the assessment of agricultural sources. These are as follows:

- *Improvements to the emissions datasets used to derive emission factors that are included in the tool.*
- *Investigations as to the impact of local vs. regional meteorological data on the performance of assessment codes.*
- *Further research into PM_{10} levels around farm buildings and the impact of re-suspended dusts on local air concentrations.*

It is worthwhile comparing the results of this validation exercise with the validation work described in section 5.5. Although the approaches of the two exercises are not directly comparable since the validation described in the previous sections used long-term monitoring data and the estimation of various model inputs, whereas that described in this section used short-term monitoring data and detailed site data, the results do show some consistency. For example, in both exercises the simplification of the source in SCAIL-Agriculture gave rise to a small (<15%) concentration error at distances more than 100 m from the source but resulted in a much larger error (~50%) at closer distances.

The validation for the Scottish sites shows a better performance of SCAIL-Agriculture when the model emission estimates are used and the meteorological data come from the nearest 'SCAIL' station (i.e. screening configuration), compared with the model performance described in the section 5.5. However, it is thought that this result was fortuitous, due to a cancelling effect of the higher concentrations predicted by the use of the Edinburgh meteorological data and the underestimation of emissions. Removing this cancelling effect of the meteorological data (by looking at the model performance using the on-site data; Scenario OR1), it can be seen that SCAIL-Agriculture under-estimates concentrations by up to a factor of four, mainly due to an under-estimation of emissions. This model uncertainty is of the same order of magnitude as that presented in section 5.5, again showing consistency between the two exercises.

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Appendix A. Emission Factors - Ammonia

Table A - 1: Emission factors for NH_3 in the SCAIL-Agriculture tool

Livestock	Housing System	Emission Factor	Units
Turkeys (male)	Litter	0.45	kg NH_3/animal place/year
Turkeys (female)	Litter	0.23	kg NH_3/animal place/year
Ducks	Litter	0.11	kg NH_3/animal place/year
Manure - belts		2.38	kg NH_3/animal place/year
Manure - deep pit		2.38	kg NH_3/animal place/year
Other litter		1.74	kg NH_3/animal place/year
Manure heap	No cover	1.49	kg NH_3/animal place/year
Slurry - circular store	No cover	1.40	kg NH_3/m^2
Slurry - circular store	Rigid cover	0.28	kg NH_3/m^2
Slurry - circular store	Floating	0.70	kg NH_3/m^2
Slurry - circular store	Low tech	1.05	kg NH_3/m^2
Slurry - lagoon	No cover	1.40	kg NH_3/m^2
Slurry - lagoon	Rigid cover	0.28	kg NH_3/m^2
Slurry - lagoon	Floating	0.84	kg NH_3/m^2
Slurry - lagoon	Low tech	1.05	kg NH_3/m^2
Broadcast	Laying hens	6.12	kg NH_3/t
Broadcast & ploughed within 24hrs	Laying hens	2.75	kg NH_3/t
Broadcast	Other poultry	9.18	kg NH_3/t
Broadcast & ploughed within 24hrs	Other poultry	4.13	kg NH_3/t
Broadcast (solid manure)		1.01	kg NH_3/t
Broadcast (solid and ploughed within 24 hrs)		0.66	kg NH_3/t
Broadcast (slurry)	<4% dry matter	0.55	kg NH_3/t
Broadcast (slurry)	4-8% dry matter	1.35	kg NH_3/t
Bandspread (slurry)	<4% dry matter	0.41	kg NH_3/t
Bandspread (slurry)	4-8% dry matter	1.01	kg NH_3/t
Trailing shoe (slurry)	<4% dry matter	0.27	kg NH_3/t
Trailing shoe (slurry)	4-8% dry matter	0.67	kg NH_3/t
Injection (open slot)	<4% dry matter	0.16	kg NH_3/t
Injection (open slot)	4-8% dry matter	0.40	kg NH_3/t
Injection (closed slot)	<4% dry matter	0.05	kg NH_3/t
Injection (closed slot)	4-8% dry matter	0.13	kg NH_3/t
Layers	Enriched Cage	0.12	kg NH_3/animal place/year
Layers	Cage with deep pit	0.29	kg NH_3/animal place/year

Livestock	Housing System	Emission Factor	Units
Layers	Ventilated deep pit	0.20	kg NH_3/animal place/year
Layers	Manure removal twice a week by manure belt	0.12	kg NH_3/animal place/year
Layers	Vertical tiered cages, forced air drying, weekly removal	0.12	kg NH_3/animal place/year
Layers	Vertical tiered cages, whisk forced air drying, weekly removal	0.09	kg NH_3/animal place/year
Layers	Vertical tiered cages, manure belt, drying tunnel, 24-36 hr removal	0.06	kg NH_3/animal place/year
Barn and free range	Perchery with deep litter	0.29	kg NH_3/animal place/year
Barn and free range	Litter system with forced air drying	0.12	kg NH_3/animal place/year
Barn and free range	Litter system with perforated floor and forced air drying	0.10	kg NH_3/animal place/year
Barn and free range	Aviary system	0.08	kg NH_3/animal place/year
Broilers	Naturally ventilated, fully littered floor, non-leaking drinkers	0.03	kg NH_3/animal place/year
Broilers	Fan ventilated, fully littered floor, non leaking drinkers	0.03	kg NH_3/animal place/year
Pullets	Naturally ventilated, fully littered floor, non-leaking drinkers	0.06	kg NH_3/animal place/year
Pullets	Fan ventilated, fully littered floor, non leaking drinkers	0.06	kg NH_3/animal place/year
Sows	Fully Slatted Floor (FSF)	3.01	kg NH_3/animal place/year
Sows	Solid Floor - straw system	4.57	kg NH_3/animal place/year
Sows	Part-Slatted Floor (PSF) with reduced manure pit	2.41	kg NH_3/animal place/year
Sows	FSF with vacuum system for frequent slurry removal	2.26	kg NH_3/animal place/year
Farrowers	Fully Slatted Floor (FSF)	5.84	kg NH_3/animal place/year
Farrowers	Solid Floor - straw system	8.88	kg NH_3/animal place/year
Farrowers	FSF/PSF with combination of water & manure channel	2.80	kg NH_3/animal place/year
Farrowers	FSF/PSF with flushing system with manure gutters	2.34	kg NH_3/animal place/year
Farrowers	FSF/PSF with manure pan underneath	2.04	kg NH_3/animal place/year
Weaners	Fully Slatted Floor (FSF)	0.29	kg NH_3/animal place/year

Livestock	Housing System	Emission Factor	Units
Weaners	Sold Floor - straw system	0.21	kg NH_3/animal place/year
Weaners	Pen/flatdeck, FSF/PSF, vacuum system for frequent slurry removal	0.22	kg NH_3/animal place/year
Weaners	Pen/flatdeck, FSF beneath with sloped floor to separate faeces or urine	0.20	kg NH_3/animal place/year
Weaners	Pen with PSF (2-climate system)	0.19	kg NH_3/animal place/year
Weaners	Pen with PSF and sloped or convex solid floor	0.17	kg NH_3/animal place/year
Weaners	Pen with PSF, triangular slats & manure channel, sloped side-walls	0.08	kg NH_3/animal place/year
Growers	Fully Slatted Floor (FSF)	1.59	kg NH_3/animal place/year
Growers	Solid Floor - straw system	2.97	kg NH_3/animal place/year
Growers	FSF with vacuum system for frequent slurry removal	3.11	kg NH_3/animal place/year
Growers	PSF with reduced manure pit including slanted walls & vacuum system	0.64	kg NH_3/animal place/year
Growers	PSF with convex solid floor & manure gutters, slanted sidewalls, sloped manure pit	0.64	kg NH_3/animal place/year
Finishers	Fully Slatted Floor (FSF)	4.14	kg NH_3/animal place/year
Finishers	Solid Floor - straw system	2.97	kg NH_3/animal place/year
Finishers	FSF with vacuum system for frequent slurry removal	3.11	kg NH_3/animal place/year
Finishers	PSF with reduced manure pit including slanted walls & vacuum system	1.66	kg NH_3/animal place/year
Finishers	PSF with convex solid floor, manure gutters, slanted sidewalls, sloped manure pit	1.66	kg NH_3/animal place/year

Appendix B. Emission Factors - Odour

Table B - 1: Emission factors for Odour in the SCAIL-Agriculture tool

Livestock	Housing System	Emission Factor	Units
Turkeys (male)	Litter	206560.8	k OU/animal place/year
Turkeys (female)	Litter	206560.8	k OU/animal place/year
Ducks	Litter	189216	k OU/animal place/year
Manure - belts		1923696	k OU/tonne fresh manure
Manure - deep pit		1923696	k OU/tonne fresh manure
Other litter		1923696	k OU/tonne fresh manure
Manure heap	No cover	2428272	k OU/tonne fresh manure
Slurry - circular store	No cover	630720	k OU/m^2
Slurry - circular store	Rigid cover	63072	k OU/m^2
Slurry - circular store	Floating	63072	k OU/m^2
Slurry - circular store	Low tech	315360	k OU/m^2
Slurry - lagoon	No cover	630720	k OU/m^2
Slurry - lagoon	Rigid cover	63072	k OU/m^2
Slurry - lagoon	Floating	63072	k OU/m^2
Slurry - lagoon	Low tech	315360	k OU/m^2
Broadcast	Laying hens	10404000	k OU/t
Broadcast & ploughed within 24hrs	Laying hens	4675000	k OU/t
Broadcast	Other poultry	15606000	k OU/t
Broadcast & ploughed within 24hrs	Other poultry	7021000	k OU/t
Broadcast (solid manure)		1717000	k OU/t
Broadcast (solid and ploughed within 24 hrs)		1122000	k OU/t
Broadcast (slurry)	<4% dry matter	935000	k OU/t
Broadcast (slurry)	4-8% dry matter	2295000	k OU/t
Bandspread (slurry)	<4% dry matter	697000	k OU/t
Bandspread (slurry)	4-8% dry matter	1717000	k OU/t
Trailing shoe (slurry)	<4% dry matter	459000	k OU/t
Trailing shoe (slurry)	4-8% dry matter	1139000	k OU/t
Injection (open slot)	<4% dry matter	272000	k OU/t
Injection (open slot)	4-8% dry matter	680000	k OU/t
Injection (closed slot)	<4% dry matter	85000	k OU/t
Injection (closed slot)	4-8% dry matter	221000	k OU/t
Layers	Enriched Cage	44150.4	k OU/animal place/year
Layers	Cage with deep pit	44150.4	k OU/animal place/year

Livestock	Housing System	Emission Factor	Units
Layers	Ventilated deep pit	44150.4	k OU/animal place/year
Layers	Manure removal twice a week by manure belt	33112.8	k OU/animal place/year
Layers	Vertical tiered cages, forced air drying, weekly removal	33112.8	k OU/animal place/year
Layers	Vertical tiered cages, whisk forced air drying, weekly removal	33112.8	k OU/animal place/year
Layers	Vertical tiered cages, manure belt, drying tunnel, 24-36 hr removal	33112.8	k OU/animal place/year
Barn and free range	Perchery with deep litter	44150.4	k OU/animal place/year
Barn and free range	Litter system with forced air drying	33112.8	k OU/animal place/year
Barn and free range	Litter system with perforated floor and forced air drying	33112.8	k OU/animal place/year
Barn and free range	Aviary system	44150.4	k OU/animal place/year
Broilers	Naturally ventilated, fully littered floor, non-leaking drinkers	15768	k OU/animal place/year
Broilers	Fan ventilated, fully littered floor, non leaking drinkers	15768	k OU/animal place/year
Pullets	Naturally ventilated, fully littered floor, non-leaking drinkers	15768	k OU/animal place/year
Pullets	Fan ventilated, fully littered floor, non leaking drinkers	15768	k OU/animal place/year
Sows	Fully Slatted Floor (FSF)	819936	k OU/animal place/year
Sows	Solid Floor - straw system	819936	k OU/animal place/year
Sows	Part-Slatted Floor (PSF) with reduced manure pit	614952	k OU/animal place/year
Sows	FSF with vacuum system for frequent slurry removal	614952	k OU/animal place/year
Farrowers	Fully Slatted Floor (FSF)	819936	k OU/animal place/year
Farrowers	Solid Floor - straw system	819936	k OU/animal place/year
Farrowers	FSF/PSF with combination of water & manure channel	614952	k OU/animal place/year
Farrowers	FSF/PSF with flushing system with manure gutters	614952	k OU/animal place/year
Farrowers	FSF/PSF with manure pan underneath	614952	k OU/animal place/year
Weaners	Fully Slatted Floor (FSF)	126144	k OU/animal place/year

Livestock	Housing System	Emission Factor	Units
Weaners	Sold Floor - straw system	126144	k OU/animal place/year
Weaners	Pen/flatdeck, FSF/PSF, vacuum system for frequent slurry removal	94608	k OU/animal place/year
Weaners	Pen/flatdeck, FSF beneath with sloped floor to separate faeces or urine	94608	k OU/animal place/year
Weaners	Pen with PSF (2-climate system)	94608	k OU/animal place/year
Weaners	Pen with PSF and sloped or convex solid floor	94608	k OU/animal place/year
Weaners	Pen with PSF, triangular slats & manure channel, sloped side-walls	94608	k OU/animal place/year
Growers	Fully Slatted Floor (FSF)	315360	k OU/animal place/year
Growers	Solid Floor - straw system	315360	k OU/animal place/year
Growers	FSF with vacuum system for frequent slurry removal	236520	k OU/animal place/year
Growers	PSF with reduced manure pit including slanted walls & vacuum system	236520	k OU/animal place/year
Growers	PSF with convex solid floor & manure gutters, slanted sidewalls, sloped manure pit	236520	k OU/animal place/year
Finishers	Fully Slatted Floor (FSF)	819936	k OU/animal place/year
Finishers	Solid Floor - straw system	819936	k OU/animal place/year
Finishers	FSF with vacuum system for frequent slurry removal	614952	k OU/animal place/year
Finishers	PSF with reduced manure pit including slanted walls & vacuum system	614952	k OU/animal place/year
Finishers	PSF with convex solid floor, manure gutters, slanted sidewalls, sloped manure pit	614952	k OU/animal place/year

Appendix C. Emission Factors – PM_{10}

Table C - 1: Emission factors for PM_{10} in the SCAIL-Agriculture tool

Livestock	Housing System	Emission Factor	Units
Turkeys (male)	Litter	0.300	kg PM_{10}/animal place/year
Turkeys (female)	Litter	0.167	kg PM_{10}/animal place/year
Ducks	Litter	0.067	kg PM_{10}/animal place/year
Manure - belts		0	kg PM_{10}/tonne fresh manure
Manure - deep pit		0	kg PM_{10}/tonne fresh manure
Other litter		0	kg PM_{10}/tonne fresh manure
Manure heap	No cover	0	kg PM_{10}/tonne fresh manure
Slurry - circular store	No cover	0	kg PM_{10}/m^2
Slurry - circular store	Rigid cover	0	kg PM_{10}/m^2
Slurry - circular store	Floating	0	kg PM_{10}/m^2
Slurry - circular store	Low tech	0	kg PM_{10}/m^2
Slurry - lagoon	No cover	0	kg PM_{10}/m^2
Slurry - lagoon	Rigid cover	0	kg PM_{10}/m^2
Slurry - lagoon	Floating	0	kg PM_{10}/m^2
Slurry - lagoon	Low tech	0	kg PM_{10}/m^2
Broadcast	Laying hens	0	kg PM_{10}/t
Broadcast & ploughed within 24hrs	Laying hens	0	kg PM_{10}/t
Broadcast	Other poultry	0	kg PM_{10}/t
Broadcast & ploughed within 24hrs	Other poultry	0	kg PM_{10}/t
Broadcast (solid manure)		0	kg PM_{10}/t
Broadcast (solid and ploughed within 24 hrs)		0	kg PM_{10}/t
Broadcast (slurry)	<4% dry matter	0	kg PM_{10}/t
Broadcast (slurry)	4-8% dry matter	0	kg PM_{10}/t
Bandspread (slurry)	<4% dry matter	0	kg PM_{10}/t
Bandspread (slurry)	4-8% dry matter	0	kg PM_{10}/t
Trailing shoe (slurry)	<4% dry matter	0	kg PM_{10}/t
Trailing shoe (slurry)	4-8% dry matter	0	kg PM_{10}/t
Injection (open slot)	<4% dry matter	0	kg PM_{10}/t
Injection (open slot)	4-8% dry matter	0	kg PM_{10}/t
Injection (closed slot)	<4% dry matter	0	kg PM_{10}/t
Injection (closed slot)	4-8% dry matter	0	kg PM_{10}/t
Layers	Enriched Cage	0.017	kg PM_{10}/animal place/year
Layers	Cage with deep pit	0.017	kg PM_{10}/animal place/year

Livestock	Housing System	Emission Factor	Units
Layers	Ventilated deep pit	0.017	kg PM_{10}/animal place/year
Layers	Manure removal twice a week by manure belt	0.017	kg PM_{10}/animal place/year
Layers	Vertical tiered cages, forced air drying, weekly removal	0.017	kg PM_{10}/animal place/year
Layers	Vertical tiered cages, whisk forced air drying, weekly removal	0.017	kg PM_{10}/animal place/year
Layers	Vertical tiered cages, manure belt, drying tunnel, 24-36 hr removal	0.017	kg PM_{10}/animal place/year
Barn and free range	Perchery with deep litter	0.033	kg PM_{10}/animal place/year
Barn and free range	Litter system with forced air drying	0.033	kg PM_{10}/animal place/year
Barn and free range	Litter system with perforated floor and forced air drying	0.033	kg PM_{10}/animal place/year
Barn and free range	Aviary system	0.033	kg PM_{10}/animal place/year
Broilers	Naturally ventilated, fully littered floor, non-leaking drinkers	0.033	kg PM_{10}/animal place/year
Broilers	Fan ventilated, fully littered floor, non leaking drinkers	0.033	kg PM_{10}/animal place/year
Pullets	Naturally ventilated, fully littered floor, non-leaking drinkers	0.033	kg PM_{10}/animal place/year
Pullets	Fan ventilated, fully littered floor, non leaking drinkers	0.033	kg PM_{10}/animal place/year
Sows	Fully Slatted Floor (FSF)	0.034	kg PM_{10}/animal place/year
Sows	Solid Floor - straw system	0.129	kg PM_{10}/animal place/year
Sows	Part-Slatted Floor (PSF) with reduced manure pit	0.034	kg PM_{10}/animal place/year
Sows	FSF with vacuum system for frequent slurry removal	0.034	kg PM_{10}/animal place/year
Farrowers	Fully Slatted Floor (FSF)	0.141	kg PM_{10}/animal place/year
Farrowers	Solid Floor - straw system	0.077	kg PM_{10}/animal place/year
Farrowers	FSF/PSF with combination of water & manure channel	0.141	kg PM_{10}/animal place/year
Farrowers	FSF/PSF with flushing system with manure gutters	0.141	kg PM_{10}/animal place/year
Farrowers	FSF/PSF with manure pan underneath	0.141	kg PM_{10}/animal place/year
Weaners	Fully Slatted Floor (FSF)	0.021	kg PM_{10}/animal place/year

Livestock	Housing System	Emission Factor	Units
Weaners	Sold Floor - straw system	0.021	kg PM_{10}/animal place/year
Weaners	Pen/flatdeck, FSF/PSF, vacuum system for frequent slurry removal	0.021	kg PM_{10}/animal place/year
Weaners	Pen/flatdeck, FSF beneath with sloped floor to separate faeces or urine	0.021	kg PM_{10}/animal place/year
Weaners	Pen with PSF (2-climate system)	0.021	kg PM_{10}/animal place/year
Weaners	Pen with PSF and sloped or convex solid floor	0.021	kg PM_{10}/animal place/year
Weaners	Pen with PSF, triangular slats & manure channel, sloped side-walls	0.021	kg PM_{10}/animal place/year
Growers	Fully Slatted Floor (FSF)	0.141	kg PM_{10}/animal place/year
Growers	Solid Floor - straw system	0.077	kg PM_{10}/animal place/year
Growers	FSF with vacuum system for frequent slurry removal	0.141	kg PM_{10}/animal place/year
Growers	PSF with reduced manure pit including slanted walls & vacuum system	0.141	kg PM_{10}/animal place/year
Growers	PSF with convex solid floor & manure gutters, slanted sidewalls, sloped manure pit	0.141	kg PM_{10}/animal place/year
Finishers	Fully Slatted Floor (FSF)	0.141	kg PM_{10}/animal place/year
Finishers	Solid Floor - straw system	0.077	kg PM_{10}/animal place/year
Finishers	FSF with vacuum system for frequent slurry removal	0.141	kg PM_{10}/animal place/year
Finishers	PSF with reduced manure pit including slanted walls & vacuum system	0.141	kg PM_{10}/animal place/year
Finishers	PSF with convex solid floor, manure gutters, slanted sidewalls, sloped manure pit	0.141	kg PM_{10}/animal place/year

Appendix D.Screenshots of the input and output webpages

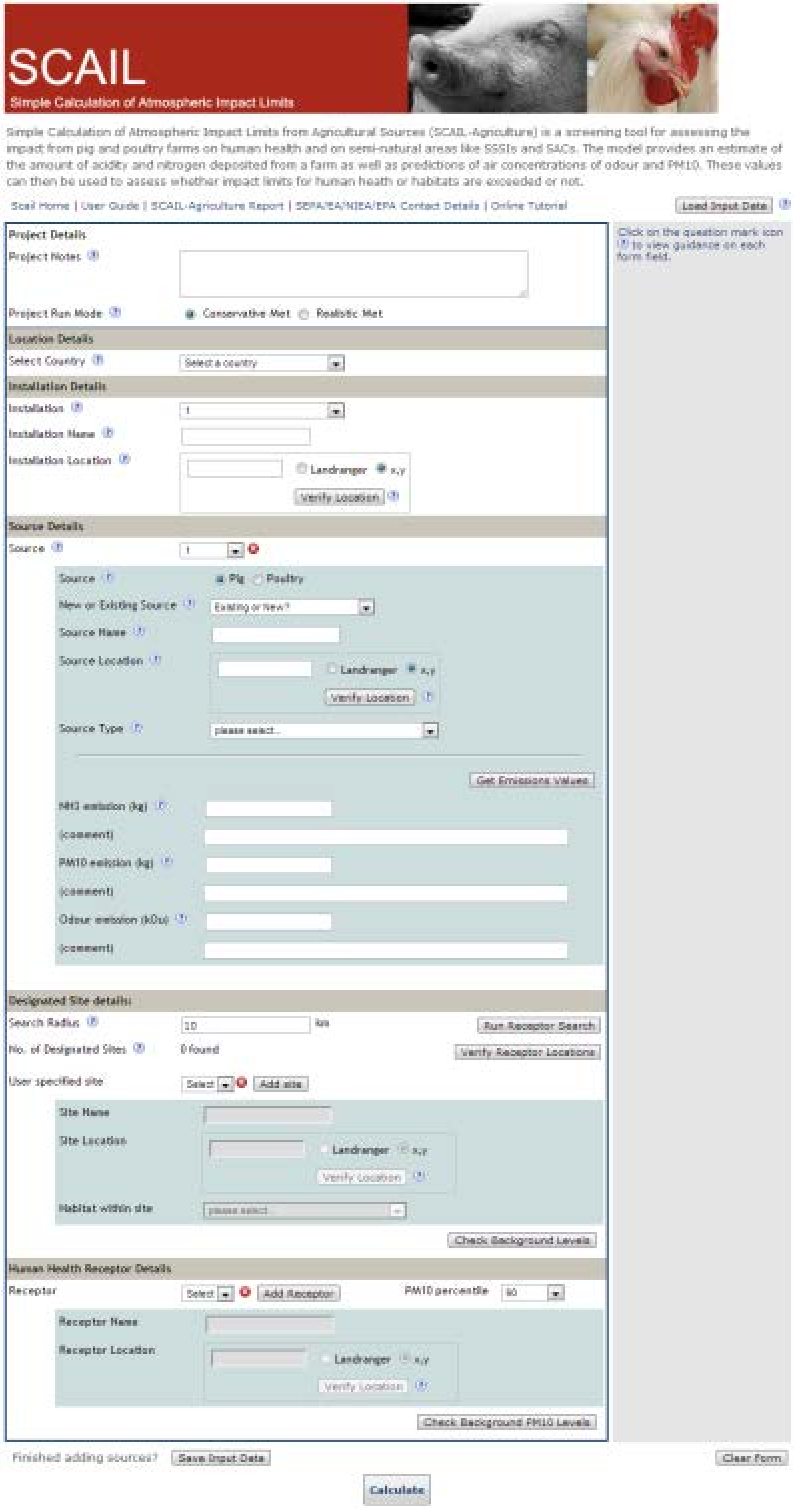


Figure D - 1: The main input page for the updated SCAIL-Agriculture tool

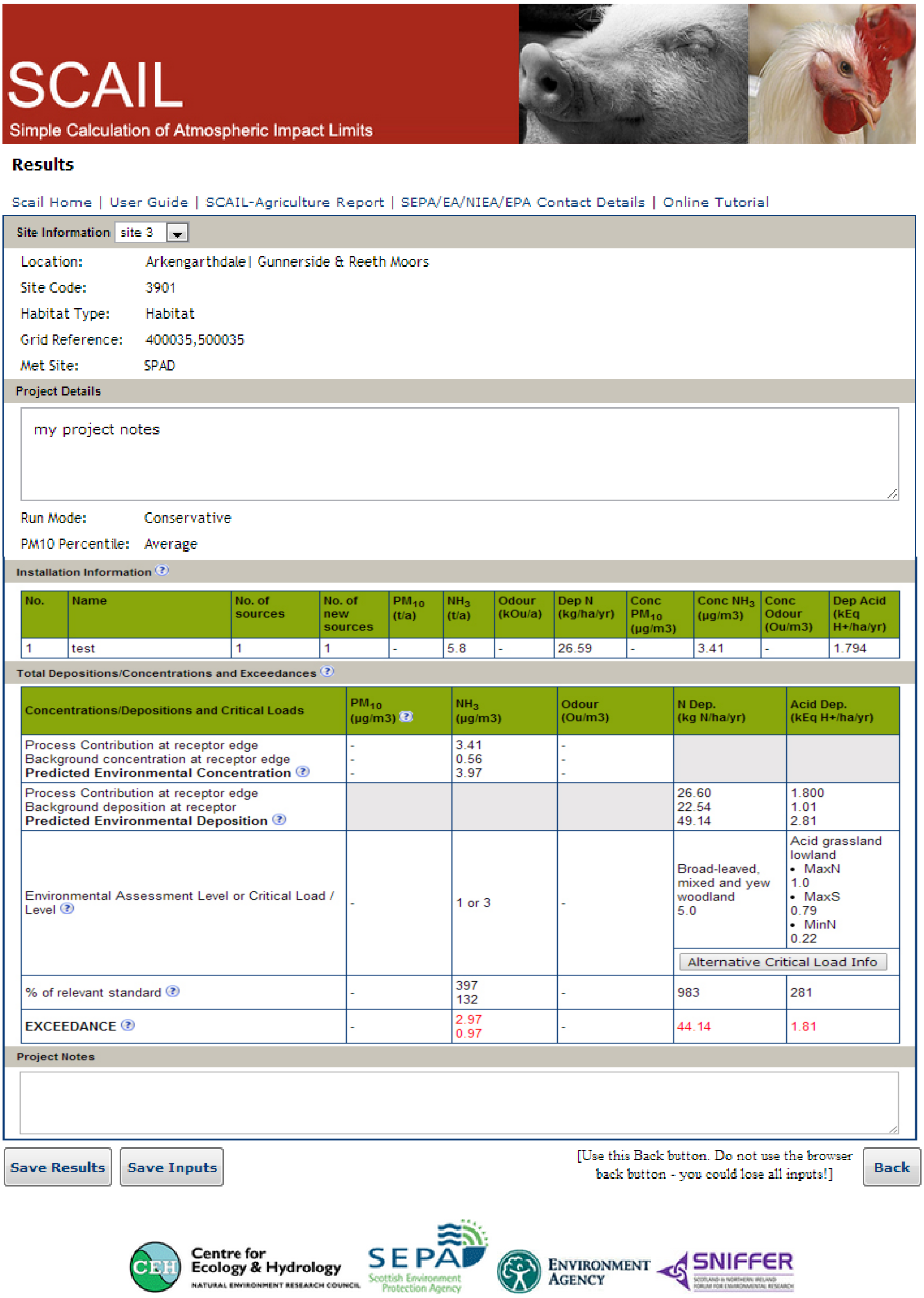


Figure D - 2: The updated SCAIL-Agriculture results page

Appendix E. Summary of ammonia data for validation

Table E - 1: Name, location and source details for the UK and Republic of Ireland datasets

Study name and reference	Organisation	Location	Lat. (N)	Long. (E)	Source	Number of animal places
ADEPT - Burrington Moor *Sutton et al., 1998*	CEH	Burrington Moor	52.34	-6.46	Slurry spreading	NA
ADEPT - Gleadthorpe *Sutton et al., 1997*	CEH	Gleadthorpe	53.23	1.11	Poultry farm plus artificial release	NA
AMBER *Theobald et al., 2001*	CEH	Blyth bank	55.72	-3.36	Artificial	NA
Bentwater *EA report (no author given)*	EA	Bentwater	53.23	-1.11	Ducks	72000
Bishop Burton *Skinner et al., 2006*	Uni. Of York	Bishop Burton	50.81	-3.67	Pigs, sheep, dairy cattle and beef cattle	2916 pigs, 660 sheep, 239 dairy cattle 82 beef cattle
Co. Wexford *Dowling (2010) PhD Thesis*	Teagasc/ UCD	Wexford, Ireland	52.24	-6.48	Dairy cows	25-70
Cubley *EA Technical Report: NMA/TR/2009/05*	EA	Cubley, Derbys	56.85	-2.58	Broilers	70000
Garvary Lodge *Tang et al., Unpublished data*	CEH	Garvary Lodge	53.85	-0.50	Layers	125000
LANAS *Theobald et al., 2004*	CEH	Norfolk	Conf.	Conf.	Broilers, ducks / geese	954750 broilers 111705 duck/geese
N. Ireland - Fan ventilated *Tang et al., 2005*	CEH	Carrycastle	54.42	-6.86	Broilers	68000
N. Ireland - Naturally ventilated *Tang et al., 2005*	CEH	Tirmacrannon	54.41	-6.63	Broilers	76000
Newborough (15 min) *Sheppard et al., 2003*	EA	Newborough	53.16	-4.34	Broilers	198700
Newborough (passive) *Donovan, 2005* *(Netcen report)*	Netcen for the EA	Newborough	53.16	-4.34	Broilers	198700

Study name and reference	Organisation	Location	Lat. (N)	Long. (E)	Source	Number of animal places
NitroEurope - S. Scotland *Vogt et al. (in prep)*	CEH	S. Scotland	Conf.	Conf.	Layers, free range / housed chickens	NS
Pitcairn - Dairy *Pitcairn et al., 1998*	CEH	NS	NS	NS	Dairy cows	400
Pitcairn - Pigs *Pitcairn et al., 1998*	CEH	E. Scotland	Conf.	Conf.	Pigs	2000
Pitcairn - Poultry 1 *Pitcairn et al., 1998*	CEH	S. Scotland	Conf.	Conf.	Broilers	120000
Pitcairn - Poultry 2 *Pitcairn et al., 1998*	CEH	S. Scotland	Conf.	Conf.	Broilers	210000
Salisbury *EA report (Emma Bates)*	EA	Salisbury	52.12	1.44	Broilers	107250
Skiba - Broilers *Skiba et al., 2005*	CEH	S. Scotland	Conf.	Conf.	Broilers	160000
Town Barton Farm *Hill et al., (2001)*	IGER	Crediton Devon	55.72	-3.36	Dairy Cows	120
Whim moss *Leith et al., 2004*	CEH	Whim moss	55.77	3.27	Artificial	NA
Woodland chicken *Braban et al., Unpublished data*	CEH	Oxfordshire	51.78	-1.32	Breeder / Layers	700
Woodland chicken (2) *Braban et al., Unpublished data*	CEH	Fife	56.12	-3.49	Layers	11000

Notes: Conf.: Location not specified due to confidentiality; NS: Not stated in reference document; NA: Not applicable

Table E - 2: Measurement summary for the UK and Republic of Ireland datasets

Study name and reference	Measurement method	Measurement height	No. sites	Closest site (m)	Furthest site (m)	Avg. period	No. periods	Total period
ADEPT - Burrington Moor *Sutton et al., 1998*	Various	Various	5	0	350	5 mins+	NA	2 wks
ADEPT - Gleadthorpe *Sutton et al., 1997*	Various	Various	5	12	630	14-29 days	6	113 days
AMBER *Theobald et al., 2001*	ALPHA samplers	1.5	8	5.5	59	9-43 days	15	418 days
Bentwater *EA report (no author given)*	NO_x analyser with NH_3 conv.	2	1	2740	2740	15 mins	NA	35 days
Bishop Burton *Skinner et al., 2006*	Modified diffusion tube	1	27	20	350	4 wks	13	12 mths
Co. Wexford *Dowling (2010) PhD Thesis*	Passive samplers	1 – 15	16	5	30	1 weeks	26	26 wks winter
Cubley *EA Technical Report: NMA/TR/2009/05*	NO_x analyser with NH_3 conv.	2	1	10	10	15 mins	NA	195 days
Garvary Lodge *Tang et al., Unpublished data*	ALPHA samplers	1.5	6	63	904	1 mth	6	6 mths
LANAS *Theobald et al., 2004*	ALPHA samplers	1.5	10	29	700	1 mth	12	13 mths
N. Ireland - Fan ventilated *Tang et al., 2005*	ALPHA samplers	1.5	4	20	320	6-8 wks	3	30 wks
N. Ireland - Naturally ventilated *Tang et al., 2005*	ALPHA samplers	1.5	5	20	320	6-8 wks	3	30 wks
Newborough (15 min) *Sheppard et al., 2003*	NO_x analyser with NH_3 conv.	2	1	30	30	15 mins	NA	119 days
Newborough (passive) *Donovan, 2005 (Netcen report)*	Diffusion tubes	1.2-2.5	17	36	847	14-31 days	11	166 days
NitroEurope - S. Scotland *Vogt et al. (in prep)*	ALPHA samplers	1.5	31	VS	VS	1 mth	20	651 days

Study name and reference	Measurement method	Measurement height	No. sites	Closest site (m)	Furthest site (m)	Avg. period	No. periods	Total period
Pitcairn - Dairy *Pitcairn et al., 1998*	ALPHA samplers	1.5	6	10	350	1 mth	12	12 mths
Pitcairn - Pigs *Pitcairn et al., 1998*	ALPHA samplers	1.5	6	14	1000	1 mth	12	12 mths
Pitcairn - Poultry 1 *Pitcairn et al., 1998*	ALPHA samplers	1.5	5	15	276	1 mth	12	12 mths
Pitcairn - Poultry 2 *Pitcairn et al., 1998*	ALPHA samplers	1.5	5	25	219	1 mth	12	12 mths
Salisbury *Bates (2010)*	NO_x analyser with NH_3 conv.	2	1	15	15	15 mins	NA	161 days
Skiba - Broilers *Skiba et al., 2005*	ALPHA samplers	1.5	4	15	270	1 mth	7	7 mths
Town Barton Farm *Hill et al., (2001)*	Passive samplers	0.5 – 12	16	5-10	150	1 day	4	14 days
Whim moss *Leith et al., 2004*	ALPHA samplers	0.1-0.5	9	1	60	1 mth	15	15 mths
Woodland chicken *Braban et al., Unpublished data*	ALPHA samplers	1.5	11	2.5	76	1 mth	11	11 mths
Woodland chicken (2) *Braban et al., Unpublished data*	ALPHA samplers	1.5	11	17.5	330	1 mth	6	6 mths

Notes: VS: Various Sources

Table E - 3: Model input data and data availability for the UK and Republic of Ireland datasets

Study name and reference	Background conc. ($\mu g\ NH_3\ m^{-3}$)	Source strength ($kg\ NH_3\ yr^{-1}$)	Land cover	On-site Met.	Nearest suitable Met.	Nearest SCAIL Met.	Availability of data
ADEPT - Burrington Moor *Sutton et al., 1998*	0.15 [b]	Calculated from meas.	Grassland	Yes	Chivenor	Plymouth Mountbatten	Available
ADEPT - Gleadthorpe *Sutton et al., 1997*	0.8 [b]	3400-4400 [d]	Mixed rural	Yes	Nottingham: Watnall	Church Fenton	Available
AMBER *Theobald et al., 2001*	0.6-5.7 [b]	2900 [d]	Wood-land	Yes	Edinburgh Gogarbank	Edinburgh Gogarbank	Available
Bentwater *EA report (no author given)*	0.5 [a]	NS	Mixed rural	Yes	Wattisham	Marham	From the EA
Bishop Burton *Skinner et al., 2006*	NS	NS	Mixed rural	No	Church Fenton	Church Fenton	From author
Co. Wexford *Dowling (2010) PhD Thesis*	NS	Yes [d]	Grassland	No	Johnstown Castle	NA	From TEAGASC
Cubley *EA Technical Report: NMA/TR/2009/05*	ca. 1.0 [a]	NS	Mixed rural	Yes	Nottingham: Watnall	Coleshill	From the EA
Garvary Lodge *Tang et al., Unpublished data*	1.9 [a]	15116 [c]	Moorland	No	Castle-derg	Port-glenone	Available
LANAS *Theobald et al., 2004*	0.85 [a]	NS [c]	Mixed rural	No	Marham	Marham	Available
N. Ireland - Fan ventilated *Tang et al., 2005*	4.8 [b]	6800 [c]	Grassland	No	Lough Fea	Port-glenone	Available
N. Ireland - Naturally ventilated *Tang et al., 2005*	6.7 [b]	7600 [c]	Grassland	No	Lough Fea	Port-glenone	Available
Newborough (15 min) *Sheppard et al., 2003*	ca. 1.0 [a]	NS	Mixed rural	Yes	Valley	Valley	From the EA
Newborough (passive) *Donovan, 2005 (Netcen report)*	1.5 [a]	NS	Mixed rural	No	Valley	Valley	NH_3 data in report
NitroEurope - S. Scotland *Vogt et al. (in prep)*	0.2 [b]	NS	Grassland	Yes	Edinburgh Gogarbank	Edinburgh Gogarbank	Available

Study name and reference	Background conc. ($\mu g\ NH_3\ m^{-3}$)	Source strength ($kg\ NH_3\ yr^{-1}$)	Land cover	On-site Met.	Nearest suitable Met.	Nearest SCAIL Met.	Availability of data
Pitcairn - Dairy *Pitcairn et al., 1998*	2.0 [a]	4323 [c]	Woodland	No	Not known	Not known	Available
Pitcairn - Pigs *Pitcairn et al., 1998*	1.5 [a]	5100 [c]	Woodland	No	Dyce	Leuchars	Available
Pitcairn - Poultry 1 *Pitcairn et al., 1998*	1.6 [a]	5829 [c]	Woodland	No	Redesdale Camp	Eskdale-muir	Available
Pitcairn - Poultry 2 *Pitcairn et al., 1998*	6.0 [a]	17000 [c]	Woodland	No	Edinburgh Gogarbank	Edinburgh Gogarbank	Available
Salisbury *Bates (2010)*	< 5.0 [a]	NS	Mixed rural	Yes	Middle Wallop	Lyneham	From the EA
Skiba - Broilers *Skiba et al., 2005*	1.2 [a]	NS	Woodland	No	Redesdale Camp	Eskdale-muir	Available
Town Barton Farm *Hill et al. (2001)*	NS	2127 [d]	Grassland	Yes	Dunkeswell Aerodrome	Plymouth: Mountbatten	Available
Whim moss *Leith et al., 2004*	0.5 [b]	1800 [d]	Moorland	Yes	Edinburgh Gogarbank	Edinburgh Gogarbank	Available
Woodland chicken *Braban et al., Unpublished data*	2.5 [a]	NS	Woodland and grass	No	Brize Norton	Lyneham	Available
Woodland chicken (2) *Braban et al., Unpublished data*	2.4 [a]	NS	Woodland and grass	No	Edinburgh Gogarbank	Edinburgh Gogarbank	Available

Notes: Estimated from a lowest measured value or b upwind measurement; Emissions c estimated or d measured; NS: Not stated; NA: Not applicable

Table E - 4: Name, location and source details for the international datasets

Study name and reference	Country	Location	Lat. (N)	Long. (E)	Source	Number of animal places
Aguilafuente *Theobald et al., (in prep)*	Spain	Aguilafuente, Segovia	41.25	-4.14	Breeding sows	565 sows and 1092 piglets
Hinz - Broilers (1) *Hinz et al., 2008*	Germany	NS	NS	NS	Broilers	3500
Hinz - Broilers (2) *Hinz et al., 2008*	Germany	NS	NS	NS	Broilers	289200
Hinz - Dairy *Hinz et al., 2008*	Germany	NS	NS	NS	Dairy cows and slurry tanks	NS
Hinz - Pigs *Hinz et al., 2008*	Germany	NS	NS	NS	Fattening pigs	50000
Hinz - Turkeys *Hinz et al., 2008*	Germany	NS	NS	NS	Turkeys	5900
Malhada de Meias *Pinho et al., 2009*	Portugal	Malhada de Meias	38.74	-8.79	Cows	200
NitroEurope - Denmark *Unpublished data*	Denmark	Bjerringbro	56.34	9.66	Pig farm	NS
NitroEurope - Italy *Unpublished data*	Italy	Piana del sele	40.53	14.96	Buffalo farm	670
NitroEurope - Poland *Unpublished data*	Poland	Turew	52.04	16.77	Cattle farm	380
Pedersen *Pedersen et al., 2007*	Denmark	Falster	54.71	11.94	Fattening pigs	2688 fattening pigs and piglets
Sather *Sather et al., 2008*	USA	Oklahoma	NS	NS	Mushrooms	NA
Sommer *Sommer et al., 2009*	Denmark	NS	NS	NS	Chickens	27100
Staebler *Staebler et al., 2009*	Canada	Alberta	NS	NS	Cattle	17220
Walker *Walker et al., 2007*	USA	North Carolina	35.52	-77.56	Finishing pigs	4900

Notes: **NS: Not stated in reference documents; NA: Not applicable**

Table E - 5: Measurement summary for the international datasets

Study name and reference	Measurement method	Measurement height (m)	No. sites	Closest site (m)	Furthest site (m)	Avg. period	No. periods	Total period
Aguilafuente *Theobald et al., (in prep)*	ALPHA samplers	1.5	21	40	1000	1 mth	12	1 yr
Hinz - Broilers (1) *Hinz et al., 2008*	Ferm samplers	2.5	7	<10	120	14 days	2	4 wks
Hinz - Broilers (2) *Hinz et al., 2008*	Ferm samplers	2	5	NS	NS	14 days	2	4 wks
Hinz - Dairy *Hinz et al., 2008*	Ferm samplers	2.5	4	<10	50	14 days	1	14 days
Hinz - Pigs *Hinz et al., 2008*	Ferm samplers	2.5	4	<10	240	14 days	4	8 wks
Hinz - Turkeys *Hinz et al., 2008*	Ferm samplers	2.5	13	2	166	14 days	78	3 yrs
Malhada de Meias *Pinho et al., 2009*	ALPHA samplers	1.5	22	6	865	13-44 days	11	352
NitroEurope - Denmark *Unpublished data*	Gradko diffusion tubes	1.5	3	150	340	1 mth	18	600 days
NitroEurope - Italy *Unpublished data*	ALPHA samplers	1.5	5	20	340	1 mth	12	1 year
NitroEurope - Poland *Unpublished data*	ALPHA samplers	1.5	4	250	2150	1 mth	12	1 year
Pedersen *Pedersen et al., 2007*	Diffusion tubes	2	23	41	308	1 wk	12	12 wks
Sather *Sather et al., 2008*	Ogawa passive samplers	1.5	6	800	1200	3 wks	8	24 wks
Sommer *Sommer et al., 2009*	Diffusion tubes	NS	14	<10	580	2-3 wks	3	43 days
Staebler *Staebler et al., 2009*	Ground: Open path laser Airborne: NO_x analyser with NH_3 conv.	1.5 30-300	1 Flight data	155 NA	155 NA	NS 4s	NA NA	3 days
Walker *Walker et al., 2007*	Diffusion tubes	1.5	22	<10	560	1 wk	98	764 days

Notes: NS: Not stated in reference documents; NA: Not applicable

Table E - 6: Model input data and data availability for the international datasets

Study name and reference	Background conc. (µg NH_3 m^{-3})	Source strength (kg NH_3 yr^{-1})	Land cover	On-site Met.	Availability of data	Study name and reference	Background conc. (µg NH_3 m^{-3})
Aguilafuente *Theobald et al., (in prep)*	1.0 [a]	6300	Arable	Yes	Available	Aguilafuente *Theobald et al., (in prep)*	1.0 [a]
Hinz - Broilers (1) *Hinz et al., 2008*	NS	NS	NS	NS	Unknown	Hinz - Broilers (1) *Hinz et al., 2008*	NS
Hinz - Broilers (2) *Hinz et al., 2008*	NS	NS	NS	Yes	Unknown	Hinz - Broilers (2) *Hinz et al., 2008*	NS
Hinz - Dairy *Hinz et al., 2008*	NS	NS	NS	Yes	Unknown	Hinz - Dairy *Hinz et al., 2008*	NS
Hinz - Pigs *Hinz et al., 2008*	NS	NS	NS	NS	Unknown	Hinz - Pigs *Hinz et al., 2008*	NS
Hinz - Turkeys *Hinz et al., 2008*	NS	NS	NS	Yes	Unknown	Hinz - Turkeys *Hinz et al., 2008*	NS
Malhada de Meias *Pinho et al., 2009*	0.4 [a]	1260	Sparse woodland	Yes	Available	Malhada de Meias *Pinho et al., 2009*	0.4 [a]
NitroEurope - Denmark *Unpublished data*	0.5 [b]	NS	Arable	Yes	Available	NitroEurope - Denmark *Unpublished data*	0.5 [b]
NitroEurope - Italy *Unpublished data*	0.5 [b]	NS	Arable	Yes	Available	NitroEurope - Italy *Unpublished data*	0.5 [b]
NitroEurope - Poland *Unpublished data*	0.4 [b]	NS	Mixed rural	Yes	Available	NitroEurope - Poland *Unpublished data*	0.4 [b]
Pedersen *Pedersen et al., 2007*	0.5 [a]	2400	Mixed rural	Yes	Available	Pedersen *Pedersen et al., 2007*	0.5 [a]
Sather *Sather et al., 2008*	0.15 [b]	NS	NS	No	Unknown	Sather *Sather et al., 2008*	0.15 [b]
Sommer *Sommer et al., 2009*	1.7 [a]	2922	Mixed rural	Yes	Unknown	Sommer *Sommer et al., 2009*	1.7 [a]
Staebler *Staebler et al., 2009*	5-8 [b]	Calculated peak: 1300000	NS	Yes	Unknown	Staebler *Staebler et al., 2009*	5-8 [b]
Walker *Walker et al., 2007*	0.2 [a]	34300	Mixed rural	Yes	Available	Walker *Walker et al., 2007*	0.2 [a]

Notes: a Estimated from lowest measured value; b Estimated from upwind measurement; NS: Not stated in reference document

Table E - 7: Assessment of the UK and Republic of Ireland datasets

Study name and reference	Criteria	Pro's	Con's
ADEPT - Burrington Moor *Sutton et al., 1998*	**Source info.**	Source well defined, emission rate measured	Slurry spreading emissions are not a focus for SCAIL
	Domain info.	Flat terrain, fairly uniform land cover (grassland)	
	Meas.	State of the art, continuous	Short monitoring period
	Meteorology	UK conditions, on-site data available	
	Other	Data on request, not confidential	
	Additional data		
ADEPT - Gleadthorpe *Sutton et al., 1997*	**Source info.**	Source well defined, emission rate measured	Real and artificial sources
	Domain info.	Flat terrain	Mixed land cover
	Meas.	State of the art, continuous (campaign measurements) and reliable method (long-term). Reasonable monitoring period (>3 months)	
	Meteorology	UK conditions, on-site data available	
	Other	Data on request, not confidential	
	Additional data	Dispersion modelling carried out	
AMBER *Theobald et al., 2001*	**Source info.**	Source well defined, emission rate measured	Artificial source
	Domain info.	Flat terrain, woodland cover	
	Meas.	Reliable method, long monitoring period (12 months)	Few locations, close to source (<60 m)
	Meteorology	UK conditions, on-site data available	
	Other	Data held, not confidential	
	Additional data	Dispersion modelling carried out, throughfall data also available	
Bentwater *EA report (no author given)*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain	Mixed land cover
	Meas.	State of the art, continuous	Only one location, short monitoring period (ca. 1 month)
	Meteorology	UK conditions, on-site data available	
	Other	Data on request, not confidential, no other studies for this source type (ducks)	
	Additional data		
Bishop Burton	**Source info.**	Number of livestock known.	No information on housing type, mixed complex source

Study name and reference	Criteria	Pro's	Con's
Skinner et al., 2006	**Domain info.**	Flat terrain	Mixed land cover
	Meas.	Reliable method, many distances/directions covered, many measurement periods and long monitoring period (12 months)	
	Meteorology	UK conditions	No on-site data available
	Other	Data held, not confidential	
	Additional data	Dispersion modelling carried out	
Co. Wexford *Dowling (2010) PhD Thesis*	**Source info.**	Number of livestock known, emissions measured directly	Relatively small source, adjacent buildings less well characterised
	Domain info.	Flat Terrain	
	Meas.	Reliable method, long monitoring period (26 weeks)	Measurements made during winter months only when livestock housed. Measurements close to building
	Meteorology	Met Eireann station close (6.2 km)	No on-site data available
	Other	Rep. of Ireland study	Dairy cows, so not directly relevant to IPPC/IED.
	Additional data		
Cubley *EA Technical Report: NMA/TR/2009/05*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain	Mixed land cover, some built up areas, other potential sources nearby
	Meas.	State of the art, continuous and reasonable monitoring period (>6 months)	Only one location, very close to source (ca. 10 m)
	Meteorology	UK conditions, on-site data available	
	Other	Data on request, not confidential	Common source type (i.e. several similar studies available)
	Additional data	PM2.5, and PM10 concentrations	
Garvary Lodge *Tang et al., Unpublished data*	**Source info.**	Number/type of livestock known, building type and emission points known. Emission estimate provided.	No information on building dimensions
	Domain info.	Flat terrain, moorland land cover	
	Meas.	Reliable method, reasonable monitoring period (6 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held, not confidential, not many studies for this source type (layers)	

Study name and reference	Criteria	Pro's	Con's
	Additional data	Ecological assessment of moorland at measurement locations	
LANAS *Theobald et al., 2004*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain	Other potential sources nearby , mixed land cover
	Meas.	Reliable method, long monitoring period (13 months)	
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location confidential
	Additional data		
N. Ireland - Fan ventilated *Tang et al., 2005*	**Source info.**	Number/type of livestock known, building type, dimensions and emission points known. Emission estimate provided.	
	Domain info.	Flat terrain	Other potential sources nearby
	Meas.	Reliable method, reasonable monitoring period (7 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held, not confidential, emission type contrasts well with N.Ireland - Naturally ventilated	Common source type (i.e. several similar studies available)
	Additional data	Dispersion modelling carried out	
N. Ireland - Naturally ventilated *Tang et al., 2005*	**Source info.**	Number/type of livestock known, building type, dimensions and emission points known. Emission estimate provided.	
	Domain info.	Flat terrain	Other potential sources nearby
	Meas.	Reliable method, reasonable monitoring period (7 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held, not confidential, emission type contrasts well with N.Ireland - Fan ventilated	Common source type (i.e. several similar studies available)
	Additional data	Dispersion modelling carried out	
Newborough (15 min)	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain, no other known sources nearby	Mixed land cover, some built up areas

Study name and reference	Criteria	Pro's	Con's
Sheppard et al., 2003	**Meas.**	State of the art, continuous and reasonable monitoring period (4 months)	Only one location, very close to source (ca. 30 m)
	Meteorology	UK conditions, on-site data available	
	Other	Data on request, not confidential, study is complementary to Newborough (passive)	Common source type (i.e. several similar studies available)
	Additional data	PM10 concentrations	
Newborough (passive) *Donovan, 2005 (Netcen report)*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain, no other known sources nearby	Mixed land cover, some built up areas
	Meas.	Reliable method, many distances/directions covered, many measurement periods and reasonable monitoring period (5.5 months)	
	Meteorology	UK conditions	No on-site data available
	Other	Data held, not confidential, study is complementary to Newborough (15 min)	Common source type (i.e. several similar studies available)
	Additional data		
NitroEurope – S. Scotland *Vogt et al., (in prep)*	**Source info.**	Number/type of livestock known, information on housing type and emission heights	
	Domain info.	Flat terrain	Mixed land cover, other potential sources nearby
	Meas.	Reliable method, many distances/directions covered, many measurement periods and long monitoring period (>20 months)	
	Meteorology	UK conditions, on-site data available	
	Other	Data held	Location confidential
	Additional data	Dispersion modelling carried out, campaign plume measurements also made	
Pitcairn - Dairy *Pitcairn et al., 1998*	**Source info.**	Number of livestock known. Emission estimate provided.	No information on housing type or building dimensions
	Domain info.		Location not known
	Meas.	Reliable method, long monitoring period (12 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location not known
	Additional data		

Study name and reference	Criteria	Pro's	Con's
Pitcairn - Pigs *Pitcairn et al., 1998*	**Source info.**	Number of livestock known. Emission estimate provided.	No information on pig type, housing type or building dimensions
	Domain info.	Flat terrain	Other potential sources nearby , mixed land cover
	Meas.	Reliable method, long monitoring period (12 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location confidential, common source type (i.e. several similar studies available)
	Additional data		
Pitcairn - Poultry 1 *Pitcairn et al., 1998*	**Source info.**	Number/type of livestock known. Emission estimate provided.	No information on housing type or building dimensions
	Domain info.	Flat terrain	Other potential sources nearby , mixed land cover
	Meas.	Reliable method, long monitoring period (12 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location confidential, common source type (i.e. several similar studies available)
	Additional data		
Pitcairn - Poultry 2 *Pitcairn et al., 1998*	**Source info.**	Number/type of livestock known. Emission estimate provided.	No information on housing type or building dimensions
	Domain info.	Flat terrain	Other potential sources nearby , mixed land cover
	Meas.	Reliable method, long monitoring period (12 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location confidential, common source type (i.e. several similar studies available)
	Additional data		
Salisbury *EA report (Emma Bates)*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain	Mixed land cover
	Meas.	State of the art, continuous and reasonable monitoring period (>5 months)	Only one location, very close to source (ca. 15 m)
	Meteorology	UK conditions, on-site data available	

Study name and reference	Criteria	Pro's	Con's
	Other	Data on request, not confidential	Common source type (i.e. several similar studies available)
	Additional data	PM2.5, and PM10 concentrations	
Skiba - Broilers *Skiba et al., 2005*	**Source info.**	Number/type of livestock known	No information on housing type or building dimensions
	Domain info.	Flat terrain	Other potential sources nearby, mixed land cover
	Meas.	Reliable method, reasonable monitoring period (7 months)	Few locations
	Meteorology	UK conditions	No on-site data available
	Other	Data held	Location confidential, common source type (i.e. several similar studies available)
	Additional data		
Town Barton Farm *Hill et al., (2001)*	**Source info.**	Number/type of livestock known, building type, dimensions and emission points known. Emission rate measured	
	Domain info.	Flat terrain, fairly uniform land cover (grassland)	Some built up areas
	Meas.	Reliable method, many locations/heights	Short monitoring period, measurements only out to 100 m from source
	Meteorology	UK conditions, on-site data available	
	Other	Data held, not confidential	
	Additional data	Dispersion modelling carried out	
Whim moss *Leith et al., 2004*	**Source info.**	Source well defined, emission rate measured	Artificial source
	Domain info.	Flat terrain, moorland cover	
	Meas.	Reliable method, long monitoring period (15 months), vertical profiles	Few locations, close to source (<60 m)
	Meteorology	UK conditions, on-site data available	
	Other	Data held, not confidential	
	Additional data		
Woodland chicken *Braban et al., Unpublished data*	**Source info.**	Number of livestock known	No information on building dimensions
	Domain info.	Site is patched with trees and two transects done downwind of two houses one with and one without trees.	Other livestock and farm activities within 300 m of measurement locations, so interferences possible
	Meas.	Reliable method, reasonable monitoring period	
	Meteorology	UK conditions	No on-site data

Study name and reference	Criteria	Pro's	Con's
	Other	Data on request, not confidential	
	Additional data	Size of trees	
Woodland chicken (2) *Braban et al., Unpublished data*	**Source info.**	Number of livestock known	No information on building dimensions
	Domain info.	Several poultry houses in area, bird numbers available for all houses during period. Site contains tree plantation: two transects done: one with and one without trees downwind of equivalent houses	
	Meas.	Reliable method, reasonable monitoring period	
	Meteorology	UK conditions	No on-site data
	Other	Data on request, not confidential	
	Additional data		

Appendix F. Summary of odour data for validation

Table F - 1: Summary of study details for UK, Ireland and international odour validation data sets

Study Name	Organisation	Location	Source	Number of animals	Measurement method	Measurement locations	Measurement periods	Met data
Dublin	University College, Dublin	Ireland	Pig production	514-sow unit	Olfactometry at source, ambient by sniffer panel	Source emissions measured at building vents. Ambient measurements 2 downwind transects, 5 locations on each transect, 100-400 m from source.	Panel recording for 10 minutes per hour, 3 times per day for 3 days.	Measured on site (50 m from building).
Carney and Dodd	University College, Dublin	Ireland	Pig production (buildings, slurry store and slurry spreading)	450-sow unit	Olfactometry for emissions and ambient samples.	0m (at source) then 30, 50, 70 or 100 m depending on the study / source.	Varies depending on the study	Stability category determined from conditions on site
Minnesota	University of Minnesota	USA	Various agricultural sources (28 sites) including dairy, swine and poultry	Various depending on the farm	Olfactometry at source, ambient by sniffer panel	7 sniffers on transects at various distances (50-500m) from source	-	Measured on site
Alberta	Alberta Research Council	Canada	Pigs	-	Olfactometry at source, ambient by sniffer panel	8 trained sniffers, 200-650m from source	Morning and evening sampling, hour-long sessions, 60 records per sniffer per hour.	Measured on site

Study Name	Organisation	Location	Source	Number of animals	Measurement method	Measurement locations	Measurement periods	Met data
Saskatchewan	University of Saskachewan	Canada	Pigs	5144-sows. Site spread over three locations.	Olfactometry at source, ambient by sniffer panel	105 locations, 200m to 6.4km from source	Study over 6 months May-Oct 2003.	Measured on site
Manitoba	University of Manitoba	Canada	Pigs	2 farms, 3000 sows each	Olfactometry at source, ambient by sniffer panel	1444 locations 100-1000m from source	Sept-Oct 2003 & June-Sept 2004. 10-min sessions, 3 per hour. For each session, 60 records per sniffer and 15 sniffers.	Measured on site
Nebraska - slurry	University of Nebraska	USA	Pigs (slurry lagoon)	800 sows. 12,022 m^2 surface area slurry lagoon	Olfactometry at source, ambient by sniffer panel	Study 1: 111-198m from source Study 2: 58-134m from source	-	Measured on site
Nebraska - feedlot	University of Nebraska	USA	Cattle (feedlot)	2 studies (1000 and 4200 animals). Study 1 51,214 m^2, Study 2 184,845 m^2	Olfactometry at source, ambient by sniffer panel	Study 1: 106-505m from source Study 2: 150-504m from source	1 day per study?	Measured on site
Iowa	University of Nebraska	USA	Swine finishing barns	4 barns each housing 450 animals	Olfactometry at source, ambient by sniffer panel	-	20 15-minute measurement events. June-Nov 2004.	Measured on site
Lohmeyer	Ingenieurburo Lohmeyer, Karlsruhe und Dresden	Germany	Pig	-	Olfactometry at source, ambient by sniffer panel	Locations 50-500 m from source	-	Measured on site

Study Name	Organisation	Location	Source	Number of animals	Measurement method	Measurement locations	Measurement periods	Met data
Minnesota	University of Minnesota	USA	Various agricultural sources (28 sites) including dairy, swine and poultry	Various depending on the farm	Olfactometry at source, ambient by sniffer panel	7 sniffers on transects at various distances (50-500m) from source	-	Measured on site
Alberta	Alberta Research Council	Canada	Pigs	-	Olfactometry at source, ambient by sniffer panel	8 trained sniffers, 200-650m from source	Morning and evening sampling, hour-long sessions, 60 records per sniffer per hour.	Measured on site

Table F - 2: Odour study references and assessment for UK and Ireland and international validation data sets

Study Name	Reference(s)	Criteria	Pro's	Con's
Dublin	Curran, T.P., V. A. Dodd, W. L. Magette. 2007. Evaluation of ISC3 and CALPUFF Atmospheric Dispersion Models for Odor Nuisance Prediction. Paper number 074181. Annual International Meeting, Minneapolis, MN, 17-20 June 2007.	**Source info.**	Number and type of animals known.	
		Domain info.	Relatively flat agricultural land. Layout of buildings and description of site and surroundings provided.	
		Measurements	Standard olfactometry and sniffer panel methods used. 150-350m from source is relevant to permitting applications.	Sniffer measurements at 100 and 150 m from source provided in paper, but not those from longer distances.
		Meteorology	Measured on site. Comparisons with forecast HIRLAM data made	
		Other	Good links with UCD for further data if needed. Both ISC3 and CALPUFF used.	Modelling only carried out for specific 10-minute periods, not annual averages.
		Additional info		
Carney and Dodd	Carney, P. G. and V. A. Dodd. 1989. A comparison between predicted and measured values for the dispersion of malodours from slurry. J agric. Eng. Res. 44(1):67-76.	**Source info.**	Distances from source to measurement points provided and dimensions of source. Number and type of animals known. Good range of sources covered.	Some source information not provided *e.g.* number and location of vents on buildings.
		Domain info.		Actual location of sites not provided.
		Measurements	Standard olfactometry methods used.	It is noted that some odour concentrations recorded are below detection threshold for olfactometry
		Meteorology		Detailed met. info not provided. Stability category determined from conditions on site. Actual wind speeds not provided.
		Other	Dispersion modelling using basic Gaussian plume model.	
		Additional info		
Minnesota	Zhu, J., L.D. Jacobson, D.R.Schmidt and R. Nicolai. 2000 Evaluation of INPUFF-2 Model for predicting downwind odors from animal production facilities. Applied Engineering in Agriculture Vol16(2): 159-164	**Source info.**	28 farms studied, good range of source types including pig and poultry.	Detailed building, site and emission point information not provided for each source.
		Domain info.		All sites in Minnesota, but detailed domain information not provided.
		Measurements	Standard olfactometry and sniffer panel methods used	Sniffer panel results not provided in paper.
		Meteorology	Measured at all sites	Met data not provided in paper
		Other		Not necessarily representative of conditions in UK and Ireland
		Additional info		
Alberta	Qu, G., D. Scott, J.C. Segura, and J.J.R. Feddes. 2006 Calibration of the ISC-PRIME model for	**Source info.**	Description of farm given	Data on animal numbers and emission rates used in modelling not obvious in paper.
		Domain info.	Specific information not given, but aerial photograph looks like flat agricultural land	

Study Name	Reference(s)	Criteria	Pro's	Con's
	odour dispersion. Presentation paper at 2006 ASABE Annual International Meeting, Portland, Oregon. Paper no. 064136	**Measurements**	Standard sniffer panel methods used	Measurement of emissions using olfactometry not mentioned
		Meteorology	Measured on site, 52% Category D.	
		Other		Not necessarily representative of conditions in UK and Ireland
		Additional info		
Saskatchewan	Guo, H., Feddes, J., Lague, C., Dehod, W., Agnew, J. 2005 Downwind swine odour monitoring by trained odour assessors – Part 1: Downwind odour occurrence as affected by monitoring time and locations. Canadian Biosystems Engineering Vol. 47(6):47-55.	**Source info.**	Pigs. Number and type of animals known. Detailed emissions data provided.	
		Domain info.	Flat, rural area	
		Measurements	Standard olfactometry and sniffer panel methods used. 105 locations measured over 6 months. Good range of distances from source (200m-6.4km)	Only two sniffers used. Ambient measurements reported as odour intensity rather than odour concentrations.
		Meteorology	Measured on site	
		Other		Not necessarily representative of conditions in UK and Ireland
		Additional info		Complex site as spread over three locations
Manitoba	Zhang, Q., X. J. Zhou, H. Q. Guo, Y. X. Li, and N. Cicek. 2005. Odour and greenhouse gas emissions from hog operations. Project MLMMI 03-HERS-01. Manitoba, Canada. Guo, H., Li Y., Zhang, Q., Zhou, X. 2006 Comparison of four setback models with field odour plume measurement by trained odour sniffers. Canadian Biosystems Engineering Vol. 48(6):39-48.	**Source info.**	Pigs. Number and type of animals known. Detailed emissions data provided. Range of sources included.	
		Domain info.	Good descriptions of the sites.	Not much information regarding surroundings or building details *e.g.* sizes.
		Measurements	Standard olfactometry and sniffer panel methods used	
		Meteorology	Measured on both sites.	Details with respect to sniffer results not provided in paper. Most measurements made in Cat B conditions.
		Other		Not necessarily representative of conditions in UK and Ireland
		Additional info		
Nebraska - slurry	Henry C. G. Ground truthing aermod for area source livestock odor dispersion using odor intensity and the mask scentometer. PhD Thesis, University of Nebraska, 2009.	**Source info.**	Pig slurry lagoon, dimensions provided. Number and type of animals known. Odour emission rates provided.	
		Domain info.	Flat, rural farmland	
		Measurements	Standard olfactometry and sniffer panel methods used as well as Mask Scentometer	Measurement distances 58-198 m from source quite close, not large range. Ambient odour intensity results reported, but not odour concentrations.
		Meteorology	Measured on site	
		Other	Modelling carried out with AERMOD	Not necessarily representative of conditions in UK and Ireland

Study Name	Reference(s)	Criteria	Pro's	Con's
		Additional info		
Nebraska - feedlot	Henry C. G. Ground truthing aermod for area source livestock odor dispersion using odor intensity and the mask scentometer. PhD Thesis, University of Nebraska, 2009.	**Source info.**	2 cattle feedlots. Odour emission rates provided.	Cattle feedlots not representative of pig and poultry sources.
		Domain info.	Flat, rural farmland	
		Measurements	Standard olfactometry and sniffer panel methods used as well as Mask Scentometer. 106-505 m from source.	Ambient odour intensity results reported, but not odour concentrations.
		Meteorology	Measured on site	
		Other	Modelling carried out with AERMOD	Not necessarily representative of conditions in UK and Ireland
		Additional info		
Iowa	Henry C. G. Ground truthing CALFUFF and AERMOD for odor dispersion from swine barns using ambient odor assessment techniques. PhD Thesis, University of Nebraska, 2009.	**Source info.**	Pig finishing barns, numbers of animals provided. Ventilation rates provided.	Odour emission rates not obvious in paper.
		Domain info.	Flat agricultural terrain. Building details and layout provided.	
		Measurements	Standard olfactometry and sniffer panel methods used as well as Mask Scentometer and Nasal Ranger. Some ambient olfactometry samples taken.	Detailed odour concentration results not provided in paper (some measured data provided but no units or distance from source provided).
		Meteorology	Measured on site.	
		Other	Modelling carried out with a variety of models.	Not necessarily representative of conditions in UK and Ireland.
		Additional info		Main emphasis of study was comparison of ambient odour measurement techniques.
Lohmeyer	Keder J., Bubnik J., Macoun J. (2005) Validation of the Czech reference model Symos'97 adapted for odour dispersion modelling. Proceedings of the 10th Harmonisation Conference, Crete.	**Source info.**	Pig farm.	Details not known.
		Domain info.	Flat terrain.	
		Measurements	Standard olfactometry and sniffer panel methods used. 50-500 m from source relevant to permitting.	
		Meteorology	Measured on site. All measurements carried out in Cat D neutral stability.	
		Other		Not necessarily representative of conditions in UK and Ireland
		Additional info		The original paper for this work (Bachlin *et al*. 2002) is written in German, therefore as yet we have not been able to extract full details of the study. The Keder *et al*. (2005) paper only provides a short description.

Appendix G. Best estimates of SCAIL-Agriculture input parameters and uncertainty ranges (where applicable) for the ammonia validation datasets

Dataset name	Model input	Best estimate	Uncertainty range
N. Ireland - Fan ventilated	Broiler Emission rate	SCAIL Emission factor: **0.03 kg NH_3 yr^{-1}**	**± 20%** (Theobald *et al.*, 2009)
	Release height	Actual value: **6.39 m**	Negligible uncertainty
	Exit flow rate	Actual value: **6.13 m^3 s^{-1}**	Negligible uncertainty
	Source diameter	Actual value: **1 m**	Negligible uncertainty
	No. of sources (fans)	Actual value: **9**	Negligible uncertainty
	Exit temperature	Realistic value: **5ºC above ambient**	Realistic range: **0-10ºC above ambient**
	Building height	Fan height: **6.39 m**	Actual value: **5.84 m**
N. Ireland - Naturally ventilated	Broiler Emission rate	SCAIL Emission factor: **0.03 kg NH_3 yr^{-1}**	**± 20%** (Theobald *et al.*, 2009)
	Building height	Actual value: **5.86 m**	Negligible uncertainty
Newborough	Broiler Emission rate	SCAIL Emission factor: **0.03 kg NH_3 yr^{-1}**	**± 20%** (Theobald *et al.*, 2009)
	Release height	Actual values: **4.5 / 5 m**	Negligible uncertainty
	Exit flow rate	Actual values: **1.2-1.5 m^3 s^{-1}**	Negligible uncertainty
	Source diameter	Actual values: **0.73-0.77 m (Effective diameter)**	Negligible uncertainty
	No. of sources (fans)	Actual value: **36-38 per house**	Negligible uncertainty
	Exit temperature	Realistic value: **5ºC above ambient**	Realistic range: **0-10ºC above ambient**
	Building height	Actual values: **4.5 / 5 m**	Negligible uncertainty
NitroEurope - S. Scotland	Layer/Pullet Emission rate	SCAIL Emission factors	No uncertainty analysis
	Release height	Calculated from actual heights of the buildings	No uncertainty analysis
	Exit flow rate	Calculated for a typical ventilation system	No uncertainty analysis
	Source diameter	Estimated: **1 m**	No uncertainty analysis
	No. of sources (fans)	Estimated from air flow recommendations	No uncertainty analysis
	Exit temperature	Realistic value: **5ºC above ambient**	No uncertainty analysis
	Building height	Actual heights of the buildings	No uncertainty analysis

Pitcairn - Pigs	Total emission rate	Published emission: **5100 kg NH_3 yr^{-1}**	**± 20%** (Theobald *et al.,* 2009)
	Release height	Assuming wall fans: **3.5 m**	Realistic range: **2-7 m** (to include the possibility of roof fans)
	Exit flow rate	Assuming wall fans **0 m^3 s^{-1}**	No uncertainty (if roof fans are present, they are capped)
	Source diameter	Estimated **1 m**	Range for typical ventilation systems: **0.4-1.4 m**
	No. of sources (fans)	Estimated from air flow recommendations: **7**	Realistic range: **5-15**
	Exit temperature	Realistic value: **5ºC above ambient**	Realistic range: **0-10ºC above ambient**
	Building height	Taken from typical building dimensions **7 m**	Realistic range: **5-10 m**
Garvary lodge	Layer Emission rates	SCAIL Emission factors: **Deep pit: 0.20 kg NH_3 yr^{-1}** **Belt: 0.12 kg NH_3 yr^{-1}**	**± 20%** (Theobald *et al.,* 2009)
	Release height	Taken from typical building dimensions **7 m**	Realistic range: **5-10 m**
	Exit flow rate	Calculated from typical ventilation system **1.5-5.2 m^3 s^{-1}**	Variation in recommended air flow rates (Theobald *et al*., unpublished data): **± 50%**
	Source diameter	Estimate: **1 m**	Range for typical ventilation systems: **0.4-1.4 m**
	No. of sources (fans)	Estimated from air flow recommendations: **10-16**	No uncertainty analysis
	Exit temperature	Realistic value: **5ºC above ambient**	Realistic range: **0-10ºC above ambient**
	Building height	Taken from typical building dimensions **7 m**	Realistic range: **5-10 m**
Pedersen (Denmark)	Total emission rate	Published emission: **34300 kg NH_3 yr^{-1}**	No uncertainty analysis
	Release height	Actual value: **6.4 m**	No uncertainty analysis
	Exit flow rate	Actual value: **4.10 m^3 s^{-1}**	No uncertainty analysis
	Source diameter	Actual value: **0.8 m**	No uncertainty analysis
	No. of sources (fans)	Actual value: **11**	No uncertainty analysis
	Exit temperature	Realistic value: **5ºC above ambient**	No uncertainty analysis
	Building height	Actual value: **6.4 m**	No uncertainty analysis

Shaded cells represent model inputs used in the uncertainty testing.

Appendix H. Model validation using monitored data from Scottish poultry farms

H.1. Introduction

This short report outlines the bespoke monitoring conducted for the validation of the tool to ensure that the tool provides realistic yet conservative results.

Two farm sites were selected for the validation monitoring based on a detailed review including site visits to 6 candidate sites. These sites were selected based on the following criteria:

- *Egg layer facilities to minimise potential variations in emission patterns associated with broiler production;*
- *Located in Central Scotland;*
- *Approximately 40,000 birds;*
- *Situated in a reasonably flat and open area and therefore suitable for collecting on-site meteorological data;*
- *Not located in close proximity to other similar sized agricultural installations to minimise background concentrations; and*
- *Livestock are likely to be present for the majority of a 3-month monitoring period.*

In addition, continuous measurements of ammonia and airborne particulate matter were conducted at one of the identified farm sites. This site had to meet the following additional criteria:

- *A location was identified within approximately 150 m of the farm for the installation of continuous monitoring equipment;*
- *This location should be over undisturbed and open land from the farm;*
- *It should be possible to install mains (240 V AC) power to the location; and*
- *It should be possible to exclude livestock from the location.*

Annotated maps of the selected farm sites are shown as follows:

Whitelees Farm , South Lanarkshire – selected for continuous monitoring (Figure H - 1)

Glendevon Farm, Fife (Figure H - 2).

Table H - 1 provides summary information for each of the farms and highlights the pros and cons of each of the locations.

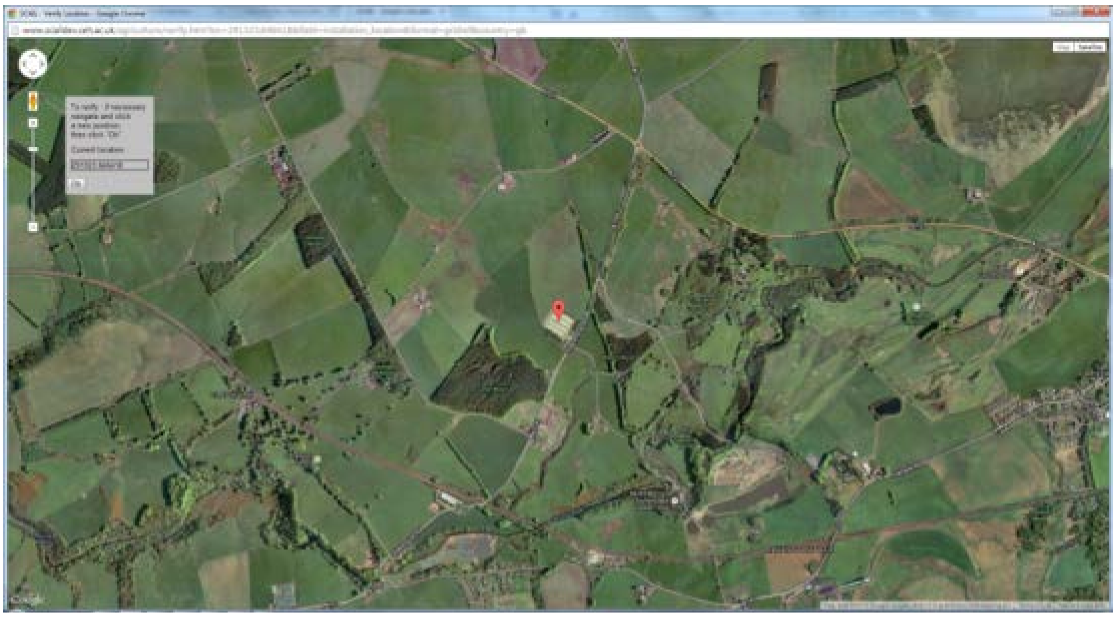


Figure H - 1: Whitelees Farm as shown in the "verify location" window of SCAIL-Agriculture

Figure H - 2: Glendevon Farm as shown in the "verify location" window of SCAIL-Agriculture

Table H - 1: Summary of information for the farm sites.

Farm (location)	# birds	Age (wks)	Pros	Cons	Site Type
Whitelees (55.699066, -3.730781)	37k (not permitted) Layers	38	Good clear NE *fetch* for measurements; clean source area away from towns and main roads;	Cows and sheep in fields to N and W of farm.	Intensive monitoring.
Glendevon (56.052808, -3.490906)	45k Layers	<40	Good *fetch*; N and south; no significant animal stocking in fields in NE transect Residential house on NE edge of site which may be suitable for PM measurements	B road between farm and NE transect area: therefore not possible to put power in.	Passive monitoring.

H.1.1. Validation methodology

The methodologies for the validation of the tool and the various datasets were discussed in the Validation Plan (Theobald, 2011). The validation process consisted of three key stages:

- *Model performance analysis using best estimates of model inputs;*
- *Estimation of model prediction uncertainty due to uncertainty in model input data;*
- *Estimation of model prediction uncertainty due to the simplification of model input data.*

The SCAIL-Agriculture tool was run using the best estimates of model input data and the default (nearest) SCAIL-Agriculture regional meteorological station (for both these farms the station was Edinburgh Gogorbank). In addition the on-site meteorological data were formatted for direct use in the model as a comparison with the regional meteorological data. These best estimates of model inputs were either the real values (where available) or based on expert judgement. The predicted concentrations (C_p) were then compared with the measured values (C_o) and the four following performance indicators were calculated for each dataset:

- *Fractional bias;*
- *Geometric mean bias;*
- *Normalised mean square error;*
- *Geometric variance.*

In addition we used a fifth metric, the fraction of model predictions within a factor of two of the observations (FAC2).

Chang and Hanna (2004) suggest ranges for five of the performance measure values that indicate acceptable model performance. The ranges suggested are:

- *-0.3<|FB|<0.3;*
- *0.7<MG<1.3;*
- *NMSE<1.5;*
- *VG<4; and*
- *FAC2>50%.*

Recent work on model performance evaluation by Hanna and Chang (2010) has recognised that, due to stochastic and turbulent processes, even an acceptable model may not meet all acceptability criteria for all experiments. As a result, they propose that an acceptable model is one that meets the criteria for at least half of the performance tests.

H.2. Methodology

H.2.2. Meteorological measurements

Meteorological measurements were conducted at each of the two farm sites with automatic weather stations, equipped with dataloggers, details of the start and end times of the measurements and the height of the anemometers are included in Table H - 2. The meteorological measurements were recorded at a time resolution of 30 minutes and integrated to provide hourly values for processing for inclusion in the model evaluation. Table H - 3 lists the meteorological instruments that were deployed and the success of the measurements, noting that Solar Radiation data were not successfully recorded for Whitelees farm and that surface moisture was not recorded at Glendevon farm. It should be noted that estimates of cloud cover that are required for the modelling were derived from the solar radiation data using a reversion of the methods described in Thomson (2000) for determining surface fluxes from cloud cover data. A comparison between the calculated cloud cover and observations of cloud cover taken on the sites confirmed that this was a reliable methodology.

Table H - 2: Start and end times for the meteorological measurements Whitelees and Glendevon Farms and details of the anemometer height.

Run	Start (GMT)	End (GMT)	Anemometer height
Whitelees Farm	14/08/2013 12:30	04/11/2013 10:00	1.7 m
Glendevon Farm	24/07/2013 13:00	08/11/2013 10:30	7.13m

Table H - 3: Meteorological instruments deployed at Whitelees and Glendevon Farms.

Instrument	Parameter	Unit	Operation
	Whitelees Farm		
A100R cup anemometer	Wind speed	m s^{-1}	OK (95%)
W200P windvane	Wind direction	oN	OK (100 %)
SKP Skye pyranometer	Total solar radiation	W m-2	Failed

Instrument	Parameter	Unit	Operation
Cassella tipping bucket	Rainfall	mm	OK (100%)
Campbell wetness grid	Surface moisture	%	OK (100%)
Vaisala HMP50 Relative humidity/T probe	Relative humidity	%	OK (100%)
Vaisala HMP50 Relative humidity/T probe	Air temperature	oC	OK (100%)
Glendevon Farm			
A100R cup anemometer	Wind speed	$m\ s^{-1}$	OK (95%)
W200P windvane	Wind direction	oN	OK (100%)
SKP Skye pyranometer	Total solar radiation	$W\ m^{-2}$	OK (100%)
Campbell wetness grid	Surface moisture	%	Failed
Rotronics Relative humidity/T probe	Relative humidity	%	OK (100 %)
Rotronics Relative humidity/T probe	Air temperature	oC	OK (100%)
Type-E thermocouple	Air temperature	oC	OK (used a primary data source with gapfilling by the Rotronics)

H.2.3. Ammonia Sampling

Nine ammonia monitoring locations were positioned around the Whitelees and Glendevon Poultry farms, within a 1km radius to provide information on the spatial concentration field (Figure H - 3 and Figure H - 4).

Figure H - 3: Google earth map of the Whitelees Poultry Farm study area, showing the locations of ammonia monitoring sites. White 1 is also the location of the meteorological and intensive (continuous) measurement site.

Figure H - 4: Google earth map of the Glendevon Farm study area, showing the locations of ammonia monitoring sites.

The measurement location closest to Whitelees farm (White1) was also the intensive (continuous) measurement site, positioned on the NE edge of the farm, about 55 m away from the buildings and 114 m from the centre of the farm. At this site, the following instruments and measurements were deployed (see Figure H - 5):

- *Meteorological station: wind direction, wind speed, temperature/humidity, solar flux, rainfall*
- *ALPHA: monthly NH_3 (one of 9 sites to provide spatial NH_3 concentration field)*
- *AiRRmonia: continuous NH_3 (measurement frequency = 1 minute)*
- *DPAS-MANDE 2-weeky NH_3*
- *DELTA: 2-weekly NH_3*
- *ALPHA: 2 weekly NH_3*

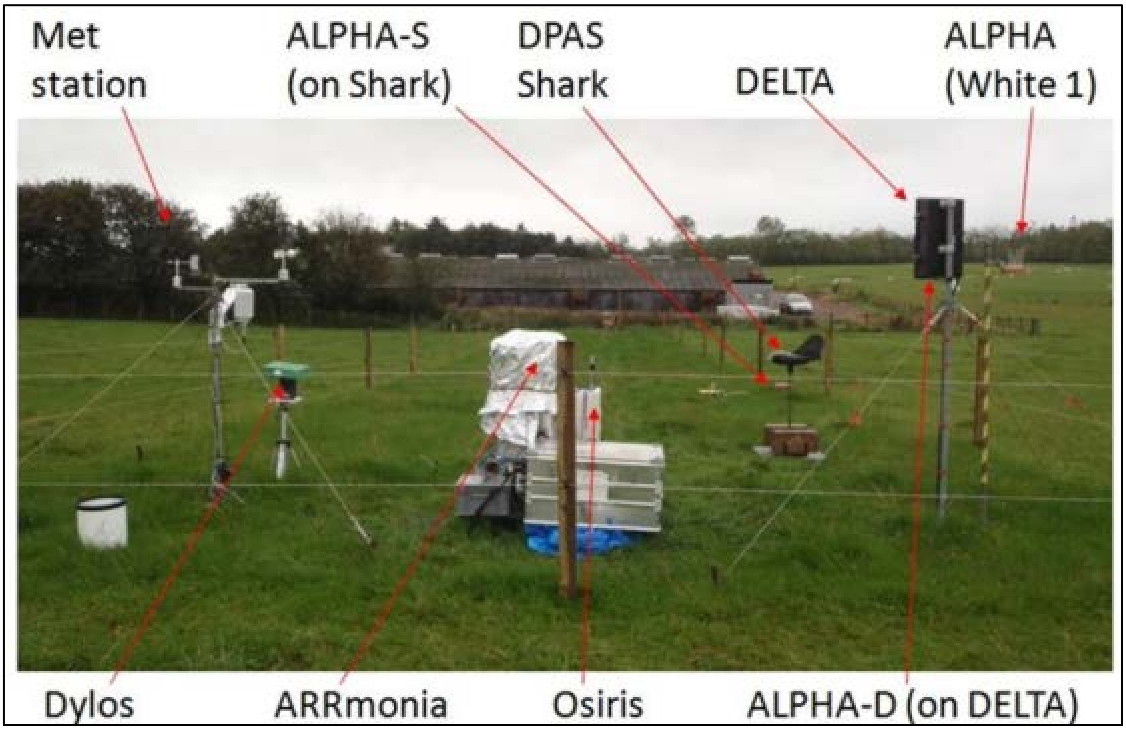


Figure H - 5: Whitelees Poultry Farm intensive measurement site (White 1) positioned approx. 55 m NE of the farm. Note that DPAS data are not part of this work.

H.2.3.1. Alpha Samplers

Atmospheric NH_3 concentrations were monitored using the CEH ALPHA (Adapted Low-cost Passive High Absorption) samplers (Tang *et al.* 2001, Puchalski *et al.* 2011). The ALPHA sampler (Figure H - 6) is widely used for ammonia measurements, *e.g.* in the UK National Ammonia Monitoring Network[3] (NAMN) and for assessments around intensive livestock farms (*e.g.* Tang *et al.* 2005, 2006).

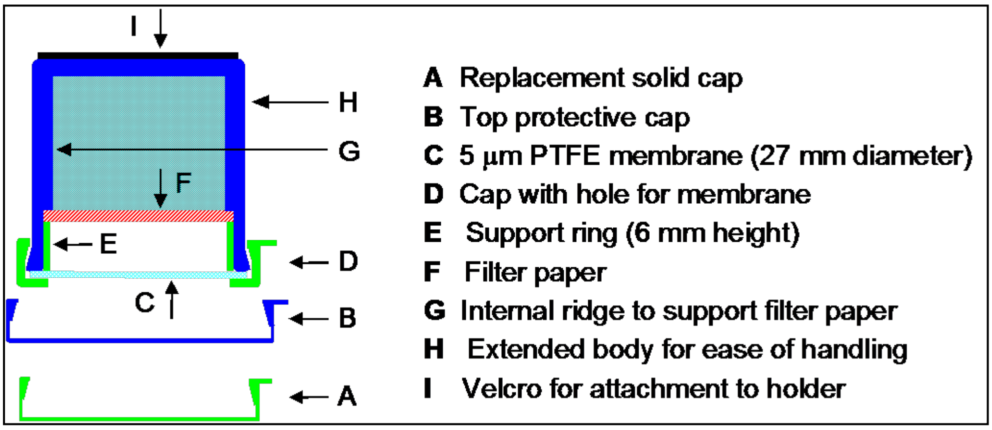


Figure H - 6: Outline diagram of a single ALPHA Sampler.

Replicate samplers (triplicate) were attached to a holder at a sampling height of approx. 1.5 m above ground, the standard monitoring height for providing the most representative ammonia concentrations in the atmosphere. Replicated sampling was used in order to provide an estimate of the precision of the method and to give a robust estimation of the air concentration of ammonia.

Monitoring was made on an approximately monthly frequency, using continuous time- integrated sampling over each period (see Table H - 4). A total of 4 sets of measurements were made over the period 6th August to 4th November 2013. The ammonia samplers were prepared and analysed by CEH

[3] NAMN: http://pollutantdeposition.defra.gov.uk/networks

according to standard protocols developed at CEH (Tang *et al.* 2001). The changeover of samples was carried out by CEH personnel.

Table H - 4: Start and end times for the ammonia alpha samplers at Whitelees and Glendevon Farms.

Run	Start (GMT)	End (GMT)	Duration (days)
Whitelees Farm			
Run 1	06/08/2013 13:00	29/08/2013 12:00	23.0
Run 2	05/09/2013 12:00	02/10/2013 12:00	27.0
Run 3	02/10/2013 12:00	14/10/2013 12:00	12.0
Run 4	21/10/2013 13:00	04/11/2013 12:00	14.0
Glendevon Farm			
Run 1	24/07/2013 13:00	22/08/2013 15:00	29.1
Run 2	22/08/2013 15:00	25/09/2013 12:00	33.9
Run 3	25/09/2013 12:00	10/10/2013 12:00	15.0
Run 4	10/10/2013 12:00	08/11/2013 11:00	29.0

H.2.3.2. Diffusion Tubes (DT)

Diffusion tubes (7.1 cm Palmes-type) were used to measure NH_3 inside the poultry buildings as detailed in Table H - 5. The tubes are made of opaque Teflon, 7.1 cm long and 1 cm diameter. Two acidified stainless steel grids (impregnated with 35ul of 1 % m/v H_2SO_4), which serve to capture the ammonia, are held under a plastic cap and this end is placed uppermost. The other end is open and this end is placed facing the ground. During transport, the open end is capped; the cap is removed to start sampling and replaced to end sampling.

Table H - 5: Start and end times for the diffusion tube samplers used within the farm buildings.

Run	Shed	Start (GMT)	End (GMT)	Duration (hours)
Glendevon				
Run 1	2	05/11/2013 12:05	07/11/2013 11:25	47.3
Run 2	3	05/11/2013 12:00	07/11/2013 11:00	47.0
Run 3	4	05/11/2013 11:55	07/11/2013 11:20	47.4
Run 4	5	05/11/2013 11:50	07/11/2013 11:05	47.3
Whitelees				
Run 1	3	11/10/2013 10:50	14/10/2013 11:02	72.2
Run 2	4	11/10/2013 11:00	14/10/2013 11:05	72.1
Run 3	5	11/10/2013 11:05	14/10/2013 11:08	72.1
Run 4	6	11/10/2013 11:12	14/10/2013 11:09	72.0

H.2.3.3. Chemical analysis of samples and blanks

The ALPHA samplers and diffusion tubes were analysed on the AMFIA (Ammonia Flow Injection Analysis) system at CEH Edinburgh. The samples were first extracted in deionised water, and then analysed for ammonium, against a series of ammonium standards and quality controls. Parallel analysis of lab and field blank (unexposed) samples was used to determine the amounts of ammonium derived from ammonia in the atmosphere during storage.

H.2.3.4. Calculation of ammonia concentrations from ALPHA samplers

Based on the amount of ammonium in the sample extracts and the exposure periods, air NH_3 concentrations were calculated initially according to the theoretical sampling rate of the ALPHA sampler for ammonia. The information from the recording cards and from the chemical analyses was incorporated into an EXCEL spreadsheet for each site for calculating NH_3 concentrations, and providing supporting information.

Based on the results from the ten intercomparison sites in the UK between ALPHA and the reference DELTA method (Sutton *et al.* 2001), the appropriate calibration were applied to the ammonia data. This is necessary because the real sampling rate is slightly lower than the theoretical derived rate, since the laminar boundary layer at the sampler inlet imposes an additional resistance to gas diffusion, which is not taken into account in the theoretically derived rate.

H.2.3.5. Calculation of ammonia concentrations from Diffusion tubes

Based on the amount of ammonium in the sample extracts and the exposure periods, air NH_3 concentrations were calculated from the derived sampling rate of the diffusion tubes for ammonia. The information from the recording cards and from the chemical analyses was incorporated into an Excel spreadsheet for each site for calculating NH_3 concentrations, and providing supporting information.

H.2.3.6. Continuous NH_3 measurement – AiRRmonia

AiRRmonia (Mechatronics, NL: Figure H - 7) is an automated ammonia analyser providing continuous ammonia measurements in the field. The analyser comprises a membrane sampler for quantitative sampling of gas-phase ammonia, followed by online measurement of NH_3 concentrations.

Diffusion of NH_3 from the air stream occurs across a 0.22 µm pore size Teflon membrane into a counter flow of deionised water. At pH 7 the NH_3 converts back to NH_4 and is then transported to the detector block below. In the detector block, aqueous sample from sampling block is mixed with a carrier flow of deionised water to which an alkali (NaOH) is added. This converts all NH_4 to NH_3 in solution around pH 12. At this pH, NH_3 is the only small molecule in solution that will readily diffuse across a 0.22 µm pore size teflon membrane. The sample is passed one side of a membrane with NH_3 passing over into a counter flow of deionised water. At pH 7 the NH_3 converts back to NH_4 and the ion concentration is then analysed by conductivity. The air sampling rate is 1 l min^{-1} with measurements recorded every minute. Data was then averaged over 10 minute periods. The AiRRmonia has a limit of detection of ~0.1 $\mu g.m^{-3}$. Calibration of the analyser was carried out before and during deployment using 50 and 500 ppb NH_4 standard solutions.

Figure H - 7: AiRRmonia automated ammonia analyser (Mechatronics, NL)

H.2.3.7. DELTA and ALPHA measurements

The DEnuder for Long-Term Atmospheric (DELTA) system (Sutton *et al.* 2001) was deployed at the "White 1" intensive site to provide a check on the calibration of the ALPHA sampler. Citric acid coated denuders (15 cm in length) were used to capture NH_3 and two denuders in series were used to establish that all the NH_3 is captured. The volume of gas sampled was measured on a high sensitivity gas meter.

H.2.4. Odour monitoring

H.2.4.1. Odour concentrations in building exhausts

Samples were collected by Silsoe Odours from within buildings at 6 locations per farm per visit. Samples were collected using Nalphan NA sample bags through FEP sampling tubes. Sample bags were fitted in rigid "barrels" which were partially evacuated to provide the vacuum to draw air along the sample tube into the bags (lung principle) (see Figure H - 8). The vacuum was generated by portable 12v battery electric pumps.

Odour measurements were made on the samples using dynamic dilution olfactometry by Silsoe Odours to the standards defined in their UKAS accreditation (Testing Laboratory No. 0609). Odour concentrations were measured according to the BSEN13725:2003 "Air quality – Determination of odour concentration measurement by dynamic olfactometry" standard. The olfactometry measurement quantifies the concentration of odour in air samples by diluting the air sample under test with known ratios of odour-free air. The diluted samples are presented to a panel of six people to determine the odour threshold value. The threshold value is the odour concentration just perceived by 50% of the panel via statistical analysis of dilution test results. Odour concentration results are expressed in European odour units per cubic metre (OUe m^{-3}), which equates to the number of dilutions to the detection threshold. The odour concentration of an undiluted sample which is at threshold level is 1 OUe m^{-3}.

Figure H - 8: Monitoring odour concentrations and fan ventilation flows in the exhaust of Glendevon farm.

Odour samples collected at a single ventilation fan that operated continuously on each of three building on each site, each building was sampled twice during the time the Field Odour assessments were being performed. The numbering system for the buildings that was used in the assessment is detailed in Figure H - 9 and Figure H - 10.

Figure H - 9: Building identifiers for Glendevon Farm.

Figure H - 10: Building identifiers for Whitelees Farm.

H.2.4.2. Ammonia concentrations in building exhausts

Ammonia concentrations in the exhaust of the buildings were measured using ammonia specific Draeger tubes by sampling the air from the same bags as were used for the odour analysis detailed in the previous section. A comparison between ammonia concentrations measured directly in the vents and those from the sample bags illustrated that this method was reliable and not affected by sampling artefacts.

H.2.4.3. Gas flows from the building exhausts

The air speed from each fan duct sampled was measured by sampling on a grid of 12 sampling points over the plane of the duct. The 12 values were averaged then the volume flow rate calculated

All the fans on the buildings at the Glendevon site were set to operate throughout the period that emissions from the buildings were measured. The normal target temperature for the internal temperature is 21 °C. This temperature was maintained on average on the 18 September but because of a lower ambient temperature on the 25th September the internal temperature was lower at an average of 17.2 °C.

Because of the elevation of Whitelees farm and cooler weather on the 19th September the fans on these buildings were set to operate on Stage 2 throughout the monitoring period. The normal target temperature for the internal temperature is 21 °C, but this temperature was not maintained on the 19th September and the average was 17.7 °C. On the 26th September the ambient temperature was lower so to maintain an acceptable internal temperature the ventilation system was set to automatic. The average internal temperature was maintained at an average of 21.3 °C.

H.2.4.4. Ambient odour analysis

Ambient odours were measured by a panel of 3 "sniffers". The "sniffers" are all members of the Silsoe odour panel and are subject to the standardisation checks and analysis required by BSEN13725:2003 (although it should be noted that the analysis by the field panellists does not fall within the UKAS accreditation of Silsoe odours).

The assessors were instructed to have stopped eating or smoking at least 30 minutes before the measurement. At each measuring point the measuring procedure lasts about 15 minutes and comprises the registration of the odour frequency, the assessment of the odour intensity and description of the odour as well as a short description of the wind and weather conditions. The assessors test the ambient air by inhaling at 10 seconds intervals, which gives 60 samples in ten minutes. Following the recognition of the odour the panelist is asked to assess the odour intensity on the 0 to 6 scale. 1 on the scale would be an odour but not recognizable, 2 is a faint recognizable odour and 3 is a distinct odour that, if offensive, might cause annoyance. All the responses are recorded on the data collection form (Figure H - 11).

The "sniffers" recorded odour quality (the type of odour – in this case they were only instructed to report on "poultry odour" or "no odour") and intensities (on a scale of 0 – 6) at 10 second intervals over a period of 10 minutes. From this information the frequency of occurrence of an odour being detected and average intensity of the odour when detected were determined. The 10 minutes duration of a single measurement provides an 80% reliability that the sample is representative of the odour situation of a particular hour. The percentage of time a given descriptor was used and the mean intensity of the odours with that description were calculated.

Odour concentrations were determined from a calibration curve established from the olfactometer between odour intensity and concentration at various downwind locations.

Locations used for the odour assessment are shown in Figure H - 12 and Figure H - 13.

SILSOE ODOURS Ltd

Building 42, Wrest Park, Silsoe,
Bedfordshire, Tel & fax +44 (0)1525 860222

Data collection form for Field Measurements

		Date		WIND direction	
Measurement point		Panel member		wind strength	
Start of measurement		End of measurement			

wind strength	
0	calm
1	smoke drifts
2	leaves rustle
3	leaves and twigs move
4	dust & paper lifte
5	branches move

1 minute		2 minute	Quality totals	intensity total
	quality			
	intensity			
3 minute		4 minute		
	quality			
	intensity			
5 minute		6 minute		
	quality			
	intensity			
7 minute		8 minute		
	quality			
	intensity			
9 minute		10 minute		
	quality			
	intensity			

Odour Qualities

N	no odour
A	poultry
B	cattle
C	sheep
D	
E	
F	

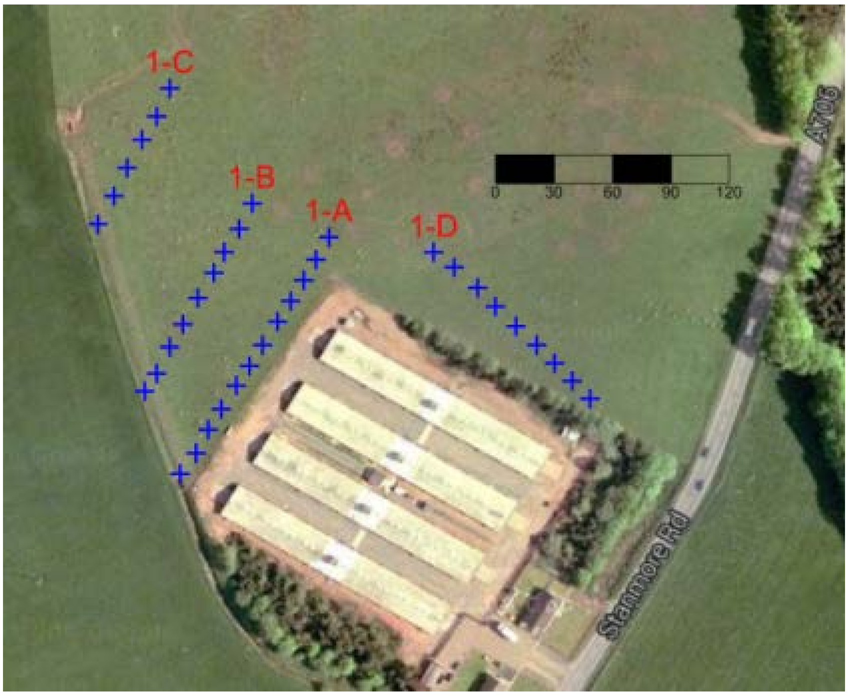
Odour intensity

0	no odour	
1	Very faint	(inkling)
2	Faint	(certain)
3	Distinct	
4	Strong	
5	Very Strong	
6	Extremely Strong	

it is not a question of a sensitive response to odours but clear recognition of the odour, odour quality, and intensity

Figure H - 11: The odour assessor's data collection form

19th September 2013



26th September2013

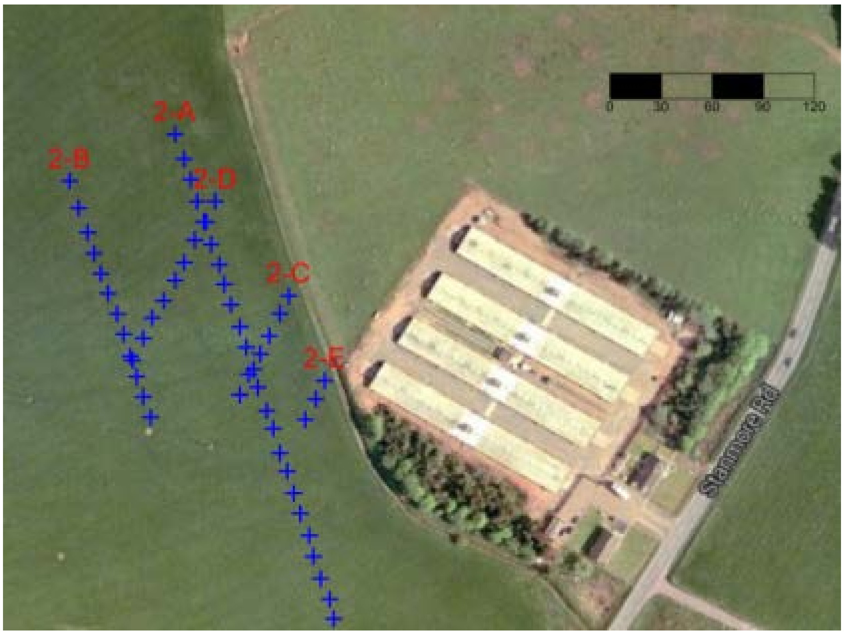


Figure H - 12: Locations of the odour sampling positions at Whitelees farm. Scale bar shown in metres.

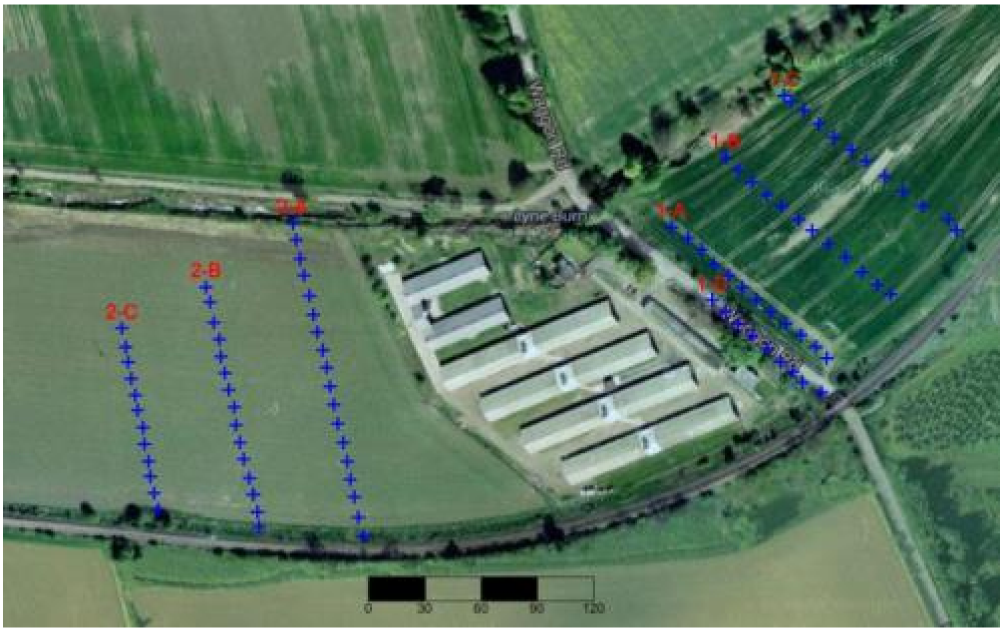


Figure H - 13: Locations of the odour sampling positions at Glendevon farm. Scale bar shown in metres.

H.2.5. PM$_{10}$ measurements

A Turnkey Osiris monitor was used for the ambient particle measurements at Whitelees farm (site White 1). This monitor is designed to be used for both fixed location and mobile monitoring and uses near forward light scattering (5^o) to count and size particles, drawn into the photocell by a diaphragm pump operating at 0.6 l minute^{-1}. As total airborne particle concentrations were less than 6 mg m^{-3}, the monitor was able to size particles into 4 fractions (note only the PM$_{10}$ data are reported herein):

- *Total Suspended Particulate (TSP);*
- *Particles of size $\leq$10 micrometres (PM$_{10}$);*
- *Particles of size $\leq$2.5 micrometres (PM$_{2.5}$); and*
- *Particles of size $\leq$1 micrometres (PM$_1$).*

The mass of particles in each class was recorded separately on the internal datalogger. The Osiris was factory calibrated for each particle size range with the calibration being certified by the manufacturer on the 9th of May 2013. The sampler also has an auto-zero facility, where filtered air is passed over the instrument's optics to confirm the zero point of the calibration. The OSIRIS was deployed at site "White 1" (see Figure H - 3 and Figure H - 5) in a protective enclosure with a heated air inlet to prevent interference from airborne water droplets (see Figure H - 14).

It should be noted that this instrument provides an indicative estimate of particle concentrations and is not an equivalent to gravimetric sampling required to demonstrate compliance with the CAFE directive.

Figure H - 14: Osiris monitor deployed in the field in a weather proof enclosure at Whitelees farm (site White 1).

A DUSTTRAK II Aerosol Monitor (Model 8532) was used to measure particulate concentrations within the vents of the animal houses. This instrument is handheld and battery-operated with an internal data-logger. It uses a light-scattering laser photometer to provide real-time aerosol mass readings and uses a sheath air system that isolates the aerosol in the optics chamber to keep the optics clean for improved reliability and low maintenance. It has been designed for clean office settings as well as harsh industrial workplaces, construction and environmental sites, and other outdoor applications. The instrument can measure aerosol concentrations corresponding to PM_1, $PM_{2.5}$, Respirable, or PM_{10} size fractions in the concentration range 0.001 to 150 mg m^{-3} and was deployed with a size selective inlet to enable the recording of PM_{10} concentrations (see Figure H - 15).

Figure H - 15: DUSTTRAK II ambient particle monitor shown with the PM_{10} size selective inlet in place.

H.3. Monitoring Results

H.3.1. Meteorological measurements

Wind roses are shown in Figure H - 16 and Figure H - 17 for Glendevon and Whitelees farms respectively. These illustrate the dominance of winds from the west at Glendevon Farm and from the south-west at Whitelees Farm over the monitoring period.

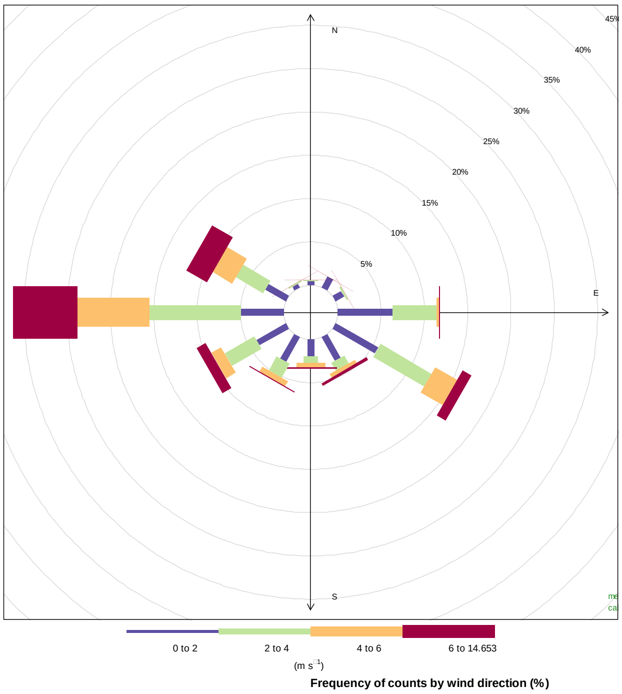


Figure H - 16: Wind rose determined from the on-site meteorological station at Glendevon farm

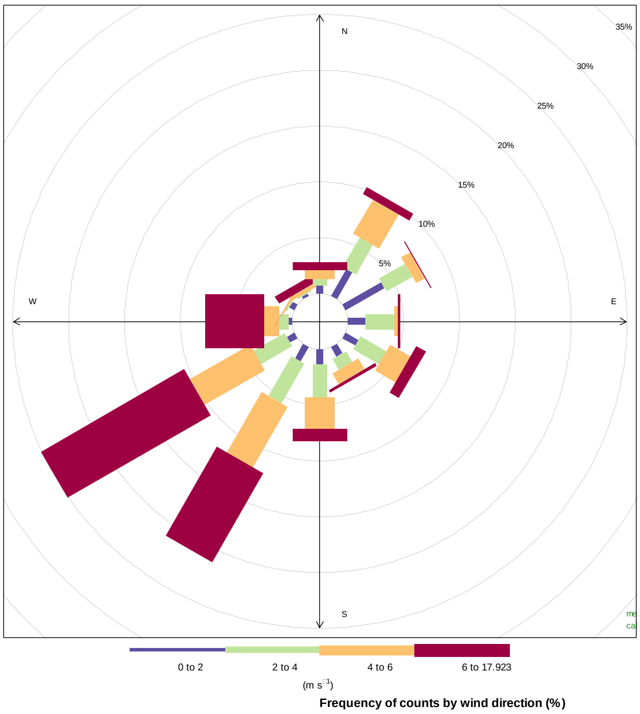


Figure H - 17: Wind rose determined from the on-site meteorological station at Whitelees farm

H.3.2. Source term measurements

H.3.2.1. Odour and ammonia concentrations and building temperature

Ammonia concentrations and odour concentrations were determined from samples collected in the vents of the farm buildings using Naptan NA sampling bags. Ammonia and odour concentrations and air temperatures for Glendevon farm are shown in Table H - 6 and for Whitelees farm are shown in Table H - 7. Ammonia concentrations in the vents of the buildings at Glendevon farm were similar to measurements collected by the site operators for ensuring compliance with Occupational Exposure Levels (data not shown). Overall there was a reasonable agreement between the concentrations collected on each of the visits to the site. There were generally higher ammonia and odour concentrations recorded from Whitelees farm than from Glendevon farm.

Ammonia concentrations were also measured in the farm buildings using Palmes diffusion tubes over periods of several days. On analysis of the results it would appear that these tubes may have been saturated and hence actual concentrations may have been underpresented. Nevertheless the concentrations recorded were similar to, if not higher than, the short term measurements collected at the building vents (see Table H - 8).

Table H - 6: Odour and ammonia results for Glendevon farm.

Date / Time (GMT)	Building	Odour concentration OUe m^{-3}	Ammonia concentration mg m^{-3} (ppm)	Temperature at fan outlet °C
18/09/13				
11:54	2	142	14 (20)	21.6
12:16	3	124	14 (20)	20.7
12:35	5	226	12 (18)	21.5
13:54	5	225	12 (17)	20.2
14:07	3	115	9 (13)	20.9
14:31	2	157	14 (21)	21.1
25/09/13				
12:44	2	540	10 (15)	17.8
13:02	3	200	10 (15)	18.1
13:29	5	249	12 (17)	17.5
14:04	5	256	10 (14)	17.1
14:20	3	158	7 (10)	16.3
14:33	2	183	8 (12)	16.5

Table H - 7: Odour and ammonia results for Whitelees farm.

Date / Time (GMT)	Building	Odour concentration OUe m^{-3}	Ammonia concentration mg m^{-3} (ppm)	Temperature at fan outlet °C
19/09/13				
09:51	1	218	11 (16)	15.1
10:15	4	307	17 (24)	17.5
10:31	8	246	19 (28)	18.6
12:27	8	347	18 (26)	19.5
12:37	4	247	16 (23)	18.3
12:54	1	218	12 (17)	17.0
26/09/13				
09:34	1	267	24 (35)	17.8
10:04	4	306	21 (31)	18.1
10:31	8	327	30 (44)	17.5
12:12	8	321	21 (31)	17.1
12:37	4	275	12 (18)	16.3
12:50	1	216	22 (32)	16.5

Table H - 8: Ammonia concentrations measured using Palmes tubes. Note that due to potential saturation of the filters these may be underestimates of actual values.

Run	Shed	Start (GMT)	End (GMT)	Duration (hours)
Glendevon				
Run 1	2	05/11/2013 12:05	07/11/2013 11:25	22.4
Run 2	3	05/11/2013 12:00	07/11/2013 11:00	22.9
Run 3	4	05/11/2013 11:55	07/11/2013 11:20	23.0
Run 4	5	05/11/2013 11:50	07/11/2013 11:05	22.4
Whitelees				
Run 1	3	11/10/2013 10:50	14/10/2013 11:02	15.2
Run 2	4	11/10/2013 11:00	14/10/2013 11:05	15.2
Run 3	5	11/10/2013 11:05	14/10/2013 11:08	15.2
Run 4	6	11/10/2013 11:12	14/10/2013 11:09	15.1

H.3.2.2. PM_{10} Concentrations and ventilation measurements

Measurements of the PM_{10} concentrations and air flows in the vents of the farm buildings are shown in Table H - 9 and Table H - 10 for Glendevon Farm and Table H - 11 for Whitelees Farm.

Table H - 9: PM_{10} concentrations and ventilation rates measured at Glendevon Farm on the 18th of September.

Date / Time (GMT)	Building	Vent	PM_{10} concentration (mg m^{-3})	Area of vent (m^2)	Speed (m/s)	Air flow (m^3/s)
11:00	3	1	0.141	0.41	1.50	0.61
11:03	3	2	0.219	0.39	0.80	0.32
11:05	3	3	0.243	0.40	4.00	1.59
11:07	3	4	0.267	0.41	3.60	1.46
11:10	3	5	0.411	0.41	3.50	1.42
11:12	3	6	0.307	0.41	2.10	0.85
11:13	3	7	0.338	0.41	3.40	1.38
11:15	3	8	0.174	0.36	5.30	1.93
11:17	3	9	0.356	0.46	0.50	0.23
11:19	3	10	0.614	0.45	2.70	1.22
11:21	3	11	0.537	0.44	2.70	1.20
11:23	3	12	0.327	0.44	4.70	2.07
11:25	3	13	0.346	0.44	4.70	2.08
11:27	3	14	0.207	0.44	2.70	1.18
11:28	3	15	0.229	0.36	4.70	1.68
11:30	3	16	0.24	0.42	2.90	1.22
13:40	5	1	0.251	0.38	5.18	1.97
13:41	5	1	0.263	0.38	5.18	1.97
13:43	5	1	0.171	0.38	5.18	1.97
14:07	3	8	0.207	0.36	5.51	2.01
14:22	2	1	0.12	0.36	3.40	1.21
14:24	2	1	0.228	0.36	3.41	1.22

Table H - 10: PM_{10} concentrations and ventilation rates measured at Glendevon Farm on the 25th of September.

Date / Time (GMT)	Building	Vent	PM_{10} concentration (mg m^{-3})	Area of vent (m^2)	Speed (m/s)	Air flow (m^3/s)
10:55	3	1	0.123	0.38	5.69	2.17
11:00	3	2	0.169	0.37	4.14	1.54
11:06	3	3	0.205	0.38	3.73	1.42
11:18	3	4	0.159	0.37	3.05	1.14
11:23	3	5	0.211	0.37	3.05	1.14
11:28	3	6	0.225	0.37	3.00	1.12
11:32	3	7	0.206	0.37	3.00	1.12
11:38	3	8	0.069	0.37	4.94	1.84
11:40	3	8	0.229	0.37	3.00	1.12
11:50	3	7	0.202	0.44	2.88	1.26
11:55	3	9	0.281	0.43	2.90	1.24
11:59	3	10	0.389	0.44	2.78	1.21
12:03	3	11	0.42	0.44	4.60	2.01
12:07	3	12	0.382	0.44	5.05	2.21
12:11	3	13	0.227	0.44	3.01	1.32
12:15	3	14	0.226	0.36	3.64	1.30
12:19	3	15	0.173	0.44	3.15	1.38
12:23	3	16	0.172	0.37	5.10	1.90
13:52	5	1	0.123	0.36	3.14	1.12
13:57	5	4	0.282	0.49	2.76	1.34
14:03	5	7	0.147	0.43	2.84	1.22
14:08	5	9	0.161	0.49	2.65	1.29
14:14	5	14	0.282	0.36	3.79	1.38
14:27	4	1	0.123	0.44	5.43	2.37
14:32	4	4	0.138	0.44	3.10	1.36
14:37	4	7	0.172	0.49	2.54	1.23
14:42	4	9	0.152	0.49	2.43	1.18
14:47	4	14	0.119	0.37	4.00	1.49
14:57	2	16	0.09	0.37	3.85	1.43
14:58	2	16	0.097	0.36	3.90	1.39
15:09	2	9	0.145	0.39	4.01	1.56
15:16	2	5	0.207	0.37	3.06	1.14
15:22	2	1	0.156	0.36	4.70	1.68
15:28	1	2	0.098	0.37	4.94	1.84

Table H - 11: PM_{10} concentrations and ventilation rates measured at Whitelees Farm.

Date / Time (GMT)	Building	Vent	PM_{10} concentration (mg m^{-3})	Area of vent (m^2)	Speed (m/s)	Air flow (m^3/s)
19/09/2013						
09:54	3	1	0.094	0.39	5.2	2.03
10:13	3	5	0.089	0.41	5.4	2.21
10:25	4	6	0.087	0.41	5.5	2.25
10:34	4	10	0.072	0.41	5.6	2.29
10:41	4	11	0.128	0.41	2.6	1.06
10:51	4	15	0.104	0.41	3.5	1.43
11:00	3	16	0.106	0.41	3.8	1.56
11:10	3	20	0.115	0.41	3.2	1.31
11:14	1	1	0.187	0.40	4.2	1.68
26/09/2013						
09:41	1	2	0.458	0.41	5.55	2.30
09:48	1	20	0.274	0.41	3.94	1.61
09:58	4	8	0.21	0.42	6.28	2.63
10:05	2	9	0.226	0.41	4.96	2.03
10:11	2	11	0.257	0.42	4.64	1.94
10:16	4	10	0.309	0.42	2.51	1.05
10:21	4	11	0.296	0.42	4.53	1.89
10:26	4	13	0.202	0.43	4.33	1.85
10:32	3	18	0.258	0.43	4.06	1.74
10:34	3	20	0.332	0.42	5.68	2.38
10:44	3	1	0.277	0.41	3.44	1.41
10:49	3	3	0.257	0.42	5.64	2.36
11:56	5	2	0.187	0.41	3.71	1.52
12:00	5	5	0.257	0.41	3.99	1.63
12:04	6	6	0.199	0.43	4.86	2.08
12:08	6	9	0.19	0.41	4.41	1.81
12:14	6	11	0.23	0.41	4.61	1.89
12:19	6	14	0.131	0.40	4.30	1.72
12:24	5	17	0.154	0.41	3.80	1.56
12:29	5	20	0.186	0.42	4.80	2.01
12:38	7	1	0.175	0.42	4.61	1.93
12:48	8	10	0.151	0.41	5.14	2.10
12:54	8	11	0.205	0.42	5.65	2.37
13:00	7	20	0.164	0.41	4.23	1.73

H.3.2.3. Emission rates from the buildings

The data on ammonia, odour and PM_{10} concentrations in the vents of the buildings at Whitelees and Glendevon farms along with the ventilation rates were used to calculate emissions from each of the buildings. Where data were not measured for a particular building then these data were interpolated as the average of the available measurements from the other buildings on the site.

Emissions data for Glendevon farm are shown in Table H - 12 and data for Whitelees farm are shown in Table H - 13. Measurements of ventilation rate from individual fans and the whole site were similar on both days but there were no records of the times when each fan was operating. Consequently for Glendevon farm the farm manager left the fans switched on continuously on the 18th and 25th of

September. Therefore the ventilation rate recorded in Table H - 12 is likely to overestimate the actual value.

Table H - 12: Summary of emissions data for Glendevon Farm.

Building	No. vents operating	Total air flow (m^3 / s)	Emissions (per year, assuming continuous operation)		
			PM_{10} (kg)	Odour (kOu)	NH_3 (kg)
18/09/2013 Glendevon					
1	14	21	1.51E+02	1.09E+08	8.31E+03
2	16	19	1.02E+02	9.16E+07	8.66E+03
3	16	21	1.98E+02	7.97E+07	7.59E+03
4	16	24	1.73E+02	1.25E+08	9.50E+03
5	16	32	2.20E+02	2.24E+08	1.20E+04
Sub total	78	117	8.45E+02	6.30E+08	4.61E+04
25/09/2013 Glendevon					
1	14	23	6.88E+01	1.95E+08	7.06E+03
2	16	22	9.49E+01	2.56E+08	6.60E+03
3	16	23	1.68E+02	1.30E+08	6.28E+03
4	16	24	1.03E+02	2.01E+08	7.24E+03
5	16	22	1.34E+02	1.75E+08	7.41E+03
Sub total	78	115	5.69E+02	9.57E+08	3.46E+04
Average	78	116	7.07E+02	7.93E+08	4.03E+04

Note: data in red were not measured for the specified building and were calculated from the average of measured data from the other buildings.

Table H - 13: Summary of emissions data for Whitelees Farm.

Building	No. vents operating	Total air flow (m^3 / s)	Emissions (per year, assuming continuous operation)		
			PM_{10} (kg)	Odour (kOu)	NH_3 (kg)
19/09/2013 Whitelees					
1	4	6.7	3.50E+01	4.62E+07	2.42E+03
2	4	7.0	2.26E+01	5.81E+07	3.39E+03
3	4	7.1	1.77E+01	5.92E+07	3.46E+03
4	4	7.0	1.68E+01	6.15E+07	3.60E+03
5	4	7.0	2.26E+01	5.81E+07	3.39E+03
6	4	7.0	2.26E+01	5.81E+07	3.39E+03
7	4	7.0	2.26E+01	5.81E+07	3.39E+03
8	4	7.0	2.02E+01	6.59E+07	4.14E+03
Sub total	32	55.9	1.80E+02	4.65E+08	2.72E+04
26/09/2013 Whitelees					
1	2	3.9	4.38E+01	2.98E+07	2.85E+03
2	4	7.9	5.79E+01	7.15E+07	5.50E+03
3	4	7.9	6.72E+01	7.09E+07	5.46E+03
4	4	7.4	5.71E+01	6.80E+07	3.96E+03
5	4	6.7	3.93E+01	6.05E+07	4.65E+03
6	4	7.5	4.18E+01	6.75E+07	5.19E+03
7	2	3.7	1.84E+01	3.29E+07	2.54E+03
8	2	4.5	2.36E+01	4.57E+07	3.65E+03

Building	No. vents operating	Total air flow (m^3 / s)	Emissions (per year, assuming continuous operation)		
			PM_{10} (kg)	Odour (kOu)	NH_3 (kg)
Sub total	26	49.5	3.49E+02	4.47E+08	3.38E+04
Average	29	52.3	2.65E+02	4.56E+08	3.05E+04

Note: data in red were not measured for the specified building and were calculated from the average of measured data from the other buildings.

H.3.3. Ambient measurements

H.3.3.1. Odour

The odour samples collected for the evaluation of the source-terms from the farm buildings were used to define the relationship between odour intensity (as defined on the 0-6 scale) and odour concentration (as determined by dynamic dilution olfactometry). The resulting calibration curves determined by fitting an exponential relationship to the data are shown in Figure H - 18 to Figure H - 21. These exponential relationships were applied to convert the odour intensities measured in the field to derive odour concentrations.

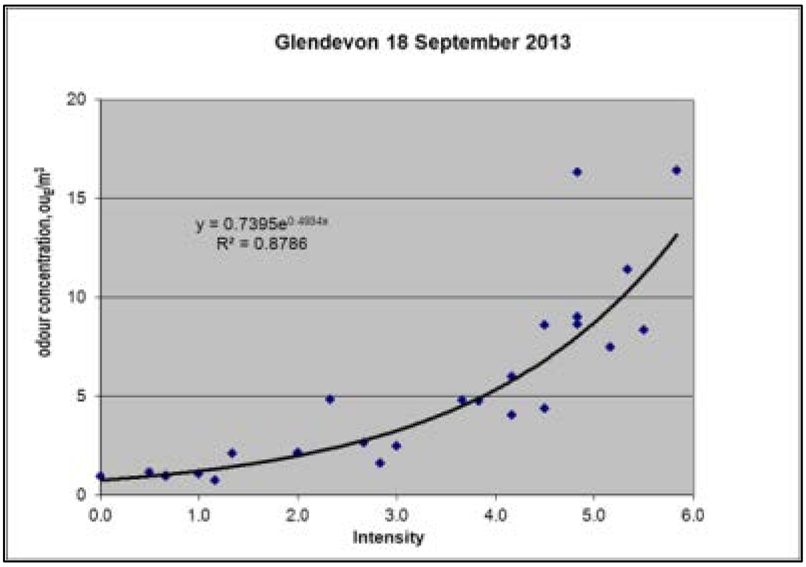


Figure H - 18: Odour concentration vs. Intensity for the Glendevon samples on 18th September.

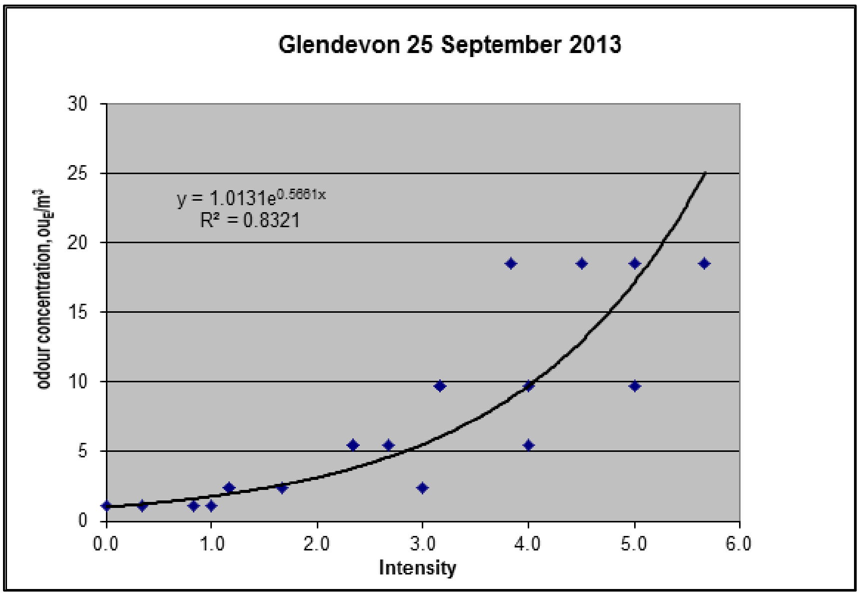


Figure H - 19: Odour concentration vs. Intensity for the Glendevon samples on 25th September.

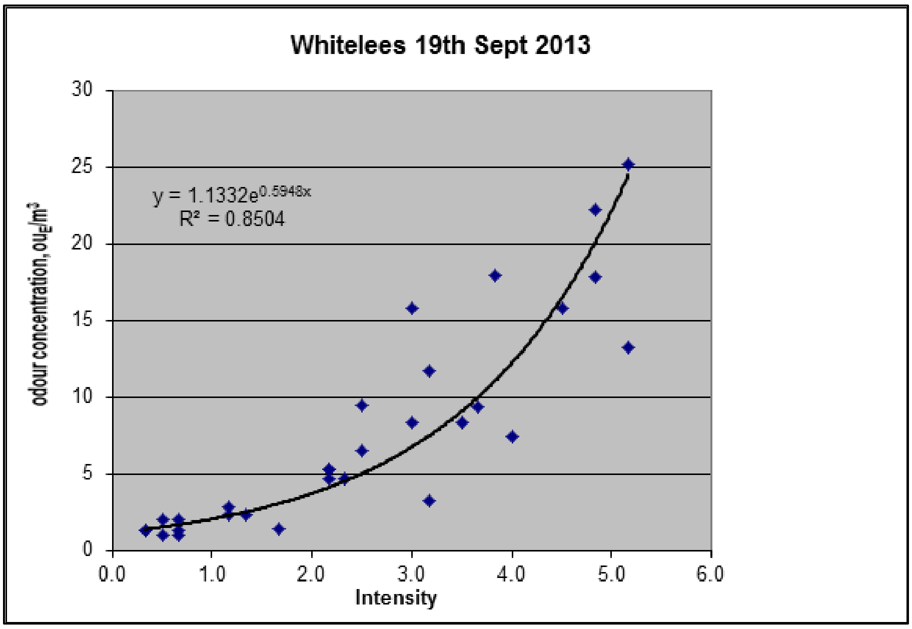


Figure H - 20: Odour concentration vs. Intensity for the Whitelees samples on 19th September.

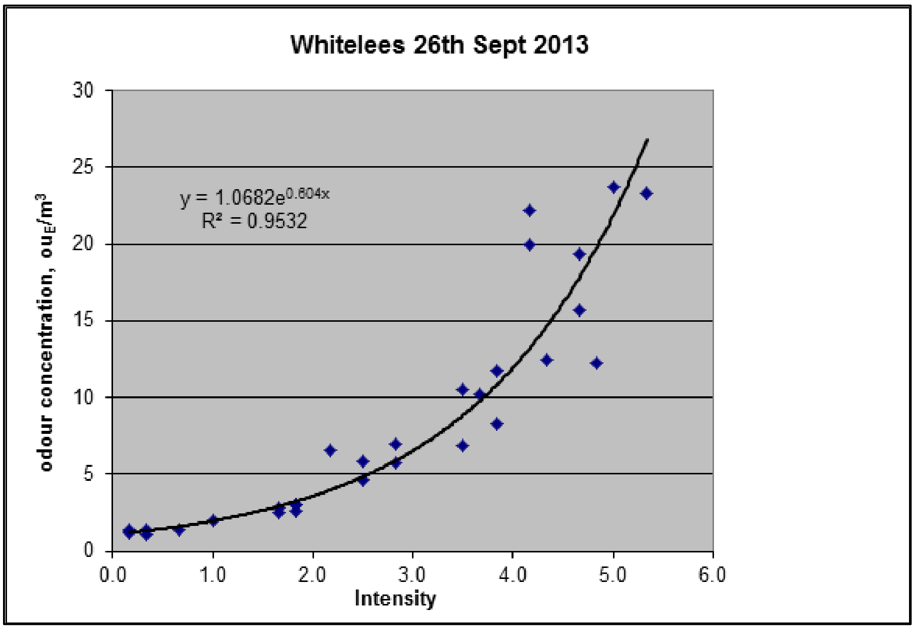


Figure H - 21: Odour concentration vs. Intensity for the Whitelees samples on 26th September.

A summary of the data collected by the field odour assessors is shown in Table H - 14 to Table H - 17. The "Average Conc." values shown are averaged over the time periods that an odour was experienced. In order to compare these data with the time-averaged predictions from SCAIL-Agriculture the "Average Conc." data were multiplied by the "Frequency of time" to convert the data to time-averaged values.

Table H - 14: Summary of odour observations at Glendevon farm on 18th September with intensity converted to odour concentration.

Transect (distance)	Time (GMT)	X-wind distance (m)	Frequency (% of time)	Mean Intensity	Average Conc. (OUe/m³)
1-D (20 m)	14:57	0	50	1.5	1.55
	14:57	10	53	2.13	2.12
	14:57	20	100	1	1.21
	15:11	30	80	2	1.98
	15:11	40	47	2.25	2.24
	15:11	50	43	1	1.21
	15:25	60	68	2.39	2.40
	15:25	70	38	2.13	2.12
	15:25	80	80	1.17	1.32
1-A (50 m)	11:24	0	48	1.31	1.41
	11:24	10	58	1.94	1.93
	11:24	20	7	1.5	1.55
	11:38	30	53	1.63	1.65
	11:38	40	45	1.74	1.74
	11:38	50	53	1.38	1.46
	11:52	60	67	1.8	1.80
	11:52	70	40	2.29	2.29
	11:52	80	10	1	1.21
	12:06	90	42	1.6	1.63
	12:06	100	17	1.6	1.63
	12:06	110	0	0	0.74
1-B (100 m)	12:21	110	17	1	1.21
	12:21	100	7	1	1.21
	12:21	90	5	1	1.21
	12:34	80	0	0	0.74
	12:34	70	25	1.67	1.69
	12:34	60	42	1.24	1.36
	13:28	50	72	1	1.21
	13:28	40	20	1.75	1.75
	13:28	30	48	1.41	1.48
	13:41	20	22	1.62	1.64
	13:41	10	23	2	1.98
	13:41	0	27	1.75	1.75
1-C (150 m)	13:58	0	15	1.11	1.28
	13:58	10	3	1	1.21
	13:58	20	2	1	1.21
	14:11	30	5	1	1.21
	14:11	40	12	1	1.21
	14:11	50	18	1	1.21
	14:24	60	2	1	1.21
	14:24	70	8	1.2	1.34
	14:24	80	0	0	0.74
	14:36	90	0	0	0.74
	14:36	100	15	1.56	1.60
	14:36	110	12	1.43	1.50

Table H - 15: Summary of odour observations at Whitelees farm on 19th September with intensity converted to odour concentration.

Transect (distance)	Time (GMT)	X-wind distance (m)	Frequency (% of time)	Mean Intensity	Average Conc. (OUe/m³)
1-A (20 m)	09:10	0	23	1.57	2.88
	09:10	10	33	1.45	2.68
	09:10	20	40	2.5	5.01
	09:22	30	87	1.44	2.67
	09:22	40	100	1.27	2.41
	09:22	50	95	2.47	4.92
	09:35	60	95	2.35	4.59
	09:35	70	70	1.67	3.06
	09:35	80	80	2.21	4.22
	09:49	90	67	2.15	4.07
	09:49	100	88	1.58	2.90
	09:49	110	67	1.83	3.37
1-B (50 m)	10:06	0	57	2.03	3.79
	10:06	10	93	1.39	2.59
	10:06	20	65	2.03	3.79
	10:18	30	18	1.64	3.01
	10:18	40	15	1	2.05
	10:18	50	15	1.33	2.50
	10:34	60	13	2.5	5.01
	10:34	70	22	2	3.72
	10:34	80	18	1.36	2.54
1-C (100 m)	10:48	0	7	1	2.05
	10:48	10	2	1	2.05
	10:48	20	3	2	3.72
	11:03	30	0	0	1.13
	11:03	40	0	0	1.13
	11:03	50	0	0	1.13
1-D (50 m)	12:24	0	15	1.44	2.67
	12:24	10	45	1.15	2.25
	12:24	20	48	1.48	2.73
	12:37	30	52	1.87	3.45
	12:37	40	100	1.28	2.43
	12:37	50	50	1.77	3.25
	12:50	60	27	1.63	2.99
	12:50	70	22	1	2.05
	12:50	80	27	1.56	2.87

Table H - 16: Summary of odour observations at Glendevon Farm on 25th September with intensity converted to odour concentration.

Transect (distance)	Time (GMT)	X-wind distance (m)	Frequency (% of time)	Mean Intensity	Average Conc. (OUe/m³)
2-A (50 m)	12:24	0	28	1.65	2.58
	12:24	10	15	1.44	2.29
	12:24	20	10	1.5	2.37
	12:37	30	43	1.92	3.00
	12:37	40	55	1.73	2.70
	12:37	50	53	2.03	3.20
	12:50	60	73	2.34	3.81
	12:50	70	55	2.61	4.44
	12:50	80	42	2.16	3.44
	13:04	90	73	2.34	3.81
	13:04	100	58	2.49	4.15
	13:04	110	42	2.16	3.44
	13:18	120	60	2.31	3.75
	13:18	130	50	2.2	3.52
	13:18	140	12	1.86	2.90
	13:32	150	47	1.79	2.79
	13:32	160	40	1.71	2.67
	13:32	170	17	1.8	2.81
2-B (100 m)	13:49	170	32	1.74	2.71
	13:49	160	23	1.79	2.79
	13:49	150	17	1.8	2.81
	14:02	140	52	1.84	2.87
	14:02	130	30	1.72	2.68
	14:02	120	20	1.67	2.61
	14:14	110	30	1.33	2.15
	14:14	100	33	1.8	2.81
	14:14	90	3	1.5	2.37
	14:27	80	13	1.5	2.37
	14:27	70	2	1	1.78
	14:27	60	5	1	1.78
	14:40	50	0	0	1.01
	14:40	40	7	1.25	2.06
	14:40	30	0	0	1.01
2-C (150 m)	14:59	170	23	1.21	2.01
	14:59	160	33	1.55	2.44
	14:59	150	25	1.47	2.33
	15:13	140	20	1.33	2.15
	15:13	130	15	1.78	2.78
	15:13	120	10	1.33	2.15
	15:26	110	17	1.3	2.11
	15:26	100	7	1.75	2.73
	15:26	90	7	1	1.78
	15:40	80	5	1.33	2.15
	15:40	70	3	1.5	2.37
	15:40	60	0	0	1.01

Table H - 17: Summary of odour observations at Whitelees farm on 26th September with intensity converted to odour concentration.

Transect (distance)	Time (GMT)	X-wind distance (m)	Frequency (% of time)	Mean Intensity	Average Conc. (OUe/m³)
2-A (50 m)	08:51	0	3	1	1.95
	08:51	10	5	1	1.95
	08:51	20	5	1	1.95
	09:03	30	10	1.17	2.17
	09:03	40	10	1.33	2.39
	09:03	50	15	1.44	2.55
	09:15	60	22	1.38	2.46
	09:15	70	18	1.73	3.04
	09:15	80	23	2	3.58
	09:27	90	52	2.26	4.18
	09:27	100	58	2.54	4.95
	09:27	110	63	2.16	3.94
	09:40	120	45	2.41	4.58
	09:40	130	55	2.42	4.61
	09:40	140	50	2.1	3.80
	09:52	150	47	2.25	4.16
	09:52	160	62	2.49	4.81
	09:52	170	22	1.31	2.36
	10:06	180	33	1.45	2.56
	10:06	190	30	2.33	4.36
	10:06	200	10	1.33	2.39
	10:18	210	17	1.2	2.21
	10:18	220	13	2.13	3.87
	10:18	230	0	0	1.07
2-B (100 m)	10:32	230	13	1.25	2.27
	10:32	220	18	2.36	4.44
	10:32	210	15	1.56	2.74
	10:43	200	38	1.57	2.76
	10:43	190	32	1.79	3.15
	10:43	180	20	1.5	2.64
	10:56	170	33	2	3.58
	10:56	160	15	2.89	6.12
	10:56	150	17	1.7	2.98
	11:08	140	2	1	1.95
	11:08	130	3	1	1.95
	11:08	120	0	1.33	2.39
2-E (20 m)	13:18	0	0	0	1.07
	13:18	10	0	0	1.07
	13:18	20	3	2.5	4.84
2-C (50 m)	12:12	0	57	1.79	3.15
	12:12	10	40	2.46	4.72
	12:12	20	50	1.87	3.31
	12:24	30	48	2.07	3.73

Transect (distance)	Time (GMT)	X-wind distance (m)	Frequency (% of time)	Mean Intensity	Average Conc. (OUe/m³)
	12:24	40	35	2.33	4.36
	12:24	50	20	1.75	3.07
2-D (100 m)	12:39	70	8	1.6	2.81
	12:39	60	5	2	3.58
	12:39	50	3	1.5	2.64
	12:51	40	10	1.17	2.17
	12:51	30	7	1.25	2.27
	12:51	20	0	0	1.07
	13:04	10	7	1	1.95
	13:04	0	7	1	1.95
	13:04	-10	0	0	1.07

H.3.3.2. Ammonia

Ambient ammonia concentrations were measured at both farms using ALPHA samplers (deployed in triplicate). In addition, a DELTA denuder and a continuous AiRRmonia sampler were deployed at Whitelees farm (see Figure H - 3).

Measurements collected using ALPHA samplers are detailed in Table H - 18 and Table H - 19 for Whitelees and Glendevon farms respectively. An intercomparison of the ALPHA, DELTA and AiRRmonia samplers is shown in Table H - 20, illustrating that (discounting periods of instrument outage) the agreement between all three methods was very good. In addition, coefficients of variation for the triplicate ALPHA samplers (data not presented) were typically less than 5% illustrating that this method has suitable precision and accuracy to provide robust data for model validation.

Polar plots were produced using the OpenAir package (Carslew, 2012; Carslaw and Ropkins, 2012) from the AiRRmonia data for each of the 4 time periods that Alpha samplers were exposed over. These are shown in Figure H - 22 and illustrate the strong NH_3 signal from Whitelees farm, with little evidence of interference from other farm buildings or from the local grazing livestock. It is interesting to note that once emptied of livestock (Run 4 of Figure H - 22) the farm buildings no longer present a source of ammonia.

Table H - 18: ALPHA sampler NH_3 measurements at Whitelees Farm.

Site	OS X (m)	OS Y (m)	Dist. (m)	Concentration ($\mu g\ m^{-3}$)			
				Run 1	Run 2	Run 3	Run 4
White1	291345	646530	114	66.5	44.9	57.0	4.1
White2	291468	646458	150	50.2	31.1	26.1	1.2
White3	291521	646628	289	13.2	9.1	9.6	0.8
White4	291629	646994	652	3.9	2.9	4.2	0.8
White5	291405	646303	141	13.0	16.3	16.0	0.6
White6	291294	646177	243	4.0	4.8	5.6	0.4
White7	291032	646427	291	3.4	8.9	3.3	0.7
White8	291205	646812	411	11.4	6.8	5.5	1.4
White9	291446	646829	429	6.7	5.4	6.2	1.2

Table H - 19: ALPHA sampler NH_3 measurements at Glendevon Farm.

Site	OS X (m)	OS Y (m)	Dist. (m)	Concentration (µg m^{-3})			
				Run 1	Run 2	Run 3	Run 4
Glen 1	307287	685511	75	101.7	69.7	44.9	60.3
Glen 2	307347	685564	151	33.9	22.3	15.3	21.8
Glen 3	307431	685621	249	18.0	13.7	10.5	11.9
Glen 4	307491	685660	319	12.2	10.3	8.6	7.7
Glen 5	307495	685525	251	34.8	44.8	30.6	22.6
Glen 6	307365	685423	108	221.9	247.7	125.0	87.6
Glen 7	307079	685365	195	13.9	13.8	39.9	41.9
Glen 8	306934	685549	342	4.4	7.6	6.4	3.7
Glen 9	307223	685727	288	3.8	21.5	1.7	2.1

Table H - 20: Intercomparison of ammonia samplers at Whitelees Farm.

Start (GMT)	End (GMT)	DELTA (µg m^{-3})	ALPHA (µg m^{-3})	AiRRmonia (µg m^{-3})
29/08/2013 11:59	17/09/2013 10:40	39.7	44.4	81.7$^{£}$
17/09/2013 10:42	02/10/2013 11:00	51.7	51.2	56.5
02/10/2013 11:00	14/10/2013 12:04	101*	61.6	56.7
21/10/2013 13:31	04/11/2013 11:02	3.94	4.2	2.3$^{\$}$

*Notes: *: DELTA sampler pump failures occurred for approximately 50% of the time; £: 12% data capture, $: 78% data capture.*

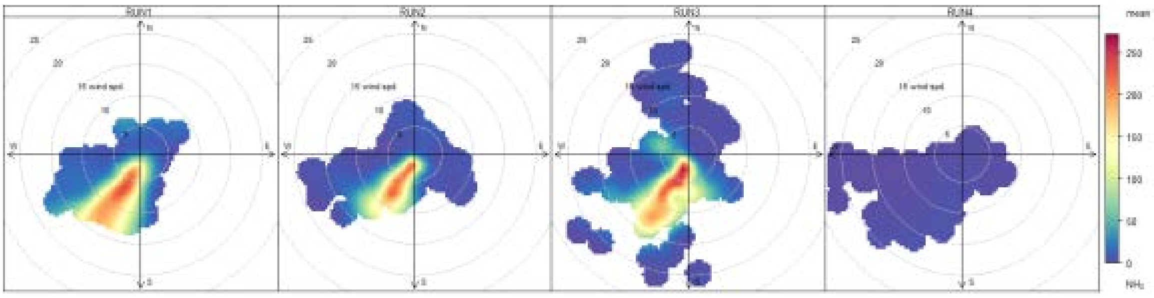


Figure H - 22: Polar Plots of ammonia concentration by wind direction and wind speed for the 4 sample runs at Whitelees Farm produced using the OpenAir package.

H.3.3.3. PM_{10}

PM_{10} concentrations were recorded at Whitelees farm (site "White1") using an OSIRIS monitor between the 6th of August and the 4th of November 2013 at a time resolution of 15 minutes. The 15-minute data were integrated to a resolution of 1 hour and 24 hours for use in the validation exercise. Data capture during the first 8 days of the deployment was poor due to power outages although there were no further issues following this initial period. As a comparison with the AiRRmonia data shown in Figure H - 22, PM_{10} data are shown in Figure H - 23 for the 4 ALPHA sampler runs at Whitelees farm. The results illustrate the PM_{10} concentrations do not show the same strong signal from the farm buildings found for the ammonia data, and clearly some other significant sources are present. In addition, it is clear that Run 4 of Figure H - 23 demonstrates a signal from the location of the farm (south-west) when the buildings are empty and ventilation systems switched off. This suggests that re-suspended dust may be a significant factor in ambient PM_{10} exposure around poultry buildings.

An intercomparison was conducted between the OSIRIS and the DUSTTRAK (used for measuring the concentration of PM_{10} in the building vents). The results of this intercomparison are shown in Table H - 21 and illustrate that a relatively poor comparison was found on the 19th of September and a good comparison was achieved on the 26th of September. It is likely that the reason for the poor performance on the 19th was due to interference from water droplets as the DUSTTRAK did not have a heated air inlet. Such interference would not have affected the source term measurements made using the DUSTTRACK within the building ducts.

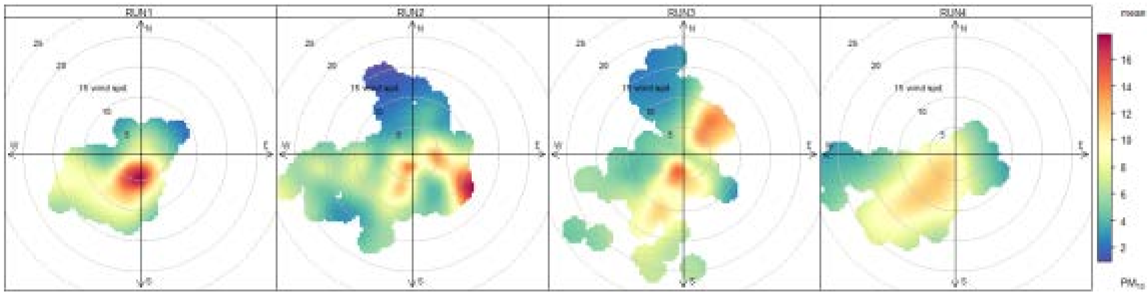


Figure H - 23: Polar Plots of PM_{10} concentration by wind direction and wind speed for the 4 sample runs at Whitelees Farm produced using the OpenAir package.

Table H - 21: Intercomparison of OSIRIS and DUSTTRAK samplers at Whitelees Farm.

Start (GMT)	End (GMT)	OSIRIS (µg m^{-3})	DUSTTRAK (µg m^{-3})	Weather
19/09/2013 12:30	19/09/2013 12:45	6.0	10.9	Drizzle
19/09/2013 12:45	19/09/2013 13:00	2.5	9.2	Drizzle
26/09/2013 12:00	26/09/2013 12:15	6.7	7.1	Dry
26/09/2013 12:15	26/09/2013 12:30	8.1	9.1	Dry

H.4. Validation Results

The monitoring data described in the previous section was used to validate the SCAIL-Agriculture Tool applying the techniques as detailed in the main report.

H.4.1. Model setups

H.4.1.1. SCAIL

The SCAIL Agriculture tool was configured for each of the farm sites by selecting the Installation location as the centre-point of the farm building complex. The buildings on each farm were configured using the parameters shown in Table H - 22 and locating each building using the "Verify Location" button on the SCAIL-Agriculture interface. The livestock type for both farms was set to "Layers" with further details of "ventilated deep pit". As "side of building" was selected for the fan location no further details on the ventilation system were required.

Table H - 22: Parameters used to configure each source in SCAIL-Agriculture for Whitelees and Glendevon farms.

Site	N. sources	Building Height	Fan Location	Livestock number	Housing floor area
Whitelees	8	4 m	Side of building	4500	539 m^2
Glendevon	5	4 m	Side of building	8954	1436 m^2 (except B1 = 1851 m^2)

H.4.1.2. AERMOD

AERMOD was configured similarly to SCAIL although with accurate information on the location and orientation of each building as well as individual locations for the ventilation fans. The same emission parameters were used in AERMOD as were applied in SCAIL and the buildings configured in AERMOD were also set to a height of 4 m.

H.4.2. Comparison of emissions data

Table H - 23 presents the comparison of emission data between SCAIL Agriculture and the field measurements. Emission rates of PM_{10} and odour that calculated by SCAIL-Agriculture were higher than those that were measured, though the calculated ammonia emission rate was lower than was measured.

It is useful to compare the ventilation rates of the buildings with typical values from the literature (detailed in Table 2-D of the SCAIL Agriculture Final report from *Seedorf et al., 1998).* The measured ventilation rates from Whitelees farm were 53 m^3/s and these compare with a literature value of 42 m^3/s whilst for Glendevon Farm the measured ventilation rate of 116 m^3/s compares with a literature value of 63 m^3/s. For Glendevon Farm the building ventilation was set to continuous operation during the period of the measurements to provide consistency in the results and therefore it is possible that the ventilation rate applied in the emissions calculations may be an overestimate of typical values. Nevertheless, the reasonable agreement between the ventilation rate estimates and literature values adds a level of confidence that the measured data are realistic.

Table H - 23: Comparison of measured emission rates with the predictions of SCAIL-Agriculture.

Site	Whitelees			Glendevon		
	PM_{10} (Kg)	Odour (KOu)	Ammonia (Kg)	PM_{10} (Kg)	Odour (KOu)	Ammonia (Kg)
SCAIL-Agriculture	7.20E+02	1.59E+09	7.20E+03	8.95E+02	1.98E+09	8.95E+03
Measured	2.65E+02	4.56E+08	3.05E+04	7.07E+02	7.93E+08	4.03E+04
measured: SCAIL	0.37	0.29	4.24	0.79	0.40	4.50

H.4.3. Comparison of ammonia data

SCAIL agriculture was run for the following scenarios for comparison with the measured long-term Alpha sampler data:

- *Default (Edinburgh) meteorological data (Realistic Mode)*
  - *SCAIL-Agriculture calculated emissions (Scenario ER1)*
  - *Measured emission data (Scenario ER2)*
- *Default (Edinburgh) meteorological data (Conservative Mode)*
  - *SCAIL-Agriculture calculated emissions (Scenario EC1)*
- *On site meteorological data (Realistic mode)*
  - *SCAIL-Agriculture calculated emissions (OR1)*
  - *Measured emission data (OR2)*

In addition the results were compared with an AERMOD simulation using Edinburgh meteorological data and the calculated emissions data (Scenario AER1).

It should be noted that the average measured data for Whitelees farm only included Runs 1 – 3 as the farm was empty for Run 4 and therefore a comparison with SCAIL-Agriculture would not be helpful.

The results of the comparison are shown in Table H - 24 and Figure H - 24. Key points from this comparison are as follows

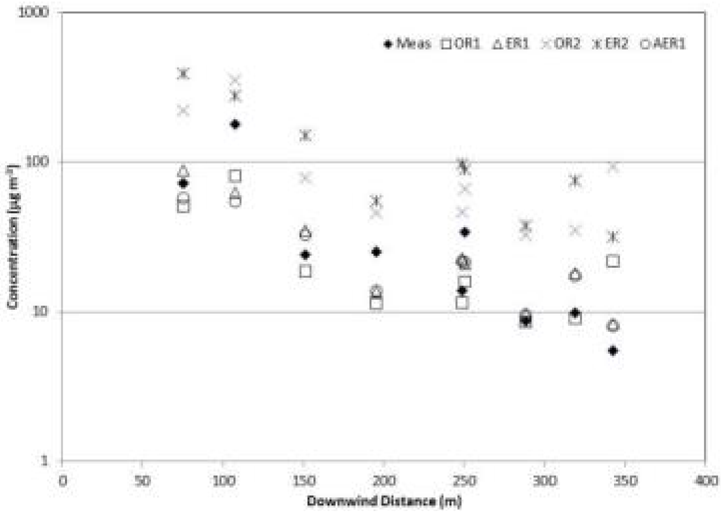
- *A very good agreement was found between SCAIL-Agriculture (ER1) and AERMOD (AER1) for both sites.*
- *The use of the Edinburgh meteorological data (ER1, ER2) resulted in higher predictions than the on-site data (OR1, OR2) for both sites. The use of Edinburgh meteorological data with measured emissions (ER2) resulted in concentrations that were significantly higher than the measured data at both sites.*
- *For Whitelees Farm, the use of onsite meteorological data and the default SCAIL emissions (OR1) provided concentrations that were significantly lower than the measured data.*
- *A good agreement was found between the OR2 scenarios and measured data for Whitelees farm, although for Glendevon farm this scenario over-predicted concentrations. This may be due to the aforementioned overestimation of building ventilation rates.*
- *Overall the default SCAIL-Agriculture configuration (ER1) provided the best agreement with the measured data meeting all the Chang and Hanna (2004) model acceptability criteria. This seems to be due to the cancelling effect of the higher concentrations predicted by the use of the Edinburgh meteorological data and the lower estimation of emissions for this scenario. A scatter plot showing the comparison between the ER1 data and SCAIL Agriculture is shown in* Figure H - *25.*

Table H - 24: Comparison of measured ammonia concentrations with the predictions of SCAIL-Agriculture and AERMOD.

Site	Distance (m)	Ammonia concentration (µg m-3)						
		Measured	ER1	EC1	ER2	OR1	OR2	AER1
White1	114	55.2	35.8	48.7	144.9	15.9	60.5	32.5
White2	150	37.2	30.8	33.9	123.8	9.7	34.4	26.9
White3	289	10.7	19.2	16.5	74.8	5.6	16.9	17.1
White4	652	3.5	8.0	7.5	27.2	2.9	5.7	7.8
White5	141	15.0	12.8	36.7	47.6	4.2	11.3	11.2
White6	243	4.7	8.6	19.9	29.9	4.3	11.4	7.7
White7	291	5.8	9.7	16.4	34.4	5.1	15.0	8.6
White8	411	8.3	6.2	11.7	19.4	2.9	5.4	5.5
White9	429	6.0	9.9	11.3	35.1	3.8	9.2	8.9
Glen1	75	72.4	88.1	121.4	390.3	50.8	222.7	57.7
Glen2	151	24.3	34.9	37.6	151.2	18.7	78.2	32.7
Glen3	249	13.9	23.0	21.4	97.4	11.6	46.2	21.9
Glen4	319	9.9	18.1	16.2	75.7	9.1	35.1	17.4
Glen5	251	34.1	21.1	21.2	88.8	16.1	66.4	21.6
Glen6	108	180.1	62.8	56.0	276.6	80.5	356.1	54.3
Glen7	195	25.1	13.7	28.1	55.5	11.5	45.6	14.0
Glen8	342	5.5	8.3	15.0	31.5	22.0	92.8	8.1
Glen9	288	8.7	9.7	18.2	37.6	8.6	32.8	9.6
Summary Statistics (shaded values illustrate meeting the Chang and Hanna, 2004 criteria)								
FB			0.16	-0.05	-1.10	0.54	-0.80	0.34
MG			0.89	0.66	0.23	1.58	0.48	0.98
NMSE			1.32	1.37	3.61	1.77	2.16	1.80
VG			1.31	1.68	11.00	1.82	2.92	1.31
FAC2			0.89	0.56	0.06	0.56	0.50	0.83

A further comparison was made between the continuous ammonia data recorded with the AiRRmonia and SCAIL-Agriculture. In order to remove some of the inherent variability associated with the prediction of short-term air concentrations the measured and modelled data were analysed to provide daily-averaged values. Overall 50 days of data were available for this comparison. SCAIL-Agriculture was run using the measured emission data from the site and the on-site meteorological data (scenario OR2). A scatterplot of this comparison is shown in Figure H - 26 and the summary statistics are shown in Table H - 25. These results show that SCAIL-Agriculture met all five of the performance criteria from Chang and Hanna (2004).

Glendevon



Whitelees

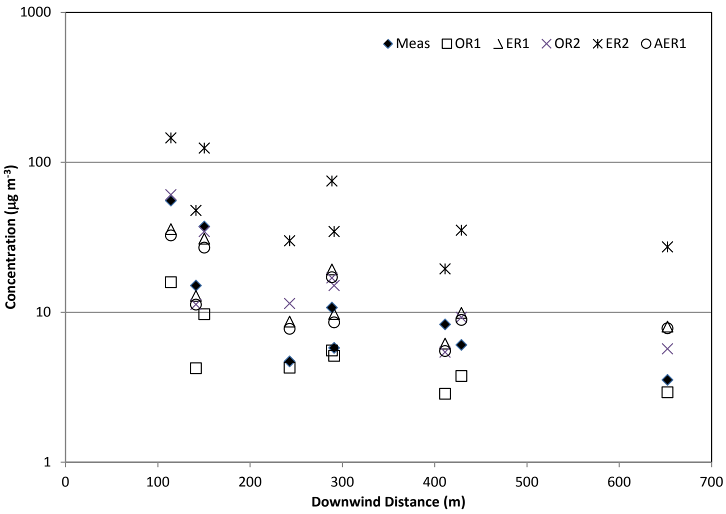


Figure H - 24: Plots of ammonia concentration VS. downwind distance for Glendevon and Whitelees farms.

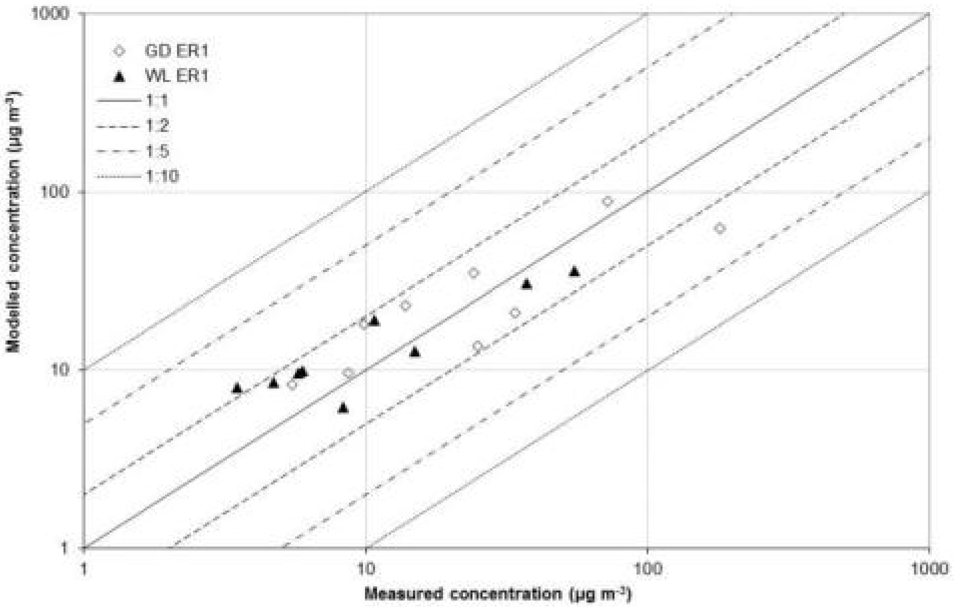


Figure H - 25: Scatter plot of measured and modelled ammonia concentrations for the default configuration of SCAIL-Agriculture for Glendevon and Whitelees farms.

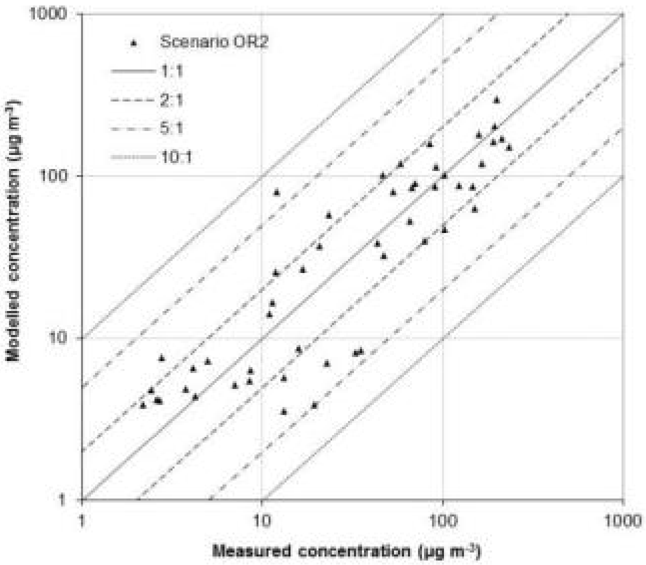


Figure H - 26: Summary of the performance indicator values for the different model runs and source parameterisations for the Whitelees 24 hour ammonia concentration dataset. Shaded cells represent values that meet the acceptability criteria.

Table H - 25: Summary of the performance indicator values for the different model runs and source parameterisations for the Whitelees 24 hour ammonia concentration dataset. Shaded cells represent values that meet the acceptability criteria.

Run / Parameterisation No.	FB	MG	NMSE	VG	FAC2
OR2 (SCAIL-Agriculture on-site meteorological data and measured emissions)	0.013	1.019	0.330	1.622	72%

H.4.4. Comparison of PM_{10} data

As noted in the previous section, the PM_{10} data measured at Whitelees farm did not clearly identify the farm buildings as the dominant emission source. The data in fact illustrates that other sources dominate the PM_{10} concentration field and also provides evidence that resuspension of surface dusts also may be significant. Re-suspension emissions are not included in SCAIL-Agriculture.

In order to account for some of the background issues the measured PM_{10} data were filtered as follows:

- When wind directions are > 245 degrees and less than 155 degrees then the recorded concentrations are assumed to be unrelated to the farm and therefore "background values".
- Background values for concentrations recorded when wind directions are between 155 degrees and 245 degrees are taken from the last recorded concentration outside of this wind sector.

Figure H - 27 shows a PolarPlot of PM_{10} concentration vs wind speed and direction for the entire monitoring period. It illustrates the multitude of potential sources of PM_{10} in the environs of Whitelees farm and the position of the 90-degree wind sector referred to above for filtering the PM_{10} data.

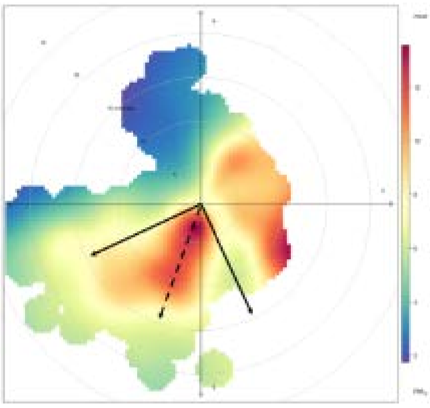


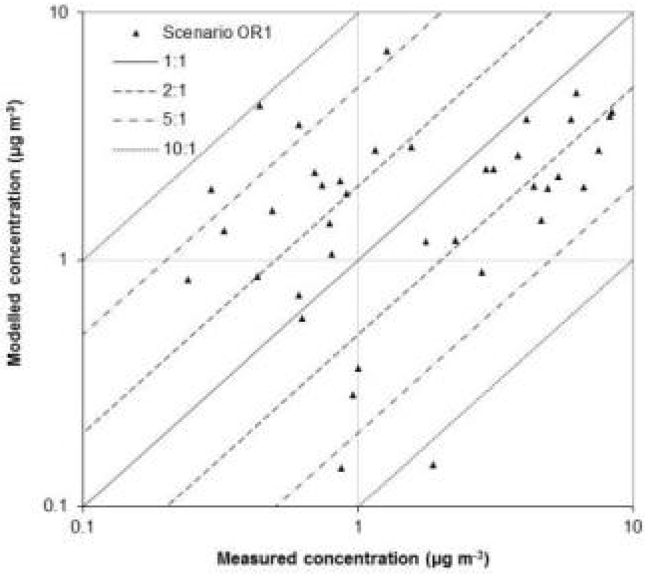
Figure H - 27: PolarPlot of PM_{10} concentrations Vs wind speed and direction for Whitelees farms. A 90-degree wind sector is shown for use in filtering the background PM10 data.

A statistical summary of these data is shown in Table H - 26. These data illustrate that the default SCAIL-Agriculture configuration (Scenario OR1) met 3 of the 5 model acceptability criteria of Chang and Hanna (2004). A significantly poorer performance was obtained when the measured emission data were used (Scenario OR2) and in this case none of the acceptability criteria were met. As a note of caution however it is possible that re-suspension of dust may also have contributed to the measured dataset.

Table H - 26: Summary of the performance indicator values for the different model runs and source parameterisations for the Whitelees 24 hour PM_{10} concentration dataset. Shaded cells represent values that meet the acceptability criteria.

Run / Parameterisation No.	FB	MG	NMSE	VG	FAC2
OR1 (SCAIL-Agriculture on-site meteorological data and default emissions)	0.201	1.087	1.154	5.372	0.319
OR2 (SCAIL-Agriculture on-site meteorological data and measured emissions)	1.072	2.938	4.837	17.047	0.277

Scatterplots showing the comparison between SCAIL-Agriculture and the monitored PM_{10} data are shown in Figure H - 28 for Scenarios OR1 and OR2.



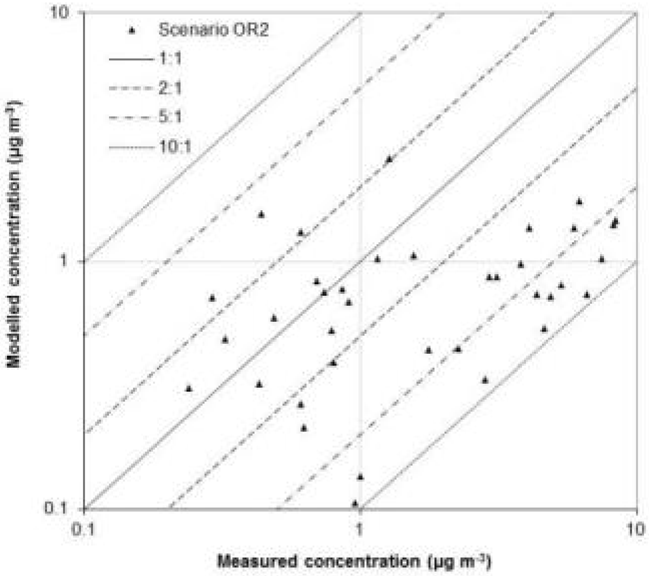


Figure H - 28: Scatter plot of measured and modelled daily averaged PM_{10} concentrations for the OR1 and OR2 configuration of SCAIL-Agriculture for Whitelees farm.

H.4.5. Comparison of Odour data

The meteorological data recorded during the field odour sampling is shown in Table H - 27 and Table H - 28 for Glendevon and Whitelees farms respectively. Odour concentrations were modelled using SCAIL-Agriculture applying the on-site meteorological data and calculated emissions (OR1) and measured emissions (OR2) scenarios. Scatterplots of the point-by-point comparison of measured and modelled odour concentrations for these scenarios are shown in Figure H - 29 and Figure H - 30 for Glendevon and Whitelees Farms respectively. These results show a considerable degree of scatter, which is to be expected for a point-to-point comparison of short term concentrations. The modelled estimates of odour concentrations are also clearly improved through the use of the measured emission data. A statistical comparison of the measured and modelled odour dataset is shown in Table H - 29 illustrating the improved statistics obtained by the use of the measured odour emission data.

The Chang and Hanna (2004) model acceptability criteria were only met for determination of Geometric Mean Bias (MG) for the OR2 scenario.

Table H - 27: Meteorological data for the odour sampling at Glendevon Farm.

Date / Time GMT	Wind speed (m/s)	Wind Direction (degrees)	Relative humidity (%)	Temp. (^oC)	Rainfall (mm)	Solar Radiation (W m^{-2})	Cloud Cover (oktas)
18/09 12:00	7.1	284.2	71.0	12.8	0.0	465.4	5
18/09 13:00	8.1	285.0	69.4	13.1	0.3	504.8	3
18/09 14:00	10.3	290.5	63.3	13.3	0.0	472.4	0
18/09 15:00	9.4	290.6	63.4	13.5	0.0	387.2	0
18/09 16:00	10.9	294.3	63.6	13.1	0.0	226.3	5
25/09 13:00	3.3	102.0	100.0	11.8	0.0	89.1	8
25/09 14:00	3.2	95.2	100.0	11.7	0.0	51.4	8
25/09 15:00	2.8	94.9	100.0	11.8	0.0	60.5	8
25/09 16:00	3.2	98.6	98.2	12.3	0.0	85.0	8

Table H - 28: Meteorological data for the odour sampling at Whitelees Farm.

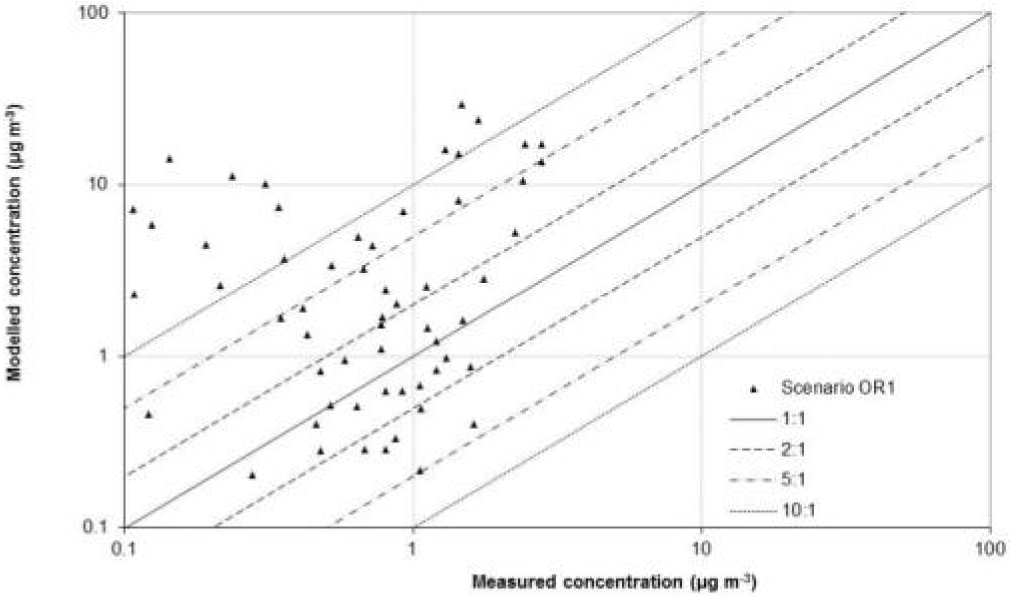
Date / Time GMT	Wind speed (m/s)	Wind Direction (degrees)	Relative humidity (%)	Temp. (^oC)	Rainfall (mm)	Solar Radiation (W m^{-2})	Cloud Cover (oktas)
19/09 10:00	2.6	117.6	92.5	7.7	0.0	96.3	8
19/09 11:00	2.6	93.2	93.4	8.2	0.0	93.2	8
19/09 12:00	4.3	212.4	92.8	10.1	0.2	132.4	8
19/09 13:00	9.6	248.5	90.9	11.2	0.2	136.8	8
26/09 09:00	2.6	88.3	84.2	9.0	0.0	265.4	5
26/09 10:00	3.0	105.3	77.7	10.5	0.0	404.6	3
26/09 11:00	3.4	117.2	68.9	11.9	0.0	445.3	4
26/09 12:00	1.8	124.7	68.4	11.9	0.0	448.7	4
26/09 13:00	1.1	110.9	66.5	12.2	0.0	250.1	7
26/09 14:00	1.1	199.0	65.1	12.9	0.0	174.9	7

Table H - 29: Summary of the performance indicator values for the different model runs and source parameterisations for the Odour concentration dataset. Shaded cells represent values that meet the acceptability criteria.

Run / Parameterisation No.	FB	MG	NMSE	VG	FAC2
Glendevon OR1	-1.429	0.431	16.231	438.542	0.256
Glendevon OR2	-0.824	1.077	5.337	217.156	0.233
Whitelees OR1	-1.418	0.214	12.168	241.575	0.233
Whitelees OR2	-0.521	0.738	1.868	24.595	0.289

It should be noted that the Chang and Hanna (2004) criteria were developed for the comparison of chemical species that can be precisely measured in the atmosphere and for arc-wise maximum concentrations determined over a long averaging period.

Figure H - 31 shows the direct comparison of measured and modelled odour concentrations at two of the transects. These figures illustrate that there is a reasonable agreement between measured and modelled odour concentrations although the measured dataset clearly demonstrates higher variability than the modelled dataset. This is expected and is due to the use of hourly-averaged meteorological data in the model and the inherent variability of atmospheric processes along with, of course, the variability associated with any quantitative measurement determined from the human nose.



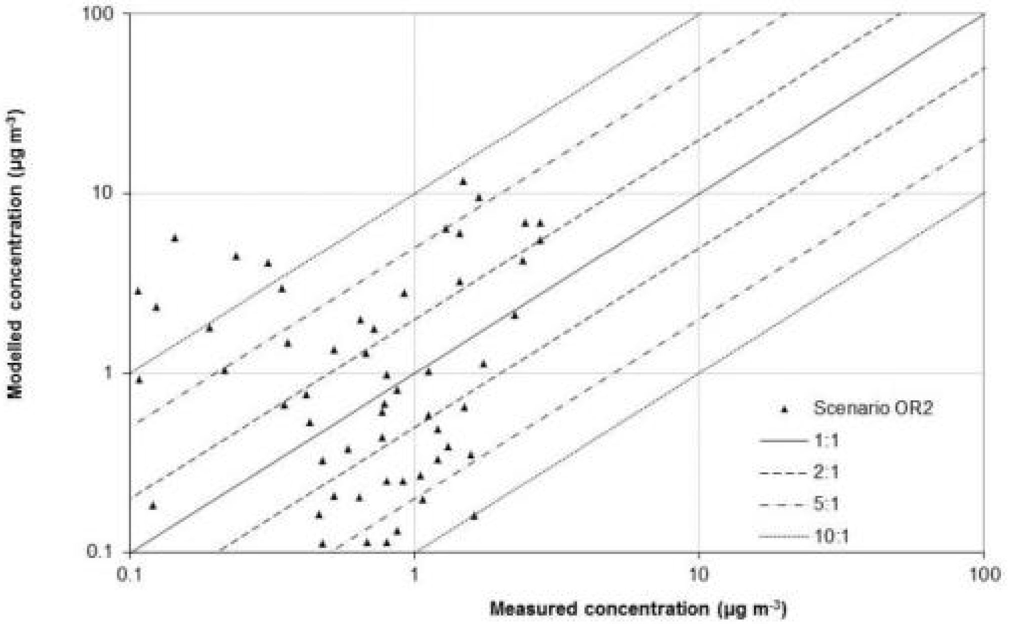
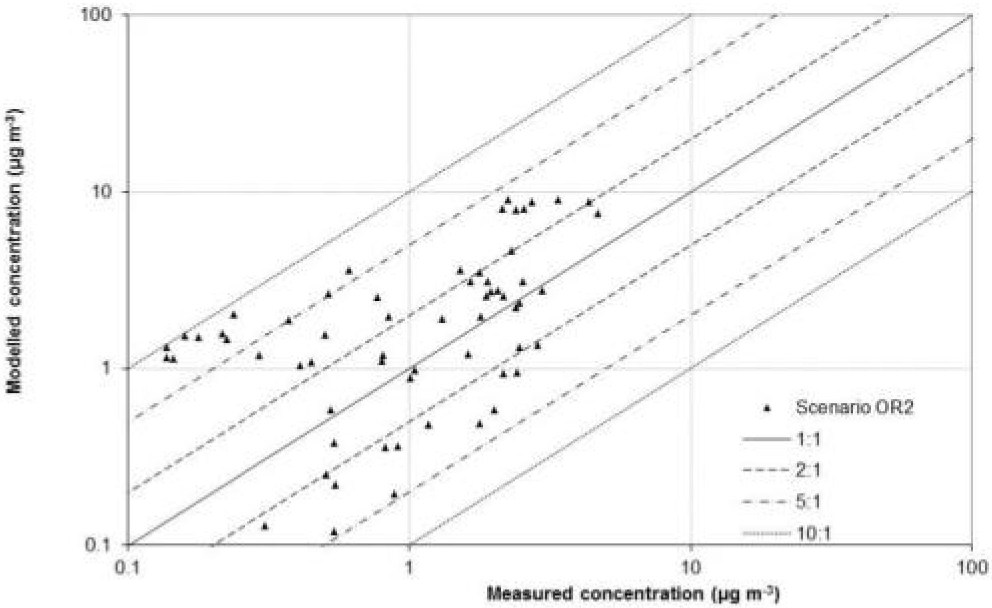


Figure H - 29: Scatterplots comparing measured and modelled odour concentrations at Glendevon farm for scenarios OR1 and OR2.



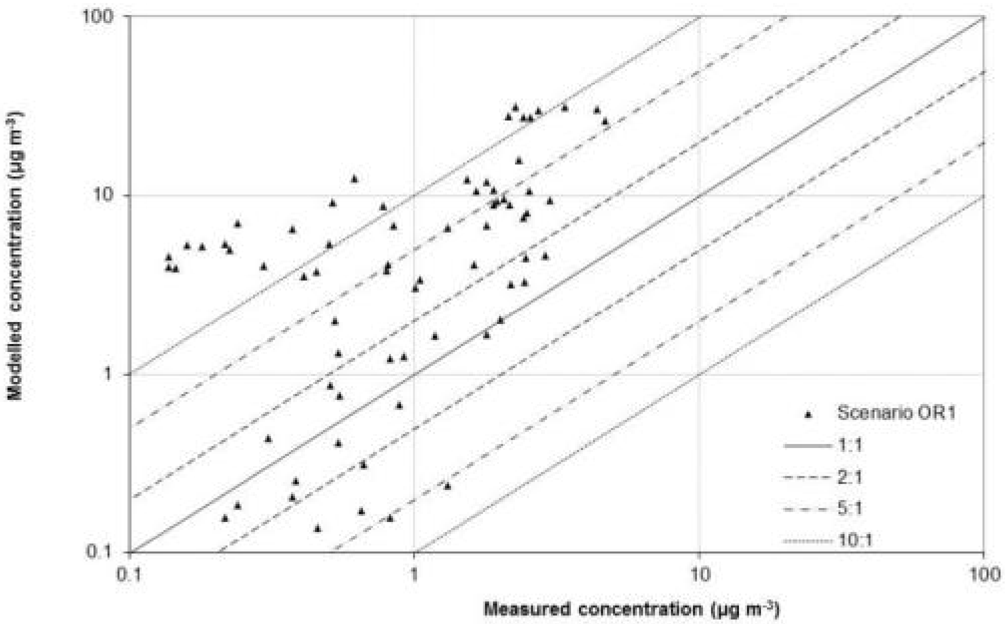


Figure H - 30: Scatterplots comparing measured and modelled odour concentrations at Whitelees farm for scenarios OR1 and OR2.

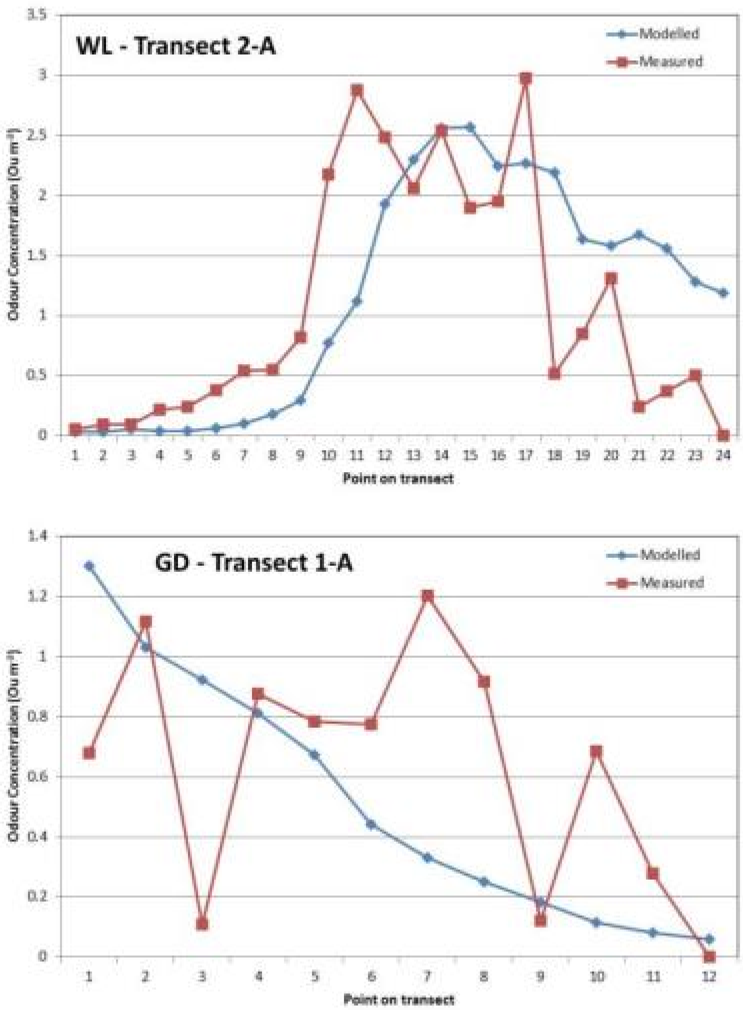


Figure H - 31: Comparison of measured and modelled odour concentrations at on transects at Glendevon farm (GD) and Whitelees Farm (WL) for scenario OR2.

H.5. Conclusions

A detailed set of model validation experiments were conducted at two farm sites in Central Scotland collecting odour, ammonia and airborne particulate data as well as recording on-site meteorological information. The following data were collected.

- *Continuous monitoring of meteorological data over a period of approximately three months at Whitelees and Glendevon Farms.*
- *Continuous monitoring of ammonia and airborne particulate concentrations was conducted over a period of approximately three months at Whitelees Farm.*
- *Monitoring of ammonia concentrations at nine locations around Whitelees and Glendevon Farms for a period of approximately three months using passive diffusion samplers (Alpha Samplers)*
- *Monitoring of ammonia, odour and PM_{10} emissions from the buildings at Whitelees and Glendevon Farms on two occasions.*
- *Monitoring ambient odour concentrations on transects at Whitelees and Glendevon Farms on two occasions.*

Measured emission data were relatively self-consistent between the two monitoring periods conducted at each farm. Measured emissions of ammonia were found to be higher than were predicted using the emission factors in SCAIL-Agriculture whilst measurements of PM_{10} emission and odour emission were lower than those predicted using the emission factors in SCAIL-Agriculture.

Measured ambient concentrations of ammonia recorded using Alpha Samplers were found to agree well with the default configuration of SCAIL-Agriculture, with the model meeting all the acceptability criteria of Chang and Hanna (2004). In addition, a good agreement was found between SCAIL-Agriculture and a detailed AERMOD model of atmospheric dispersion from both farms. Ambient ammonia concentrations recorded using the continuous AiRRmonia monitor were also found to agree well with SCAIL Agriculture when configured using on-site meteorological data and measured emission rates, again meeting all the acceptability criteria of Chang and Hanna (2004).

Measured PM_{10} concentrations showed a relatively weak signal from Whitelees Farm, illustrating that other PM_{10} sources (either local or distant) were significant contributors. A filtering process was used to attempt to correct the measured data to remove these "background" contributions and a comparison of daily-averaged concentrations was made with the predictions of the SCAIL model. This comparison illustrated that, when configured with the default emissions parameters, SCAIL-Agriculture met 3 of the 5 model acceptability criteria of Chang and Hanna (2004).

Odour concentrations measured on transects by field "sniffers" around both farms were compared with the model predictions. It should be noted that there is a high level of inherent uncertainty associated with the comparison of data determined with the human nose over a short time period and the predictions of a numerical model configured with hourly averaged meteorological data. However, it was clear that, whilst only one of the five acceptability criteria of Chang and Hanna (2004) were met, the model (when configured using measured emissions data) provided realistic estimates of the magnitude of ambient concentrations and also their spatial distribution.

In conclusion the SCAIL-Agriculture model was found to broadly meet recognised acceptability criteria for the prediction of ammonia, PM_{10} and odour concentration arising from farm buildings. There are however a number of areas where further research could clearly improve the assessment of agricultural sources. These are as follows:

- *Improvements to the emissions datasets used to derive emission factors that are included in the tool.*
- *Investigations as to the impact of local vs. regional meteorological data on the performance of assessment codes.*
- *Further research into PM_{10} levels around farm buildings and the impact of re-suspended dusts on local air concentrations.*

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