



A Report on the Modelling of the Dispersion and Deposition of Ammonia from the Existing and Proposed Free Range Egg-Laying Chicken Houses at Poplar Farm, Keal Cotes, near Spilsby in Lincolnshire

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1. Introduction

AS Modelling & Data Ltd. has been instructed by Mr. Oliver Grundy of JHG Planning Consultancy Ltd., on behalf of Mr. David Wright, to use computer modelling to assess the impact of ammonia emissions from the existing and proposed free range egg-laying chicken houses at Poplar Farm, Hagnaby Lane, Keal Cotes, near to Spilsby in Lincolnshire. PE23 4AL.

Ammonia emission rates from the existing and proposed poultry houses and ranging areas have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors. The ammonia emission rates have then been used as inputs to an atmospheric dispersion and deposition model which calculates ammonia exposure levels and nitrogen and acid deposition rates in the surrounding area.

This report is arranged in the following manner:

- Section 2 provides relevant details of the farm and potentially sensitive receptors in the area.
- Section 3 provides some general information on ammonia; details of the method used to estimate ammonia emissions, relevant guidelines and legislation on exposure limits and where relevant, details of likely background levels of ammonia.
- Section 4 provides some information about ADMS, the dispersion model used for this study and details the modelling procedure.
- Section 5 contains the results of the modelling.
- Section 6 provides a discussion of the results and conclusions.

2. Background Details

The site of the poultry unit at Poplar Farm is in a rural area approximately 1 km to the west-north-west of the village of Keal Cotes, near to Spilsby in Lincolnshire. The site is at an elevation of around 10 m on a low-lying area that is very gently undulating; the land, which is predominantly used for arable cultivation on loamy and clayey soils, benefits from a network of drainage channels.

There is currently one poultry house at Poplar Farm, which provides accommodation for up to 32,000 free range egg laying chickens. This poultry house is ventilated by uncapped high speed ridge fans, each with a short chimney and manure is removed from the poultry house using a belt system, twice weekly and removed from the site in covered trailers. The chickens have daytime access to outside ranging areas via a series of pop holes along the sides of the poultry house.

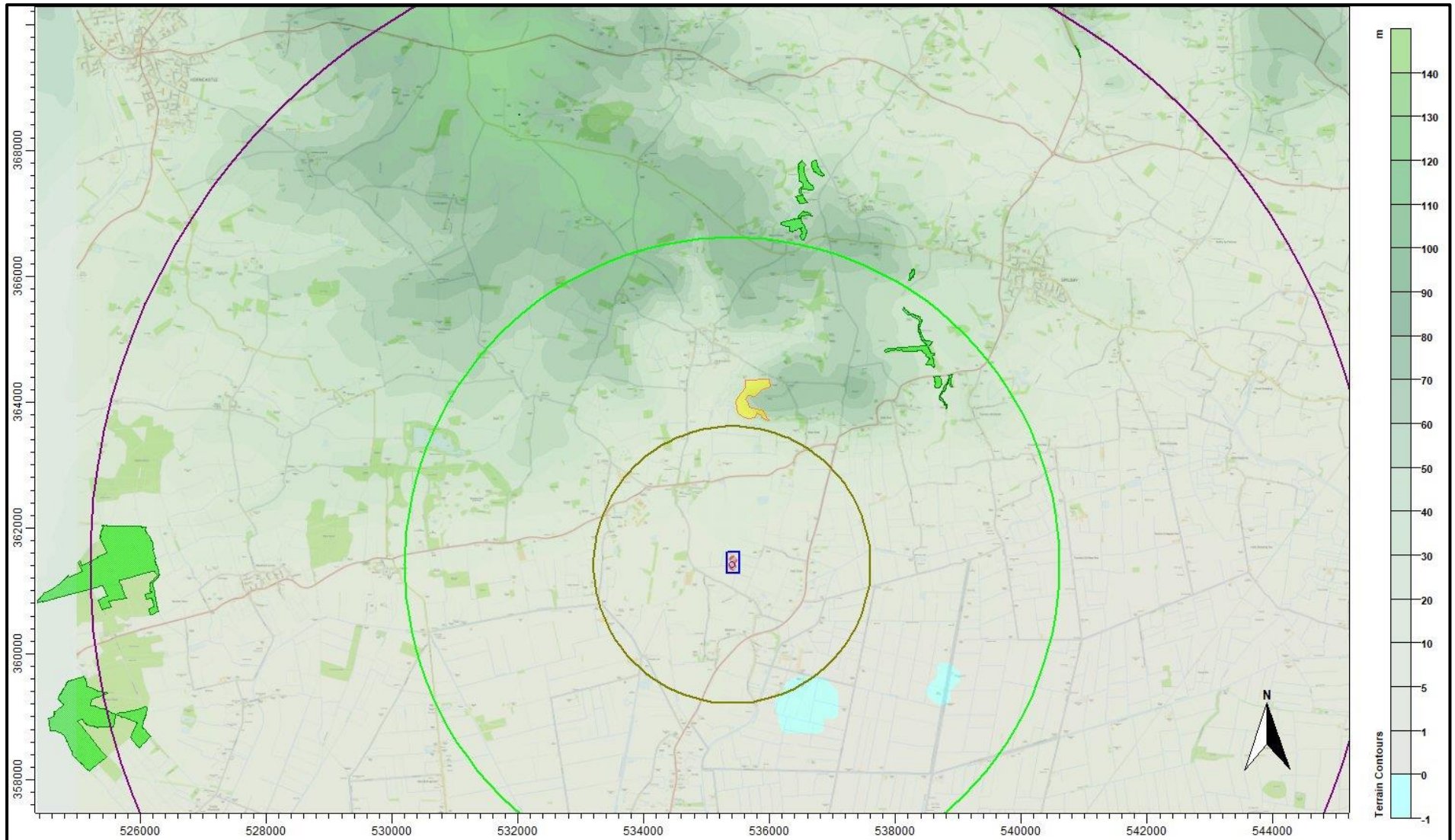
It is proposed that a second poultry house be constructed to the south of the existing poultry house. The proposed poultry house would provide accommodation for a further 32,000 free range egg laying chickens. The proposed poultry house would be ventilated by uncapped high speed ridge fans, each with a short chimney. Manure would be removed from the proposed poultry house using a belt system, twice weekly and removed from the site on covered trailers. The chickens would have daytime access to outside ranging areas via a series of pop holes along the sides of the proposed poultry house.

There is one area that has been designated as a Local Wildlife Site (LWS) within 2 km (the normal screening distance for a non-statutory wildlife site) of the existing and proposed poultry houses at Poplar Farm. There are two areas that have been designated as Sites of Special Scientific Interest (SSSIs) within 5 km (the normal screening distance for a SSSI) and a further six SSSIs within 10 km of the site. There are no internationally designated sites within 10 km (the normal screening distance for an internationally designated wildlife site) of the existing and proposed poultry houses. Some details of the ecology of the SSSIs that are within 10 km of the proposed poultry house and are sensitive to ammonia emissions and nitrogen deposition are given below.

- **Mavis Enderby Valley SSSI** - Approximately 5.1 km to the north-north-east - Formed by a beck cutting through the porous Spilsby Sandstone. On the steeper sides there is species-rich unimproved grassland. The poorly draining valley floor to the south has developed as a marsh alongside the beck. In the north, associated with the spring-line, is a series of alder carrs, each with a different species composition.
- **Keal Carr SSSI** - Approximately 4.0 km to the north-east - A base-rich spring-line alder woodland, which supports a rich flora typical of flushed ground.
- **Jenkins Carr SSSI** - Approximately 4.2 km to the north-east - The wooded slopes lead down to a narrow valley running north to south cut by a stream which widens at one point to form a small lake. An area of open water/swamp in the east and the stream sides has wetland species.
- **Fulsby Wood SSSI** - Approximately 9.0 km to the west - Supports a rich flora characteristic of ancient acidic oak woodlands. Traditional management and a mosaic of dominant tree species on a wide range of soil types and drainage, together with several ponds, shaded gravelly streams, marginal earthworks and broad rides, have resulted in a great diversity of communities.
- **Troy Wood SSSI** - Approximately 9.5 km to the west-south-west - This extensive oak woodland with a diverse flora typical of ancient sites is managed traditionally as coppice with standards. Streams, ditches, earthworks and species-rich rides add to the interest.

A map of the surrounding area showing the position of the proposed poultry house and the nearby wildlife sites is provided in Figure 1. In this figure, the LWS is shaded in yellow with a red outline, the SSSIs are shaded in green and the site of the existing and proposed poultry houses is outlined in blue.

Figure 1. The area surrounding Poplar Farm, with concentric circles radii 2.0 km (olive), 5.0 km (green) and 10.0 km (purple)



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3. Ammonia, Background Levels, Critical Levels & Loads & Emission Rates

3.1 Ammonia concentration and nitrogen and acid deposition

When assessing potential impact on ecological receptors, ammonia concentration is usually expressed in terms of micrograms of ammonia per metre cubed of air ($\mu\text{g-NH}_3/\text{m}^3$) as an annual mean. Ammonia in the air may exert direct effects on the vegetation, or indirectly affect the ecosystem through deposition which causes both hyper-eutrophication (excess nitrogen enrichment) and acidification of soils. Nitrogen deposition, specifically in this case the nitrogen load due to ammonia deposition/absorption, is usually expressed in kilograms of nitrogen per hectare per year (kg-N/ha/y). Acid deposition is expressed in terms of kilograms equivalent (of H^+ ions) per hectare per year (keq/ha/y).

3.2 Background ammonia levels and nitrogen and acid deposition

The source of the background figures is the Air Pollution Information System (APIS, November 2023). It should be noted that the 1 km APIS database background levels are extrapolated from 5 km modelled data. Ammonia levels may vary markedly over relatively short distances and the APIS website itself notes that, the background values cannot be considered representative on any particular location within the 5 km grid square; extrapolation to a 1 km grid does not alter this.

The APIS figures for background ammonia concentration for the area around the existing and proposed poultry houses at Poplar Farm is $2.45 \mu\text{g-NH}_3/\text{m}^3$. The background nitrogen deposition rate to woodland is 33.73 kg-N/ha/y and to short vegetation is 19.38 kg-N/ha/y . The background acid deposition rate to woodland is 2.16 keq/ha/y and to short vegetation is 1.15 keq/ha/y .

The APIS background figures are subject to revision and appear to change fairly frequently, the latest figures can be obtained at <https://www.apis.ac.uk/search-location>.

3.3 Critical Levels & Critical Loads

Critical Levels and Critical Loads are a benchmark for assessing the risk of air pollution impacts to ecosystems. It is important to distinguish between a Critical Level and a Critical Load. The Critical Level is the gaseous concentration of a pollutant in the air, whereas the Critical Load relates to the quantity of pollutant deposited from air to the ground.

Critical Levels are defined as, "concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur according to present knowledge" (UNECE).

Critical Loads are defined as, "a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (UNECE).

For ammonia concentration in air, the Critical Level for higher plants is 3.0 µg-NH₃/m³ as an annual mean. For sites where there are sensitive lichens and bryophytes present, or where lichens and bryophytes are an integral part of the ecosystem, the Critical Level is 1.0 µg-NH₃/m³ as an annual mean.

Critical Loads for nutrient nitrogen are set under the Convention on Long-Range Transboundary Air Pollution. They are based on empirical evidence, mainly observations from experiments and gradient studies. Critical Loads are given as ranges (e.g. 10-20 kg-N/ha/y); these ranges reflect variation in ecosystem response across Europe.

The Critical Levels and Critical Loads at the wildlife sites assumed in this study are provided in Table 1. N.B. Where the Critical Level of 1.0 µg-NH₃/m³ is assumed, it is usually unnecessary to consider the Critical Load as the Critical Level provides the stricter test. However, it may be necessary to consider nitrogen deposition should a Critical Load of 5.0 kg-N/ha/y be appropriate. Normally, the Critical Load for nitrogen deposition provides a stricter test than does the Critical Load for acid deposition.

Table 1. Critical Levels and Critical Loads at the wildlife sites

Site	Critical Level (µg-NH ₃ /m ³)	Critical Load - Nitrogen Deposition (kg-N/ha/y)	Critical Load - Acid Deposition (keq/ha/y)
LWS	1.0 ¹	10.0 ²	-
Mavis Enderby Valley SSSI, Keal Carr SSSI, Fulsby Wood SSSI, Troy Wood SSSI, Jenkins Carr SSSI	1.0 ¹	10.0 ²	-
Hundleby Clay Pit SSSI, Winceby Rectory Pit SSSI, Dalby Hill SSSI	n/a ³	n/a ³	n/a ³

1. A precautionary figure used where details of the site are unavailable, or citations or APIS indicate that sensitive lichens and bryophytes may be present.
2. The lower bound of the range of Critical Loads for the habitats.
3. Designated for geology.

3.4 Guidance on the significance of ammonia emissions

3.4.1 Environment Agency Criteria

The Environment Agency web-page titled “Intensive farming risk assessment for your environmental permit”, contains a set of criteria, with thresholds defined by percentages of the Critical Level or Critical Load, for: internationally designated wildlife sites (Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar sites); Sites of Special Scientific Interest (SSSIs) and other non-statutory wildlife sites. The lower and upper thresholds are: 4% and 20% for SACs, SPAs and Ramsar sites; 20% and 50% for SSSIs and 100% and 100% for non-statutory wildlife sites. If the predicted process contributions to Critical Level or Critical Load are below the lower threshold percentage, the impact is usually deemed acceptable.

If the predicted process contributions to Critical Level or Critical Load are in the range between the lower and upper thresholds; 4% to 20% for SACs, SPAs and Ramsar sites; 20% to 50% for SSSIs and 100% to 100% for other non-statutory wildlife sites, whether or not the impact is deemed acceptable is at the discretion of the Environment Agency. In making their decision, the Environment Agency will consider whether other farming installations might act in-combination with the farm and the sensitivities of the wildlife sites. In the case of LWSs and AWs, the Environment Agency do not usually consider other farms that may act in-combination and therefore a PC of up to 100% of Critical Level

or Critical Load is usually deemed acceptable for permitting purposes and therefore the upper and lower thresholds are the same (100%).

3.4.2 Natural England advisory criteria

Natural England are a statutory consultee at planning and usually advise that, if predicted process contributions exceed 1% of Critical Level or Critical Load at a SSSI, SAC, SPA or Ramsar site, then the local authority should consider whether other farming installations¹ might act in-combination or cumulatively with the farm and the sensitivities of the wildlife sites.

1. The process contribution from most farming installations is already included in the background ammonia concentrations and nitrogen and acid deposition rates. Therefore, it is normally only necessary to consider new installations and installations with extant planning permission and proposed developments when understanding the additional impact of a proposal upon nearby ecologies. However, established farms in close proximity may need to be considered given the background concentrations and deposition rates are derived as an average for a 5 km by 5 km grid.

3.4.3 Environment Agency and Natural England May 2022 Air Quality Risk Assessment Interim Guidance

Although it seems important to include a reference to this document, it appears to be primarily about internal Environment Agency screening models and the SCAIL model and AS Modelling & Data Ltd. have been unable to draw any conclusions from the document as to what thresholds may or may not apply, nor in what circumstances the threshold may or may not apply.

3.4.4 Joint Nature Conservancy Committee - Guidance on Decision-making Thresholds for Air Pollution

In December 2021, the Joint Nature Conservancy Committee (JNCC) published a report titled, "Guidance on Decision-making Thresholds for Air Pollution" This report provides decision-making criteria to inform the assessment of air quality impacts on designated conservation sites. The criteria are intended to be applied to individual sources to identify those for which a decision can be taken without the need for further assessment effort.

The Decision-making thresholds (DMT) for on-site emission sources provided in the JNCC report are reproduced below:

- For lichens and bryophytes - 0.08%, 0.20%, 0.34% and 0.75% of the Critical Level for high, medium, low and very low development density areas, respectively.
- For higher plants - 0.08%, 0.20%, 0.34% and 0.75% of the Critical Level for high, medium, low and very low development density areas, respectively.
- For nitrogen deposition to woodland (Critical Load 10 kg-N/ha/y) - 0.13%, 0.34%, 0.57% and 1.30% of the Critical Level for high, medium, low and very low development density areas, respectively.
- For nitrogen deposition to grassland (Critical Load 10 kg-N/ha/y) 0.09%, 0.24%, 0.40% and 0.88% of the Critical Level for high, medium, low and very low development density areas, respectively.

Note that 'development density' is defined as, the assumed number of additional new sources below the DMT within 5 km of the proposed development over 13 years: very low density being 1 development; low 5 developments; medium 10 developments and high 30 developments.

Subject to some exceptions, where the process contribution from an on-site source is below the DMT, no further assessment is required. Where the process contribution exceeds the DMT there are two possible outcomes:

- Where site-relevant thresholds have been derived these can be applied to see if it is possible to avoid further assessment effort on the basis of site specific circumstances.
- If site-relevant thresholds have not yet been derived, further assessment in combination with other plans and projects is required.

3.5 Quantification of ammonia emissions

Ammonia emission rates from poultry houses and ranging areas depend on many factors and are likely to be rather variable. However, the benchmarks for assessing impacts of ammonia and nitrogen deposition are framed in terms of an annual mean ammonia concentration and annual nitrogen deposition rates. To obtain relatively robust figures for these statistics it is not necessary to model short term temporal variations and a steady continuous emission rate can be assumed. In fact, modelling short term temporal variations might introduce rather more uncertainty than modelling continuous emissions.

3.5.3 Ammonia emissions from the proposed poultry houses

For free-range egg laying chickens, in an aviary system, where manure is removed frequently using a belt system, the Environment Agency standard emission factor is 0.08 kg-NH₃/bird place/y. This figure is used for the existing and proposed poultry houses at Poplar Farm.

Previously, it has been customary to reduce housing emissions by a factor based upon the proportion of droppings estimated to occur during ranging. This practice is not followed in this case for two reasons: firstly, ammonia emissions are most probably more dependent on surface area than they are on the absolute amount of excreta and secondly, the emission factors used are already at the lower end of the range of likely emission rates from the types of housing under consideration in this case.

3.5.2 Ammonia emissions from ranging areas

As the birds have, or would have, access to outdoor ranging areas, some of the birds' droppings, which is the source of the ammonia, would be deposited on these ranging areas. In their pre-application screening report, the Environment Agency provide an emission factor of 0.225 kg-NH₃/bird place/y (we assume this figure is based upon National Ammonia Emission Inventory figures for total N excreted, proportion of ammoniacal N and proportion of ammoniacal N released as ammonia and is for theoretical birds ranging 100% of the time). The Environment Agency also provide an estimate of 20% of birds ranging and 80% in the housing (we assume that this is an average figure when ranging is available and would note that this figure is at the high end of the range of observed range usage figures). Assuming average daily range availability of 8 hours per day^A the ammonia emission factor for the ranging is calculated to be 0.015 kg-NH₃/bird place/y.

A. Ranging availability may be longer in the summer and shorter in winter. The unavailability of ranging due to inclement weather or disease control for example is not considered.

A series of other peer reviewed scientific papers have also been considered. The findings from these papers are summarised below. It should be noted that the Aarnink provides direct measurements of ammonia emissions from ranging areas and is in accord with the calculated figure:

1. **Larsen, H., Cronin, G.M., Gebhardt-Henrich, S., Smith, C.L. Hemsworth, P.H. and Rault, J-L. (2017) - Individual ranging behaviour patterns in commercial free-range layers as observed through RFID tracking. *Animals*, 7 (21).**

This paper is from Australian studies and given the very different climate regimes in the UK and Australia, there can be no expectation that bird behaviour would be similar. This aside:

The Simple Summary appears to indicate high range usage (68.6% in Flock A, and 82.2% in Flock B). However, it should be noted that these percentages are the percentages of hens that used the ranging at some point in time, they are not overall range usage figures, which is the number we need to determine.

At page 6 it is stated "Flock A spent a mean of 46 +/- 1.1 h ranging between a total duration of 34 s and 83 h outside over the 13 days, and hens in Flock B spent a mean of 30 +/- 0.7 h ranging between a total duration of 50 min and 57 h outside over the 10 days."

So for Flock A the average range usage is - $68.6\% \times 46h / (24h \times 13d) = 10.1\%$.

And for Flock B the average range usage is - $82.2\% \times 30h / (24h \times 10d) = 10.3\%$.

It should also be noted that these figures do not account for days where ranging for any reason may not be available (disease control, inclement weather etc.).

2. Campbell, D.L.M., Hinch, G.N., Dyall, T.R., Warin, L., Little, B.A. and Lee, C (2016) - Outdoor stocking density in free-range laying hens: radio-frequency identification of impacts on range use. Animal: 1 - 10.

This paper is from New Zealand studies and given the potentially very different climate regimes in the UK and Australia, there can be no expectation that bird behaviour would be similar. This aside:

The abstract states the following "On average, 38% to 48% of hens were seen on the range simultaneously and used all available areas of all ranges". However, these are the figures for when ranging is available.

On page 4, the range availability is given as from 0900 h (pop hole opening) to 1630 h (pop hole closing).

Therefore, range usage is between $38\% \times 6.5h / 24h = 10.3\%$ and $48\% \times 6.5h / 24h = 13.0\%$.

It should also be noted that these figures do not account for days where ranging for any reason may not be available (disease control, inclement weather etc.).

3. Pettersson, I.C., Freire, R. and Nicol, C.J. (2016) - Factors affecting ranging behaviour in commercial free-range hens. World Poultry Science Journal, 72.

This is a review of other papers.

It is not stated explicitly whether the figures from all papers are for range usage when ranging is available; however, since it appears to be common practice to express ranging use this way, we have assumed this is the case for all figures reported, except where it is stated otherwise.

It should be noted that the figures with the exception of one (Whay figures) from this report are all from smaller flocks. Figures from small flocks are included, but it should be fully acknowledged that ranging usage in smaller flocks may be higher than for large flocks.

Farmers estimates are excluded and measured figures only are used below:

Range availability is not stated (this may be available in source papers), but assumed to be 8 hours per day, this is likely to be a high figure.

The highest reported ranging usage figure is 57% (count from very small flock), which assuming 8h per day ranging gives an overall figure of **19%**.

The lowest reported ranging usage is 11% (lowest figure from 1000-16000 bird flocks) and the lowest, which assuming 8h per day ranging gives an overall figure of **3.7%**.

The highest lowest reported ranging usage from 1000-16000 bird flocks is >25%, which assuming 8h per day ranging gives an overall figure of **>8.33%**.

It should also be noted that these figures do not account for days where ranging for any reason may not be available (disease control, inclement weather etc.).

4. L. Hegelund , J.T. Sørensen , J.B. Kjær & I.S. Kristensen b. Use of the range area in organic egg production systems: effect of climatic factors, flock size, age and artificial cover.

This is a Danish study, but climate and housing/ranging systems are similar to the UK. This is an older study (late 90s) and the flocks were small (513 to 6000 individuals/flock). However, this is still a useful paper.

The paper stated that average range usage was 9% (11% for flocks with artificial cover on ranges).

These figures are range usage when ranging is available. Range availability is not stated, but if it is assumed to be 8 hours per day then the range usage is: $9\% \times 8\text{h}/24\text{h} = 3\%$ and for birds with cover on ranges $11\% \times 8\text{h}/24\text{h} = 3.67\%$.

5. Leonard Ikenna Chielo *, Tom Pike and Jonathan Cooper Ranging Behaviour of Commercial Free-Range Laying Hens.

This is a UK study with large flocks and typical housing/ranging systems, so should carry some weight. The paper stated that average range usage was 12.5%.

These figures are range usage when ranging is available. Range availability is stated as 7-9h. If it is assumed to be an average 8 hours per day then the range usage is: $12.5\% \times 8\text{h}/24\text{h} = 4.17\%$.

It should also be noted that these figures do not account for days where ranging for any reason may not be available (disease control, inclement weather etc.).

6. Pettersson paper 2. I. C. Pettersson, C. A. Weeks, K. I. Norman, T. G. Knowles & C. J. Nicol. Internal roosting location is associated with differential use of the outdoor range by free-range Laying.

This is a UK study with typical 16,000 bird flocks and typical housing/ranging systems, so should carry some weight. The paper states that on average, across all flocks and observations 7.34% of the whole flock (both marked and unmarked birds) were seen out on the range at a time.

Range availability is not stated, but if it is assumed to be an average 8 hours per day then the range usage is: $7.34\% \times 8\text{h}/24\text{h} = 2.45\%$.

It should also be noted that these figures do not account for days where ranging for any reason may not be available (disease control, inclement weather etc.).

7. A.J.A. Aarnink*, J.M.G. Hoi and A.G.C. Beurskens. Ammonia emission and nutrient load in outdoor runs of laying hens.

This paper provides direct measurement of ammonia emissions from ranging areas. The key figure presented is the average ammonia emission rate, this is 2.0 mg-NH₃/hen/h. This equates to an emission factor of **0.017 kg-NH₃/hen/y**.

Details of the poultry numbers and types, emission factors used and calculated ammonia emission rates used in the modelling are provided in Table 2. Note that results obtained using these figures are scaled to actual bird numbers and emission factors to provide the final results.

Table 2. Details of poultry numbers, manure storage and baseline ammonia emission rates modelled

Source	Number of Birds	Housing Emission Factor (kg-NH ₃ /bird/y)	Baseline Housing Emission Rate (g-NH ₃ /s)	Ranging Emission Factor (kg-NH ₃ /bird/y) ¹	Baseline Ranging Emission Rate (g-NH ₃ /s)
EX1	32,000	0.08	0.081122	0.225	0.228154 ²
PR1	32,000	0.08	0.081122	0.225	0.228154 ²

1. Assumed to be for 100% ranging.
2. Results obtained using these figures are scaled by a factor of 0.0666 (actual overall range usage) to provide the final results.

4. The Atmospheric Dispersion Modelling System (ADMS) and Model Parameters

The Atmospheric Dispersion Modelling System (ADMS) ADMS 5 is a new generation Gaussian plume air dispersion model, which means that the atmospheric boundary layer properties are characterised by two parameters; the boundary layer depth and the Monin-Obukhov length rather than in terms of the single parameter Pasquill-Gifford class.

Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetrical Gaussian expression).

ADMS has a number of model options that include: dry and wet deposition; NO_x chemistry; impacts of hills; variable roughness; buildings and coastlines; puffs; fluctuations; odours; radioactivity decay (and γ -ray dose); condensed plume visibility; time varying sources and inclusion of background concentrations.

ADMS has an in-built meteorological pre-processor that allows flexible input of meteorological data both standard and more specialist. Hourly sequential and statistical data can be processed and all input and output meteorological variables are written to a file after processing.

The user defines the pollutant, the averaging time (which may be an annual average or a shorter period), which percentiles and exceedance values to calculate, whether a rolling average is required or not and the output units. The output options are designed to be flexible to cater for the variety of air quality limits which can vary from country to country and are subject to revision.

4.1 Meteorological data

Computer modelling of dispersion requires hourly sequential meteorological data and to provide robust statistics the record should be of a suitable length; preferably four years or longer.

The meteorological data used in this study is obtained from assimilation and short term forecast fields of the Numerical Weather Prediction (NWP) system known as the Global Forecast System (GFS)¹.

Prior to April 2019 the GFS was a spectral model, post April 2019 the physics are discrete. The physics/dynamics model has a resolution or had an equivalent resolution of approximately 7 km over the UK; terrain is understood to be resolved at a resolution of approximately 2 km, with sub-7 km terrain effects parameterised. Site specific data may be extrapolated from nearby archive grid points or a most representative grid point chosen. The GFS resolution adequately captures major topographical features and the broad-scale characteristics of the weather over the UK. Smaller scale topological features may be included in the dispersion modelling by using the flow field module of ADMS (FLOWSTAR²). The use of NWP data has advantages over traditional meteorological records because:

- Calm periods in traditional observational records may be over represented, this is because the instrumentation used may not record wind speeds below approximately 0.5 m/s and start up wind speeds may be greater than 1.0 m/s. In NWP data, the wind speed is continuous down to 0.0 m/s, allowing the calms module of ADMS to function correctly.
- Traditional records may include very local deviations from the broad-scale wind flow that would not necessarily be representative of the site being modelled; these deviations are difficult to identify and remove from a meteorological record. Conversely, local effects at the site being modelled are relatively easy to impose on the broad-scale flow and provided horizontal resolution is not too great, the meteorological records from NWP data may be expected to represent well the broad-scale flow.
- Information on the state of the atmosphere above ground level which would otherwise be estimated by the meteorological pre-processor may be included explicitly.

The raw GFS wind speeds are modified by the treatment of roughness lengths (see Section 4.7) and where terrain data is included in the modelling, wind speeds and directions will be further modified. The raw GFS wind rose is shown in Figure 2a and the terrain and roughness length modified wind rose for Poplar Farm is shown in Figure 2b. Note that elsewhere in the modelling domain, the modified wind rose may differ more or less markedly. Please also note that FLOWSTAR² is used to obtain a local flow field, not to explicitly model dispersion in complex terrain as defined in the ADMS User Guide; therefore, the ADMS default value for minimum turbulence length has been amended³. The resolution of the wind field in terrain runs is approximately 360 m.

1. The GFS data used is derived from the high resolution operational GFS datasets, the data is not obtained from the lower resolution (0.5 degree) long-term archive.
2. Note that FLOWSTAR requirements are for meteorological data representative of the upwind flow over the modelling domain and that single site meteorological data (observational or from high resolution modelled

data) that is representative of the application site is not generally suitable (personal correspondence: CERC 2019 and UK Met O 2015). If data are deemed representative of a particular application site, either wholly or partially, then these data cannot also be representative of the upstream flow over the modelling domain. Furthermore, it would be extremely poor practice to use such data as the boundary conditions for a flow-solver, such as FLOWSTAR.

3. When modelling complex terrain with ADMS, by default, the minimum turbulence length has 0.1 m added to the flat terrain value (calculated from the Monin-Obukhov length). Whilst this might be appropriate over hill/mountain tops in terrain with slopes $> 1:10$ (and quite possibly only in certain wind directions) in lesser terrain it introduces model behaviour that is not desirable where FLOWSTAR is simply being used to modify the upwind flow. Specifically, the parameter σ_z of the Gaussian plume model is overly constrained, which for elevated point sources emissions, may on occasion cause over prediction of ground level concentrations in stable weather conditions and light winds (Steven R. Hanna & Biswanath Chowdhury, 2013), conversely for low level emission sources, this will cause gross under prediction. Note that this becomes particularly important overnight and if calm and light wind conditions are not being ignored, as they often are when using traditional observational meteorological datasets. To reduce this behaviour, where terrain is modelled, AS Modelling & Data Ltd. have set a minimum turbulence length of 0.025 m in ADMS. This approximates the normal behaviour of ADMS with flat terrain.

Figure 2a. The wind rose. Raw GFS derived data for 53.132 N, 0.024 E, 2019-2022

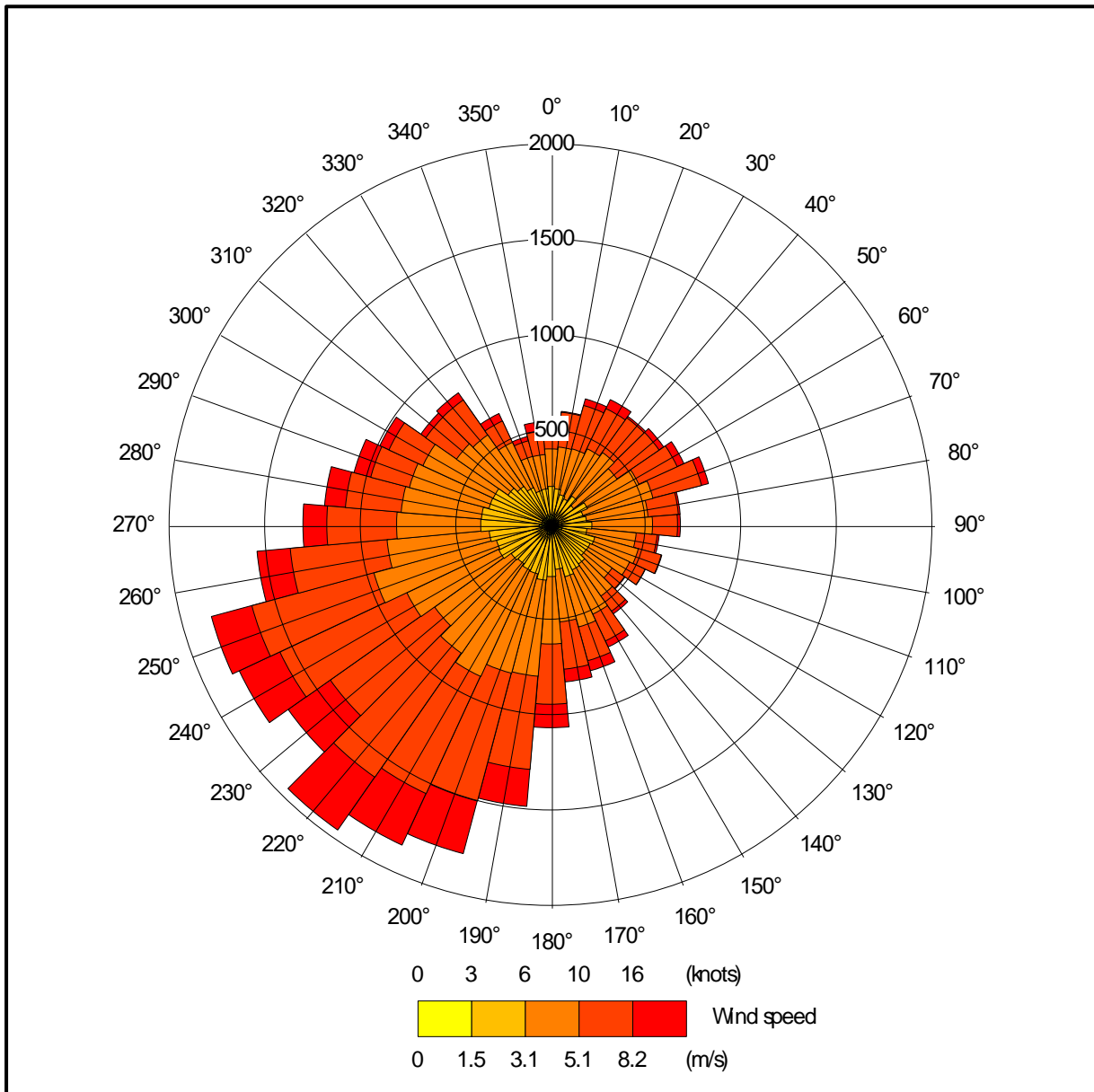
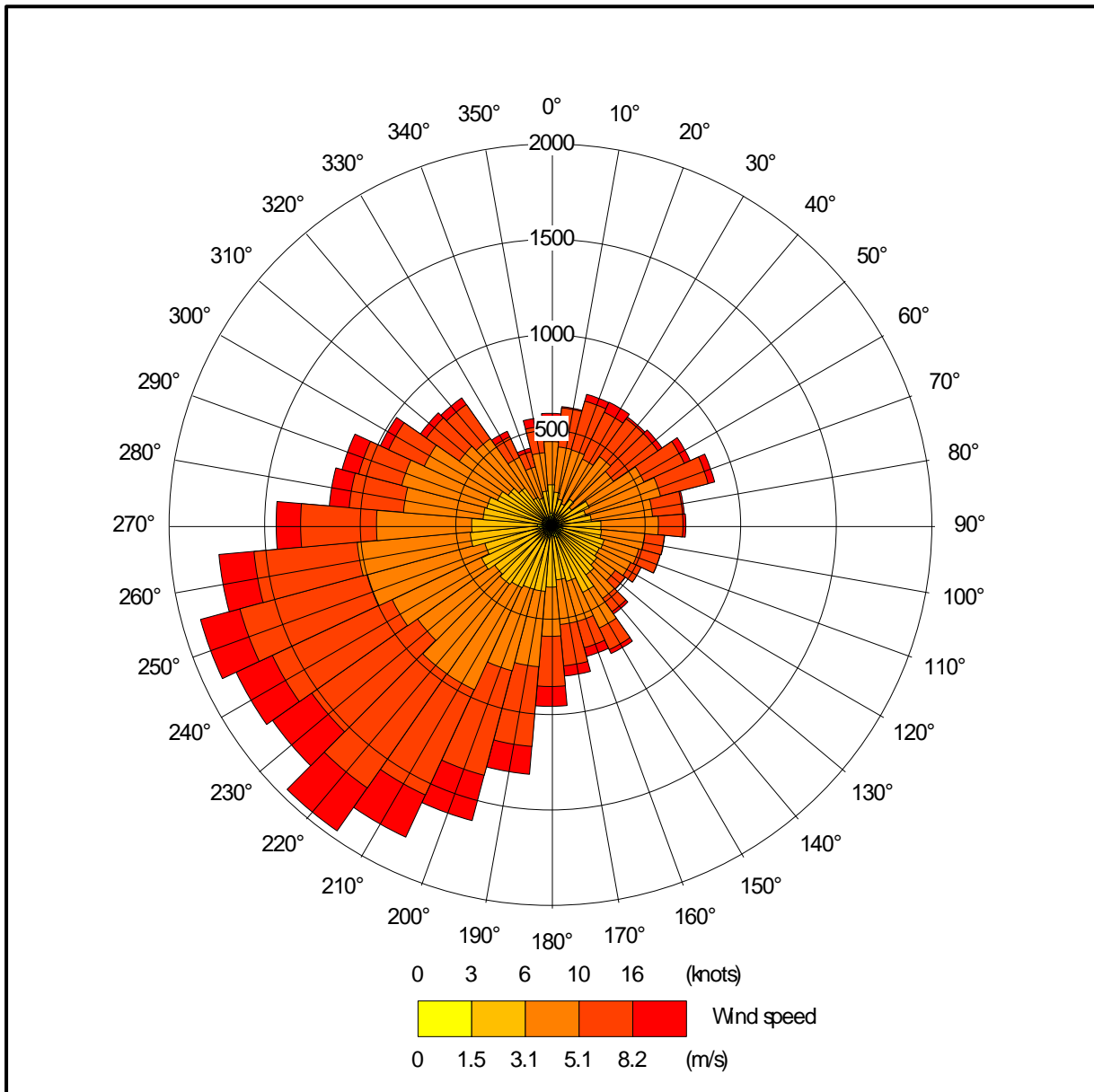


Figure 2b. The wind rose. FLOWSTAR modified GFS derived data for NGR 535400, 361420, 2019-2022



4.2 Emission sources

Emissions from the chimneys of the high speed ridge fans that are, or would be, used to ventilate the existing and proposed poultry houses are represented by point sources within ADMS (EX1 and PR1; 1, 2 and 3). Details of the point source parameters are shown in Table 3a. The positions of the point sources used are shown in Figure 3 (marked as red stars).

Table 3a. Point source parameters

Source ID	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (°C)	Emission rate per source (g-NH ₃ /s)
EX1 and PR1; 1, 2 & 3	5.5	0.8	11.0	21.0	0.027041

The existing and proposed poultry houses would have ranging areas, each of which would be a further source of ammonia. Emissions from the ranging areas are represented by area sources within ADMS (EX_RAN_E, EX_RAN_W, PR_RANM_E, PR_RAN_W). Note that the area sources cover the parts of the ranges that are most likely to be used frequently and not the whole of the ranging areas. Details of the area source parameters are shown in Table 3b (scaling factors(s) applied). The positions of the areas sources used are shown in Figure 3 (marked by red polygons).

Table 3b. Area source parameters

Source ID	Area (m ²)	Base height (m)	Emission temperature (°C)	Emission rate (g-NH ₃ /s)
EX_RAN_E	2,753	0.0	Ambient	0.007598
EX_RAN_W	3,555	0.0	Ambient	0.007598
PR_RAN_E	1,584	0.0	Ambient	0.007598
PR_RAN_W	2,905	0.0	Ambient	0.007598

4.3 Modelled buildings

The structure of the existing and proposed poultry houses may affect the odour plumes from the point sources. Therefore, these buildings are modelled within ADMS. The positions of the modelled buildings may be seen in Figure 3 (marked by grey rectangles).

4.4 Discrete receptors

Sixteen discrete receptors have been defined: three at the LWSs (1 to 3) and thirteen at the SSSIs (4 to 16). These receptors are defined at ground level within ADMS. The positions of the discrete receptors may be seen in Figure 4 (marked by enumerated pink rectangles).

4.5 The regular Cartesian grid

To produce the contour plots presented in Section 5 of this report and to define the spatially varying deposition velocity field, two regular Cartesian grids have been defined within ADMS; one measuring 10.0 km by 10.0 km with a 500 m horizontal resolution and one measuring 5.0 km by 5.0 km with a 100 m horizontal resolution. The individual grid receptors are defined at ground level within ADMS. The positions of the Cartesian grids may be seen in Figure 4, where they are marked by grey lines.

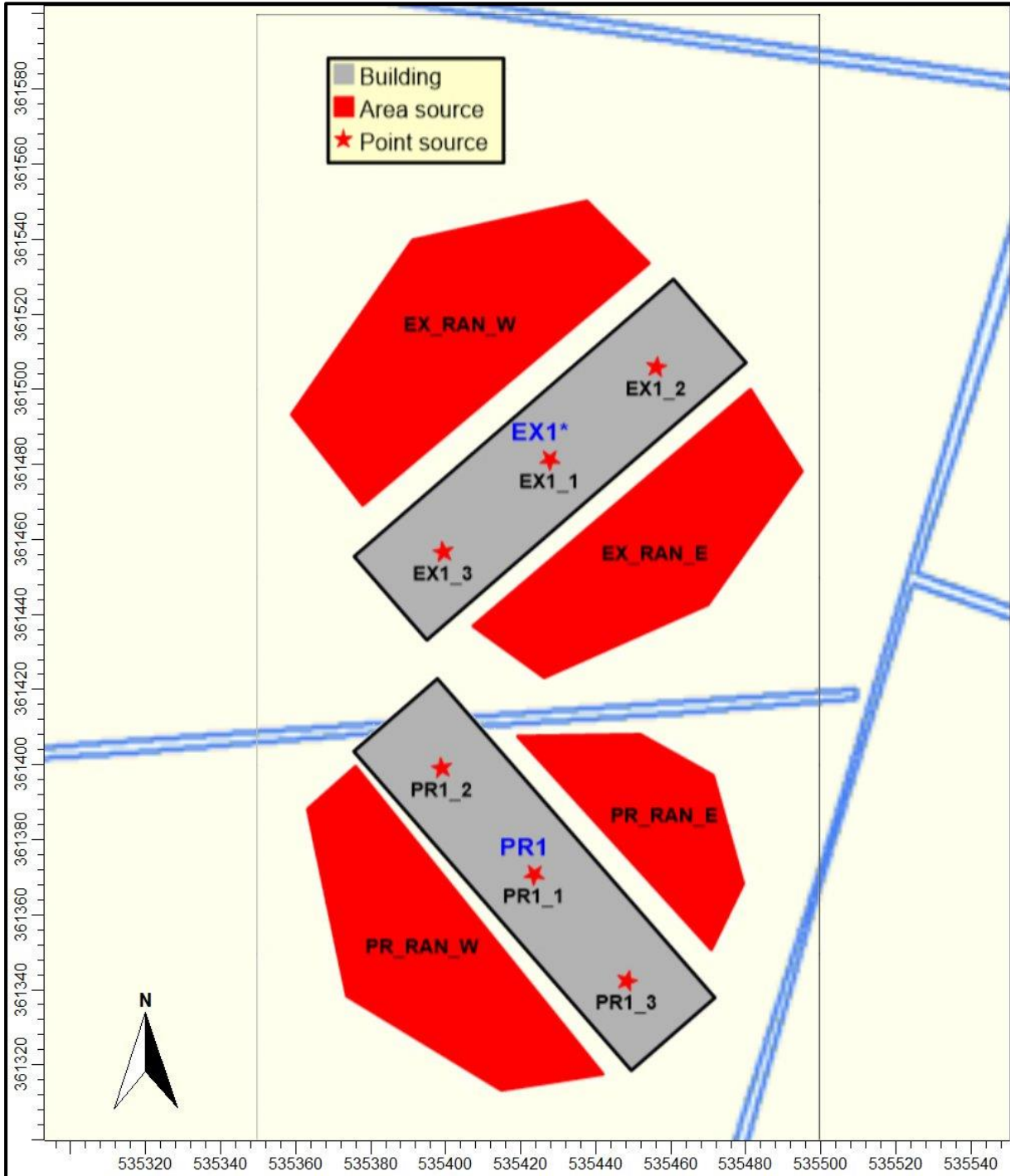
4.6 Terrain data

Terrain has been considered in the modelling. The terrain data are based upon the Ordnance Survey 50 m Digital Elevation Model. A 22.0 km by 22.0 km domain has been resampled at 100 m horizontal resolution for use within ADMS. N.B. The resolution of FLOWSTAR is 64 x 64 grid points; therefore, the effective resolution of the wind field is approximately 340 m.

4.7 Roughness Length

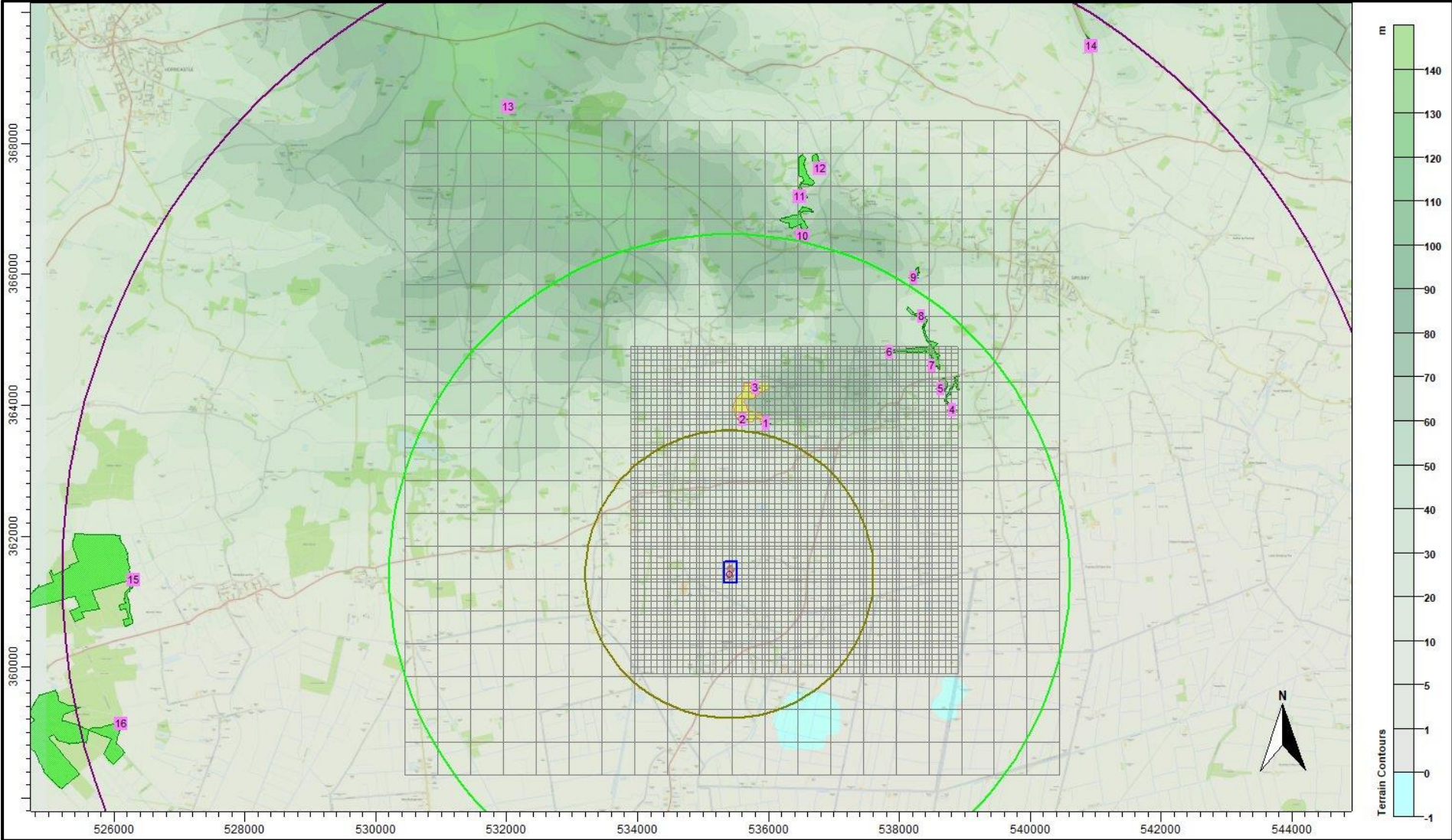
In this case, a spatially varying roughness length file has been defined, this is based upon the Defra Living Landscapes land use database. The GFS meteorological data is assumed to have a roughness length of 0.126 m, which is the average of the surface roughness from the spatially varying roughness length field. The sample of the central area of the spatially varying roughness length field is shown in Figure 5.

Figure 3. The positions of the modelled sources



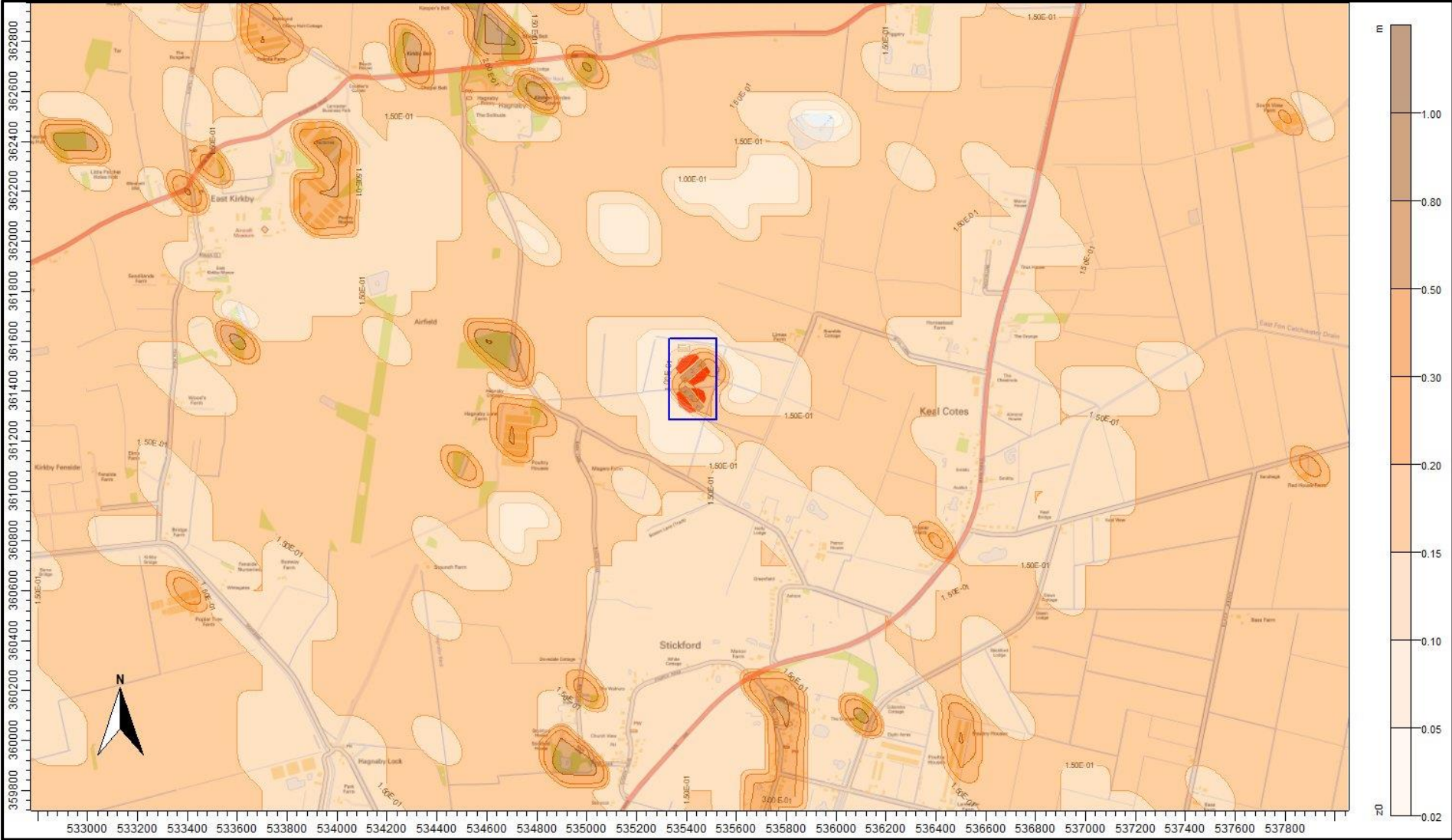
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Figure 4. The discrete receptors and regular Cartesian grids



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Figure 5. The roughness length field



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4.8 Deposition

The method used to model deposition of ammonia and consequent plume depletion is based primarily upon Frederik Schrader and Christian Brümmer. Land Use Specific Ammonia Deposition Velocities: a Review of Recent Studies (2004-2013). AS Modelling & Data Ltd. has restricted deposition over arable farmland and heavily grazed and fertilised pasture; this is to compensate for possible saturation effects due to fertilizer application and to allow for periods when fields are clear of crops (Sutton), the deposition is also restricted over areas with little or no vegetation and the deposition velocity is set to 0.002 m/s where grid points are over the poultry housing and 0.010 m/s to 0.015 m/s over heavily grazed grassland. Where deposition over water surfaces is calculated, a deposition velocity of 0.005 m/s is used. Land use data used to derive deposition velocity is based upon the Defra Living Landscapes land use database.

In summary, the method is as follows:

- A preliminary run of the model without deposition is used to provide an ammonia concentration field.
- The preliminary ammonia concentration field, along with land usage is used to define a deposition velocity field. The deposition velocities used are provided in Table 4.

Table 4. Deposition velocities

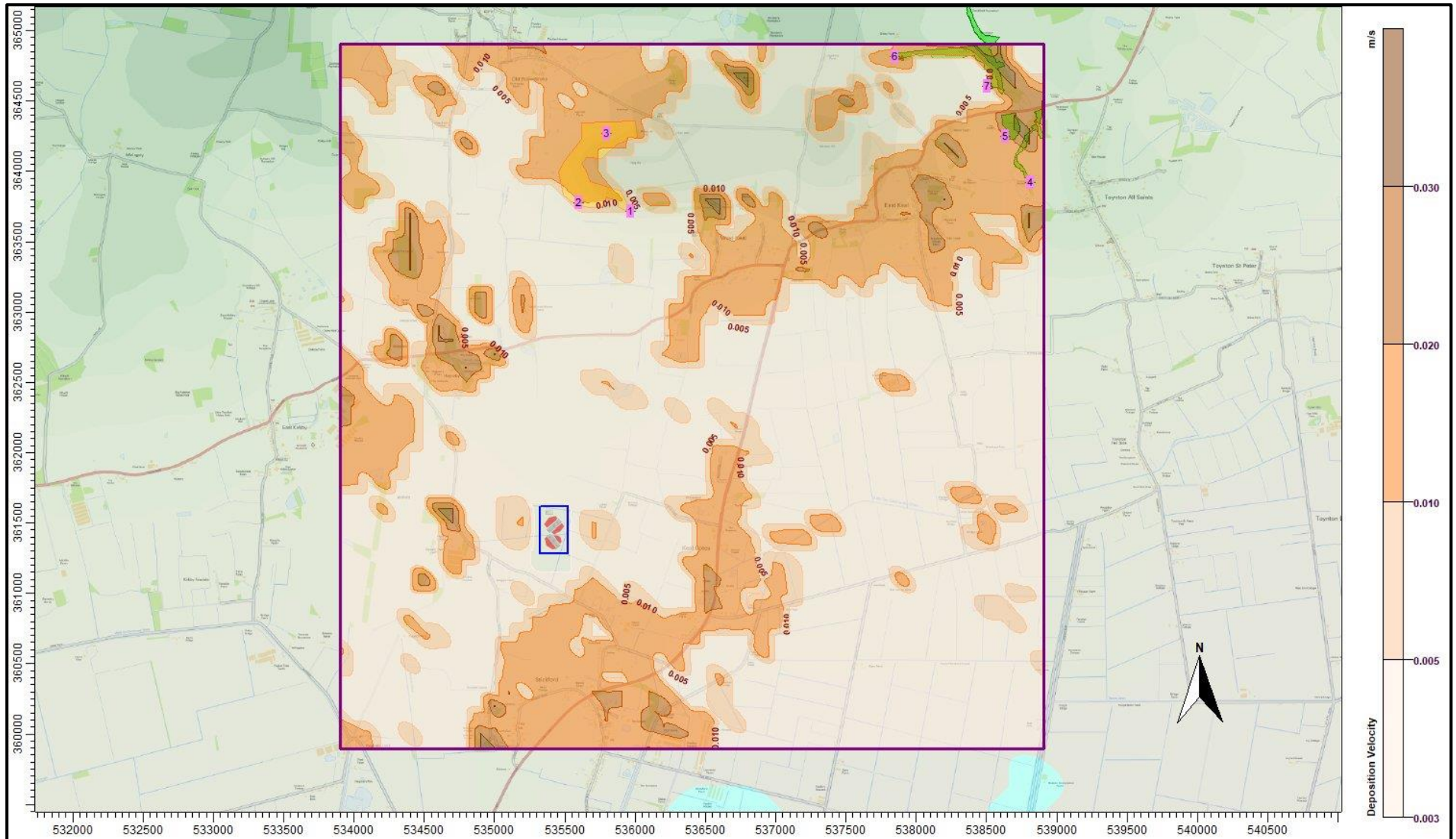
NH ₃ concentration (PC + background) (µg/m ³)	< 10	10 - 20	20 - 30	30 - 80	> 80
Deposition velocity - woodland (m/s)	0.03	0.015	0.01	0.005	0.003
Deposition velocity - short vegetation (m/s)	0.02 (0.010 to 0.015 over heavily grazed grassland)	0.015	0.01	0.005	0.003
Deposition velocity - arable farmland/rye grass (m/s)	0.005	0.005	0.005	0.005	0.003

- The model is then rerun with the spatially varying deposition module.

A contour plot of the spatially varying deposition field is provided in Figure 6.

In this case, the model has also been run with a fixed deposition at 0.003 m/s and similarly to not modelling deposition at all, the predicted ammonia concentrations (and nitrogen and acid deposition rates) are always higher than if spatially varying deposition were modelled explicitly, particularly where there is some distance between the source and a receptor.

Figure 6. The spatially varying deposition field



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5. Details of the Model Runs and Results

5.1 Preliminary modelling and model sensitivity tests

ADMS was run a total of sixteen times, once for each year in the meteorological record, in the following four modes:

- In basic mode without calms, or terrain - GFS data.
- With calms and without terrain - GFS data.
- Without calms and with terrain - GFS data.
- Without calms, with terrain and fixed deposition at 0.003 m/s - GFS data.

For each mode, statistics for the maximum annual mean ammonia concentration at each receptor were compiled.

Details of the predicted annual mean ammonia concentrations at each receptor are provided in Table 5 for the existing and proposed poultry houses and ranges. Note:

- The modelling of all of the ranges has been conducted on the basis of an emission factor of 0.225 kg-nh₃/place/y, which assumes 100% of the birds are occupying the ranges 100% of the time. However, availability of the ranges is assumed to be for 8 hours a day and the Environment Agency estimate 20% range usage. Therefore, the process contribution from the ranges has been multiplied by a factor of 0.0666 (0.2 * 0.333).

In the Table, predicted ammonia concentrations (or concentrations equivalent to deposition rates) that are in excess of the Environment Agency's upper percentage threshold of the relevant Critical Level or Critical Load for the site (50% for a SSSI and 100% for a non-statutory site) are highlighted in red. Predicted ammonia concentrations (or concentrations equivalent to deposition rates) that are in the range between the Environment Agency's upper threshold and lower threshold percentages of the relevant Critical Level or Critical Load (20% to 50% for a SSSI and 100% to 100% for a non-statutory site) are highlighted in blue. Additionally, predicted ammonia concentrations (or concentrations equivalent to deposition rates) that exceed 1% of the relevant Critical level or Critical Load at a SSSI are highlighted with emboldened text.

For convenience, cells referring to the LWSs are shaded yellow and cells referring to the SSSIs are shaded green.

Table 5. Predicted maximum annual mean ammonia concentration at the discrete receptors

Receptor number	X(m)	Y(m)	Designation	Maximum annual mean ammonia concentration - ($\mu\text{g}/\text{m}^3$)			
				GFS No calms No terrain	GFS Calms No terrain	GFS No calms Terrain	GFS No calms Terrain Fixed depo 0.003 m/s
1	535965	363716	LWS	0.052	0.052	0.041	0.025
2	535601	363776	LWS	0.047	0.047	0.040	0.023
3	535793	364272	LWS	0.036	0.036	0.029	0.017
4	538808	363921	Jenkins Carr SSSI	0.022	0.022	0.020	0.015
5	538637	364250	Jenkins Carr SSSI	0.021	0.021	0.019	0.013
6	537846	364816	Keal Carr SSSI	0.021	0.021	0.018	0.012
7	538503	364608	Keal Carr SSSI	0.020	0.020	0.017	0.012
8	538331	365353	Keal Carr SSSI	0.017	0.017	0.014	0.009
9	538227	365950	Hundleby Clay Pit SSSI	0.015	0.015	0.012	0.007
10	536519	366584	Mavis Enderby Valley SSSI	0.016	0.016	0.012	0.007
11	536481	367181	Mavis Enderby Valley SSSI	0.014	0.014	0.011	0.006
12	536795	367621	Mavis Enderby Valley SSSI	0.012	0.012	0.010	0.005
13	532024	368561	Winceby Rectory Pit SSSI	0.007	0.007	0.005	0.002
14	540933	369486	Dalby Hill SSSI	0.006	0.006	0.006	0.003
15	526293	361329	Fulsby Wood SSSI	0.006	0.006	0.006	0.003
16	526110	359131	Troy Wood SSSI	0.007	0.007	0.007	0.003

5.2 Detailed deposition modelling

In this case, detailed modelling has been carried out over a high resolution (100 m) domain that extends 5.0 km by 5.0 km. The primary purpose is to determine the magnitude of deposition of ammonia and consequent plume depletion close to the sources where it is of the greatest importance. Outside of this 5.0 km by 5.0 km domain, including across the grid receptors spaced at 500 m intervals over a 10.0 km by 10.0 km domain, a fixed deposition velocity of 0.005 m/s is assumed (with appropriate deposition velocities applied post-modelling at the discrete receptors).

Terrain effects may be significant at some receptors; therefore, the detailed deposition run was made with terrain. Calms cannot be used with terrain or spatially varying deposition; however, in this case the results of the preliminary modelling show that the impact of calms is not significant.

The results of the detailed deposition modelling are shown in Table 6. In the Table, predicted ammonia concentrations (or concentrations equivalent to deposition rates) that are in excess of the Environment Agency's upper percentage threshold of the relevant Critical Level or Critical Load for the site (50% for a SSSI and 100% for a non-statutory site) are highlighted in red. Predicted ammonia concentrations (or concentrations equivalent to deposition rates) that are in the range between the Environment Agency's upper threshold and lower threshold percentages of the relevant Critical Level or Critical Load (20% to 50% for a SSSI and 100% to 100% for a non-statutory site) are highlighted in blue. Additionally, predicted ammonia concentrations (or concentrations equivalent to deposition rates) that exceed 1% of the relevant Critical Level or Critical Load at a SSSI are highlighted with emboldened text.

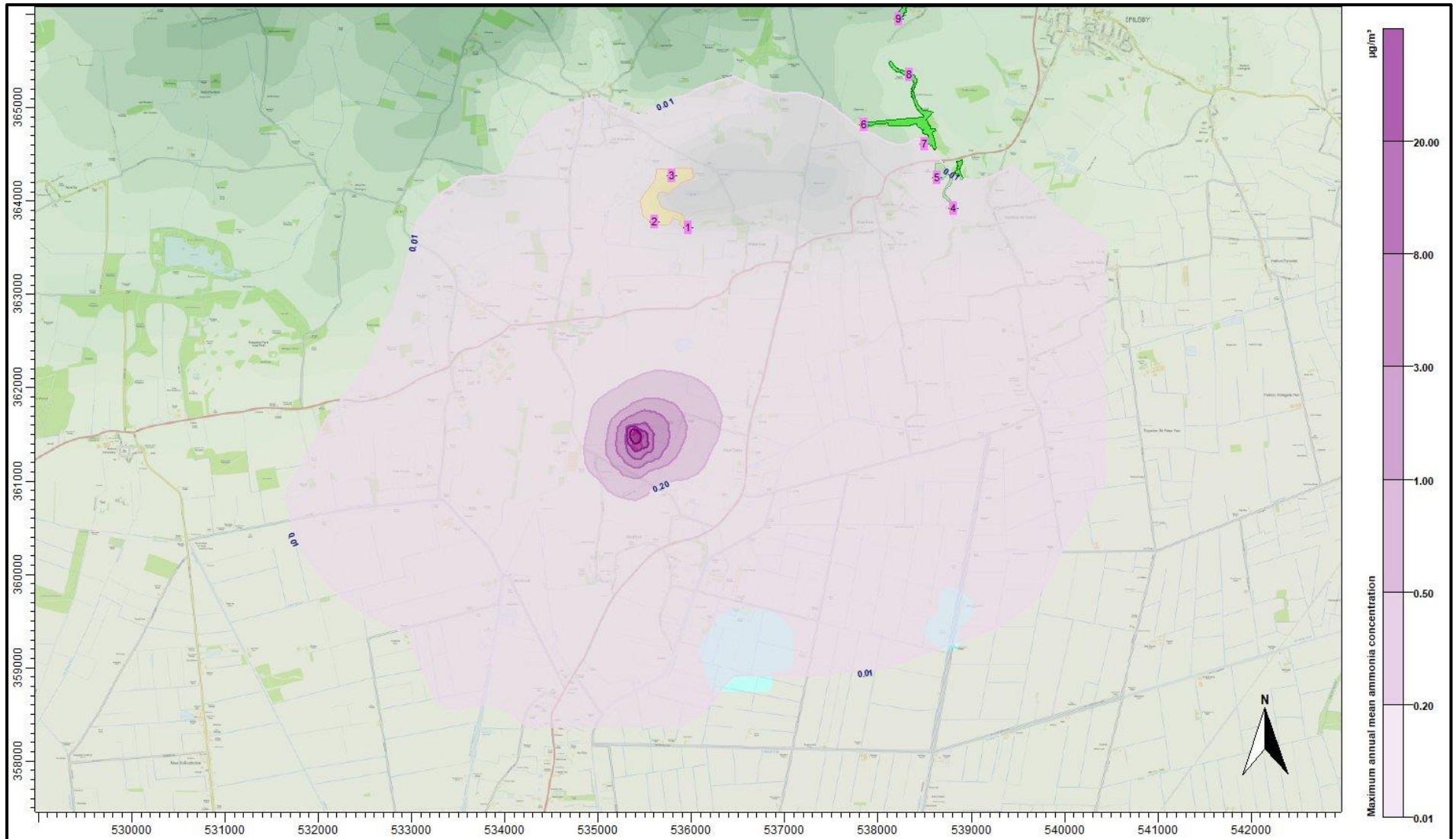
For convenience, cells referring to the LWSs are shaded yellow and cells referring to the SSSIs are shaded green.

Contour plots of the predicted process contribution from the proposed poultry house to ground level maximum annual mean ammonia concentration and the maximum nitrogen deposition rates are shown in Figures 7a and 7b. Please note that outside of the 5.0 km by 5.0 km, deposition contours should be interpreted with caution because, whilst appropriate deposition velocities applied at the discrete receptors, elsewhere a fixed deposition velocity is applied.

Table 6. Maximum annual mean ammonia concentration and nitrogen deposition rates at the discrete receptors

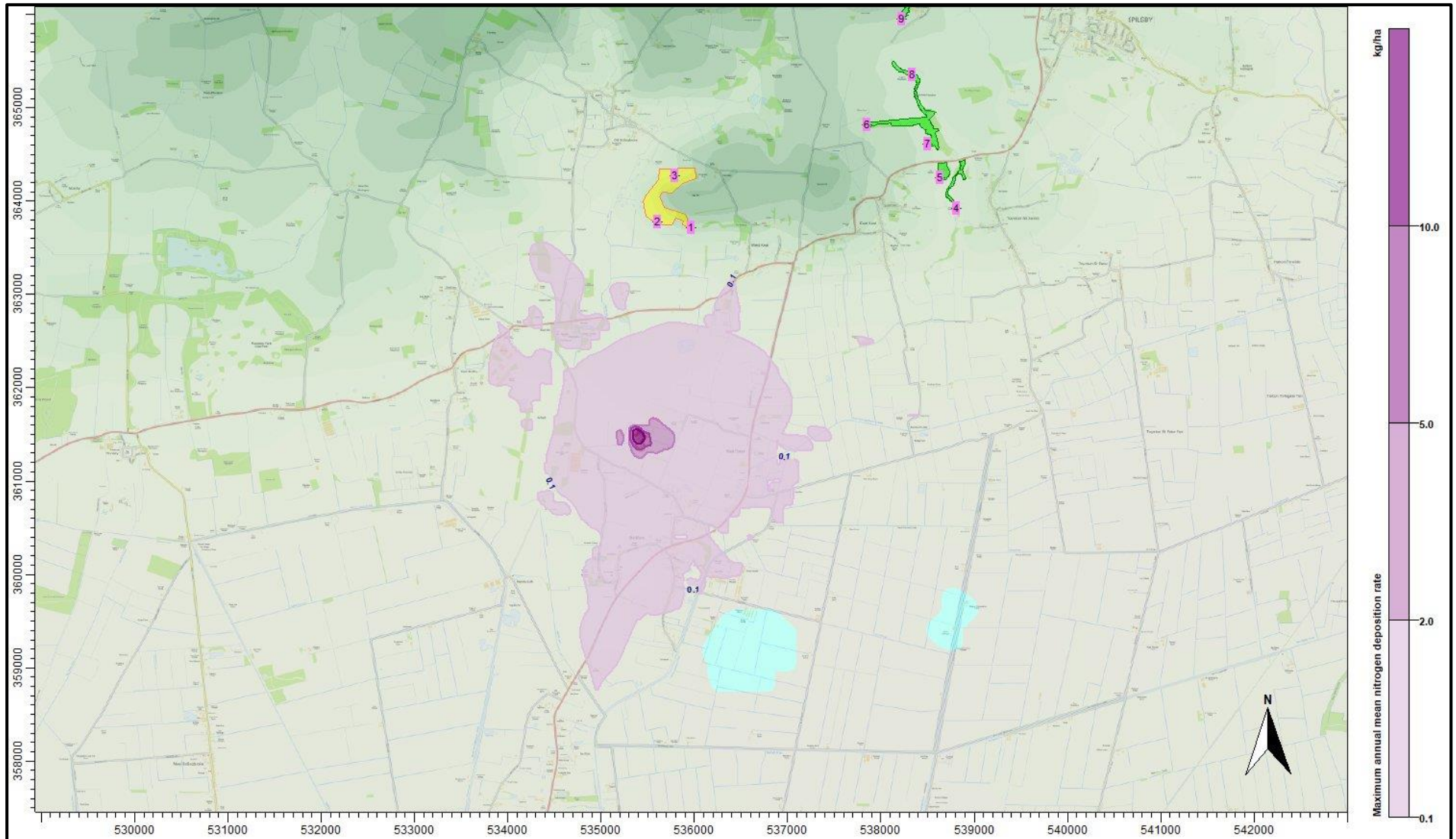
Receptor number	X(m)	Y(m)	Designation	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level ($\mu\text{g}/\text{m}^3$)	Critical Load (kg/ha)	Process Contribution ($\mu\text{g}/\text{m}^3$)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	535965	363716	LWS	0.03	1.0	10.0	0.023	2.29	0.179	1.79
2	535601	363776	LWS	0.03	1.0	10.0	0.020	1.99	0.155	1.55
3	535793	364272	LWS	0.03	1.0	10.0	0.015	1.46	0.113	1.13
4	538808	363921	Jenkins Carr SSSI	0.03	1.0	10.0	0.012	1.17	0.091	0.91
5	538637	364250	Jenkins Carr SSSI	0.03	1.0	10.0	0.011	1.07	0.083	0.83
6	537846	364816	Keal Carr SSSI	0.03	1.0	10.0	0.010	0.95	0.074	0.74
7	538503	364608	Keal Carr SSSI	0.03	1.0	10.0	0.011	1.05	0.082	0.82
8	538331	365353	Keal Carr SSSI	0.03	1.0	10.0	0.008	0.84	0.065	0.65
9	538227	365950	Hundleby Clay Pit SSSI	-	-	-	0.007	-	-	-
10	536519	366584	Mavis Enderby Valley SSSI	0.03	1.0	10.0	0.006	0.62	0.049	0.49
11	536481	367181	Mavis Enderby Valley SSSI	0.03	1.0	10.0	0.005	0.54	0.042	0.42
12	536795	367621	Mavis Enderby Valley SSSI	0.03	1.0	10.0	0.005	0.50	0.039	0.39
13	532024	368561	Winceby Rectory Pit SSSI	-	-	-	0.002	-	-	-
14	540933	369486	Dalby Hill SSSI	-	-	-	0.003	-	-	-
15	526293	361329	Fulsby Wood SSSI	0.03	1.0	10.0	0.002	0.22	0.017	0.17
16	526110	359131	Troy Wood SSSI	0.03	1.0	10.0	0.002	0.25	0.019	0.19

Figure 7a. Predicted maximum annual mean ammonia concentrations



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Figure 7b. Maximum annual nitrogen deposition rates



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6. Summary and Conclusions

AS Modelling & Data Ltd. has been instructed by Mr. Oliver Grundy of JHG Planning Consultancy Ltd., on behalf of Mr. David Wright, to use computer modelling to assess the impact of ammonia emissions from the existing and proposed free range egg-laying chicken houses at Poplar Farm, Hagnaby Lane, Keal Cotes, near to Spilsby in Lincolnshire. PE23 4AL.

Ammonia emission rates from the existing and proposed poultry houses and ranging areas have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors. The ammonia emission rates have then been used as inputs to an atmospheric dispersion and deposition model which calculates ammonia exposure levels and nitrogen and acid deposition rates in the surrounding area.

The modelling predicts that:

- The process contribution to annual mean ammonia concentrations and nitrogen deposition rates would not exceed the Environment Agency's lower threshold percentage of the relevant Critical Level or Critical Load at any of the wildlife sites included in this study.
- There are exceedances of 1% of the strictest Critical Level of $1.0 \mu\text{g}/\text{m}^3$ at Keal Carr SSSI. These exceedances are small and it should be noted that this threshold used as an indicator to determine whether further assessment is required and exceedance of the threshold does not imply harm.
- This existing poultry house has previously been the subject of a cumulative assessment as a matter of methodological rigour this report presents results for both the existing and proposed poultry houses. However, it should be emphasised that results for the proposed poultry house alone would be approximately half of those presented and therefore the process contributions for the proposed house alone would be below 1% of Critical Level or Critical Load. Results for individual components of the modelling are available upon request.
- There are no exceedances of 1% of the relevant Critical Levels or Critical Loads at any of the other SSSIs identified for this study

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