A Dispersion Modelling Study of the Impact of Odour from the Proposed Poultry Houses at Pear Tree Hill Road, near Whaplode Drove, Spalding in Lincolnshire

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1. Introduction

AS Modelling & Data Ltd. has been instructed by Mr. James Whilding of Acorus Rural Property Services Ltd., on behalf of Mr. Stuart Adams of Holbeach Poultry Ltd/Bowler Adams LLP, to use computer modelling to assess the impact of odour emissions from the proposed broiler chicken rearing houses at Pear Tree Hill Road, Whaplode Drove, Spalding, Lincolnshire. PE12 0SL.

Odour emission rates from the proposed poultry houses have been assessed and quantified based upon an emissions model that takes into account the likely internal odour concentrations and ventilation rates of the poultry houses. The odour emission rates so obtained have then been used as inputs to an atmospheric dispersion model which calculates odour exposure levels in the surrounding area.

This report is arranged in the following manner:

- Section 2 provides relevant details of the site and potentially sensitive receptors in the area.
- Section 3 provides some general information on odour, details of the method used to estimate odour emissions from the poultry houses, relevant guidelines and legislation on exposure limits and where relevant, details of likely background levels of odour.
- Section 4 provides some information about ADMS, the dispersion model used for this study and details the modelling parameters and procedures.
- 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 proposed poultry rearing houses at Pear Tree Hill Road is in an isolated rural area; the surrounding land is used almost exclusively for arable farming. The site is approximately 2.4 km to the east-south-east of the village of Moulton Chapel in Lincolnshire, at an altitude of around 3 m on level drained fenland.

Under the proposal, twelve new broiler chicken rearing houses would be constructed on land off Pear Tree Hill Road. The new poultry houses would provide accommodation for up to 552,120 birds. The new houses would be ventilated by uncapped high speed ridge mounted fans, each with a short chimney, with gable end fans for supplementary ventilation in hot weather. The chickens would be reared from day old chicks for a period of 38 days and houses would be empty for around 10 days at the end of each crop.

There are some residences, commercial properties and amenity areas in the area around the site. Excluding the proposed workers dwellings at the farm, the closest residential properties are at: Peartree Farm, approximately 410 m to the south; Falconer's Rest, approximately 450 m to the north-west and Shepherds Cottage, approximately 660 m to the north-east.

A map of the surrounding area is provided in Figure 1, the positions of the proposed poultry houses at Pear Tree Hill Farm are outlined in blue.

Figure 1. The area surrounding the site of the proposed poultry houses at Pear Tree Hill Road

3. Odour, Emission Rates, Exposure Limits & Background Levels

3.1 Odour concentration, averaging times, percentiles and FIDOR

Odour concentration is expressed in terms of European Odour Units per metre cubed of air (ou_E/m^3). The following definitions and descriptions of how an odour might be perceived by a human with an average sense of smell may be useful, however, it should be noted that within a human population there is considerable variation in acuity of sense of smell.

- 1.0 ou_E/m^3 is defined as the limit of detection in laboratory conditions.
- At 2.0 - 3.0 ou_E/m^3, a particular odour might be detected against background odours in an open environment.
- When the concentration reaches around 5.0 ou_E/m^3, a particular odour will usually be recognisable, if known, but would usually be described as faint.
- At 10.0 ou_E/m^3, most would describe the intensity of the odour as moderate or strong and if persistent, it is likely that the odour would become intrusive.

The character, or hedonic tone, of an odour is also important; typically, odours are grouped into three categories.

Most offensive:

- Processes involving decaying animal or fish remains.
- Processes involving septic effluent or sludge.
- Biological landfill odours.

Moderately offensive:

- Intensive livestock rearing.
- Fat frying (food processing).
- Sugar beet processing.
- Well aerated green waste composting.

Less offensive:

- Brewery.
- Confectionery.
- Coffee roasting.
- Bakery.

Dispersion models usually calculate hourly mean odour concentrations and Environment Agency guidelines and findings from UK Water Industry Research (UKWIR) are also framed in terms of hourly mean odour concentration.

The Environment Agency guidelines and findings from UKWIR use the 98th percentile hourly mean; this is the hourly mean odour concentration that is equalled or exceeded for 2% of the time period considered, which is typically one year. The use of the 98th percentile statistic allows for some consideration of both frequency and intensity of the odours.

At some distance from a source, it would be unusual if odour concentration remained constant for an hour and in reality, due to air turbulence and changes in wind direction, short term fluctuations in concentration are observed. Therefore, although average exposure levels may be below the detection threshold, or a particular guideline, a population may be exposed to short term concentrations which are higher than the hourly average. It should be noted that a fluctuating odour is often more noticeable than a steady background odour at a low concentration. It is implicit that within the model's hourly averaging time and the Environment Agency guidelines and findings from UKWIR that there would be variation in the odour concentration around this mean, i.e. there would be short periods when odour concentration would be higher than the mean and lower than the mean.

The FIDOR acronym is a useful reminder of the factors that will determine the degree of odour pollution:

- **F**requency of detection.
- **I**ntensity as perceived.
- **D**uration of exposure.
- **O**ffensiveness.
- **R**eceptor sensitivity.

3.2 Environment Agency guidelines

In April 2011, the Environment Agency published H4 Odour Management guidance (H4). In Appendix 3 - Modelling Odour Exposure, benchmark exposure levels are provided. The benchmarks are based on the 98th percentile of hourly mean concentrations of odour modelled over a year at the site/installation boundary. The benchmarks are:

- 1.5 ou_E/m^3 for most offensive odours.
- 3.0 ou_E/m^3 for moderately offensive odours.
- 6.0 ou_E/m^3 for less offensive odours.

Any modelled results that project exposures above these benchmark levels, after taking uncertainty into account, indicates the likelihood of unacceptable odour pollution.

3.3 UK Water Industry Research findings

The main source of research into odour impacts in the UK has been the wastewater industry. An in-depth study of the correlation between modelled odour impacts and human response was published by UKWIR in 2001. This was based on a review of the correlation between reported odour complaints and modelled odour impacts in relation to nine wastewater treatment works in the UK with on-going odour complaints. The findings of this research and subsequent UKWIR research indicated the following, based on the modelled 98th percentile of hourly mean concentrations of odour:

- At below 5.0 ou_E/m^3, complaints are relatively rare at only 3% of the total registered.
- At between 5.0 ou_E/m^3 and 10.0 ou_E/m^3, a significant proportion of total registered complaints occur, 38% of the total.
- The majority of complaints occur in areas of modelled exposures of greater than 10.0 ou_E/m^3, 59% of the total.

3.4 Choice of odour benchmarks for this study

Odours from poultry rearing are usually placed in the moderately offensive category. Therefore, for this study, the Environment Agency's benchmark for moderately offensive odours, a 98th percentile hourly mean of 3.0 ou_E/m^3 over a one year period, is used to assess the impact of odour emissions from the proposed poultry unit at potentially sensitive receptors in the surrounding area.

3.5 Quantification of odour emissions

Odour emission rates from broiler houses depend on many factors and are highly variable. At the beginning of a crop cycle, when chicks are small, litter is clean and only minimum ventilation is required, the odour emission rate may be relatively small. Towards the end of the crop, odour production within the poultry housing increases rapidly and ventilation requirements are greater, particularly in hot weather, therefore emission rates are considerably greater than at the beginning of the crop.

Peak odour emission rates are likely to occur when the housing is cleared of spent litter at the end of each crop. There is little available information on the magnitude of this peak emission, but it is likely to be greater than any emission that might occur when there are birds in the house. The time taken to perform the operation is usually around two hours per shed and it is normal to maintain ventilation during this time. There are measures that can be taken to minimise odour production whilst the housing is being cleared of spent litter and there may be some discretion as to when the operation is carried out; therefore, to avoid high odour levels at nearby sensitive receptors, it may be possible to time the operation to coincide with winds blowing in a favourable direction.

To calculate an odour emission rate, it is necessary to know the internal odour concentration and ventilation rate of the poultry house. For the calculation, the internal concentration is assumed to be a function of the age of the crop and the stocking density.

The internal concentrations used in the calculations increase exponentially from 300 ou_E/m^3 at day 1 of the crop, to approximately 700 ou_E/m^3 at day 16 of the crop, to approximately 1,800 ou_E/m^3 at day 30 of the crop and approximately 2,300 ou_E/m^3 at day 34 of the crop. These figures are based primarily on Robertson *et al.* (2002); however, other available literature and olfactometric measurements[1] available to AS Modelling & Data Ltd. are also considered.

1. The reports on the olfactometric measurements can be made available to regulators for inspection upon request.

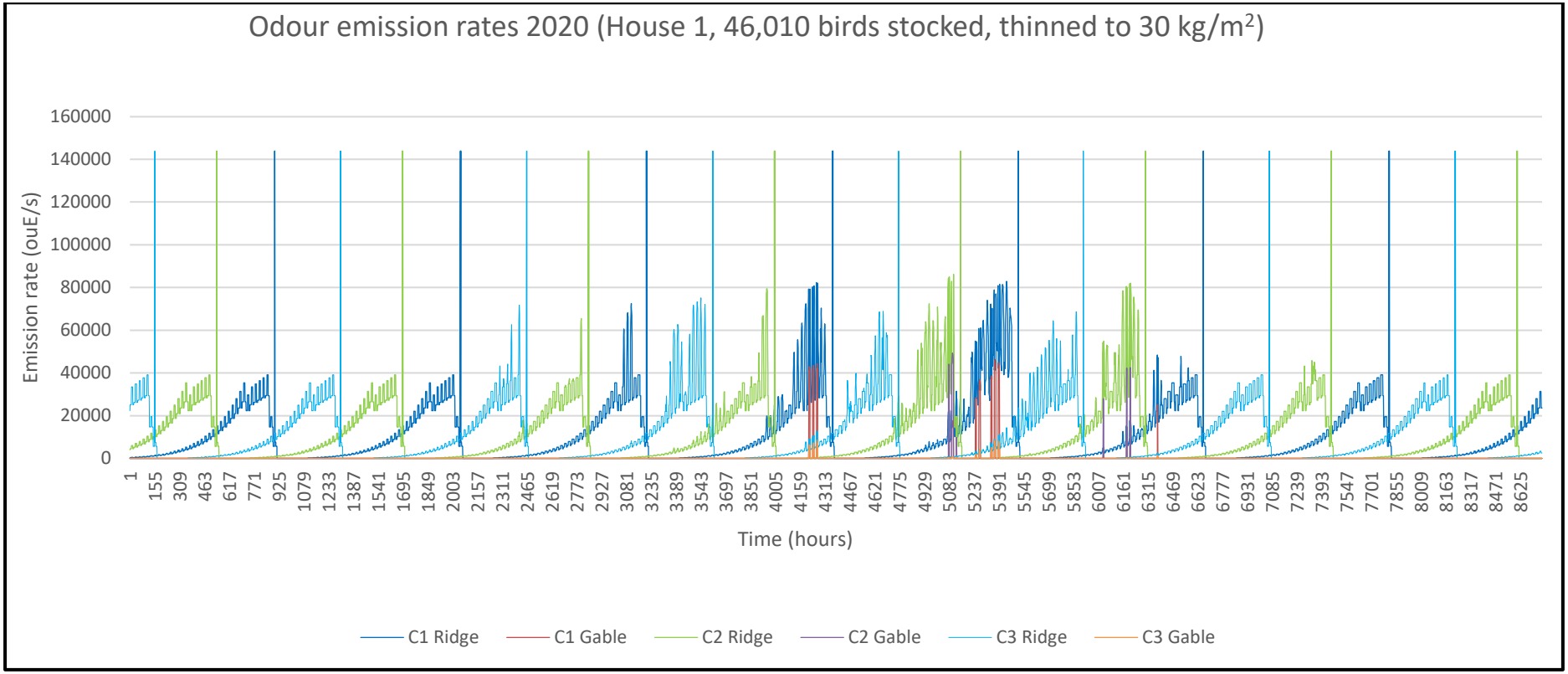
The ventilation rates used in the calculations are based on industry practices and standard bird growth factors. Minimum ventilation rates are as those of an operational poultry house and maximum ventilation rates are based on Defra guidelines (the maximum ventilation rate is ~10 m^3-air/bird/h). Target internal temperature is 33 Celsius at the beginning of the crop and is decreased to 22 Celsius by day 34 of the crop. If the external temperature is 7 Celsius, or more, lower than the target temperature, minimum ventilation only is assumed for the calculation. Above this, ventilation rates are increased in proportion to the difference between ambient temperature and target internal temperature. A maximum transitional ventilation rate (35% of the maximum possible ventilation rate) is reached when the ambient temperature is equal to the target temperature. A high ventilation rate (70% maximum possible ventilation rate) is reached when the temperature is 4 degrees above target and if external temperature is above 33 Celsius the maximum ventilation rate is assumed.

At high ventilation rates, it is observed that internal odour concentrations fall because odour is extracted much faster than it is created. Therefore, if the calculated ventilation rate exceeds that required to replace the volume of air in the house every 5 minutes, internal concentrations are reduced (by a factor of the square root of 7.5 times the shed volume divided by the ventilation rate as an hourly figure). Based upon these principles, an emission rate for each hour of the period modelled is calculated by multiplying the concentration by the ventilation rate. Both the crop length and period the housing is empty can be varied. An estimation of the emission during the cleaning out process can also be included. In this case, it is assumed that the houses are cleared sequentially and each house takes 2 hours to clear.

In this case, it is assumed for the calculations that the crop length is 38 days and that there is an empty period of 10 days after each crop. To provide robust statistics, three sets of calculations were performed; the first with the first day of the meteorological record coinciding with day 1 of the crop cycle, the second coinciding with day 16 of the crop and the third coinciding with day 32 of the crop.

As examples, the odour emission rates for a single house over 2020 for each of the three crop cycles are shown in Figure 2 (House 1, 46,010 birds initially stocked, 30 kg/m^2 maximum stocking).

Figure 2. Emission rates in 2022 for each of the three crop cycles –House 1 (maximum stocking 30 kg/m^2), 46,010 birds initially stocked



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

The Atmospheric Dispersion Modelling System (ADMS) ADMS 6 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 (FLOWSTAR[2]). 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.

A wind rose showing the distribution of wind speeds and directions in the GFS derived data is shown in Figure 3a. Wind speeds are modified by the treatment of roughness lengths (see Section 4.7). The roughness length modified wind rose for Pear Tree Hill Farm is shown in Figure 3b. The resolution of the wind field within ADMS is 100 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 sigma 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 3a. The wind rose. Raw GFS derived data for 52.737 N, 0.039 W, 2020-2023

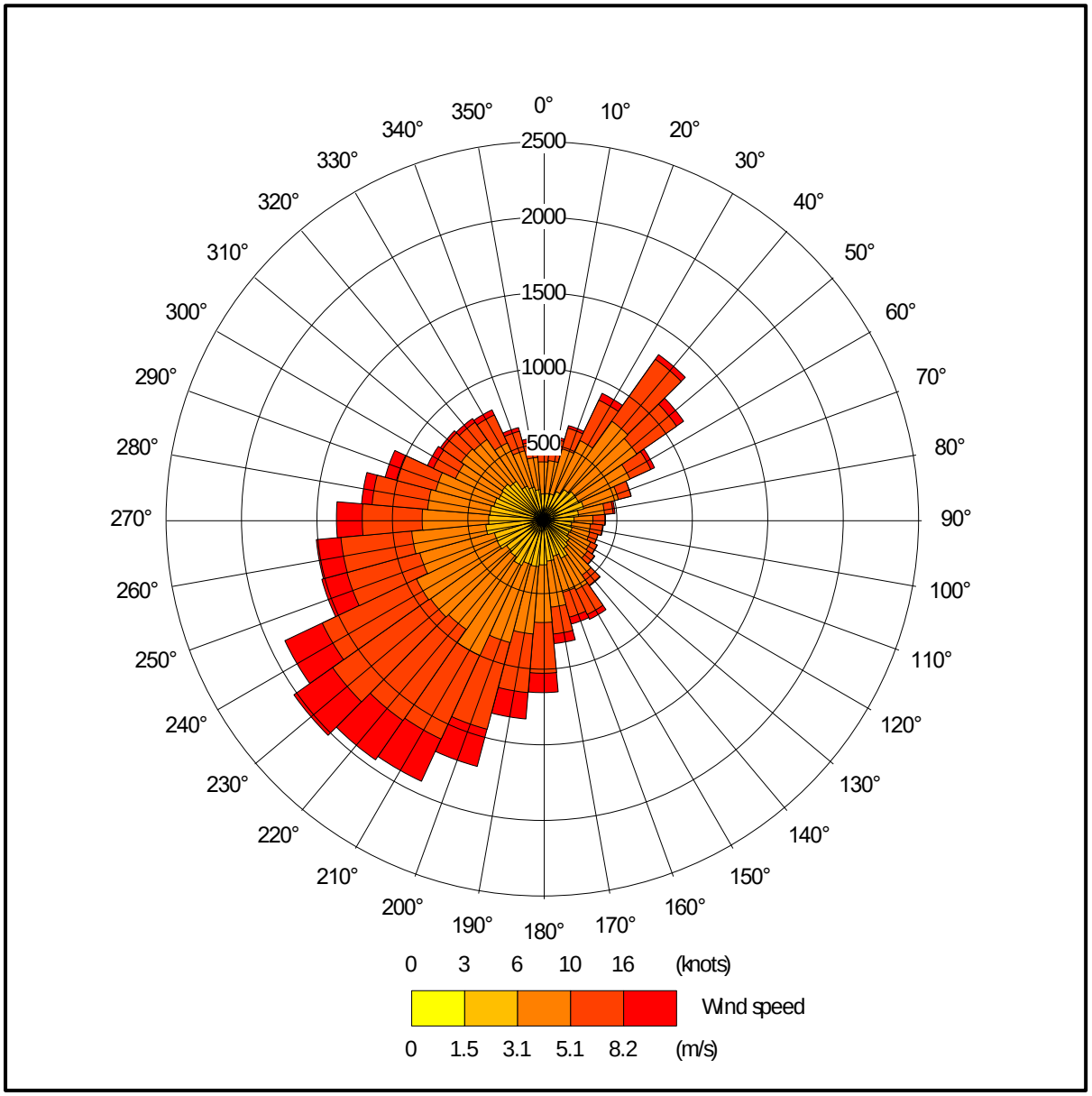
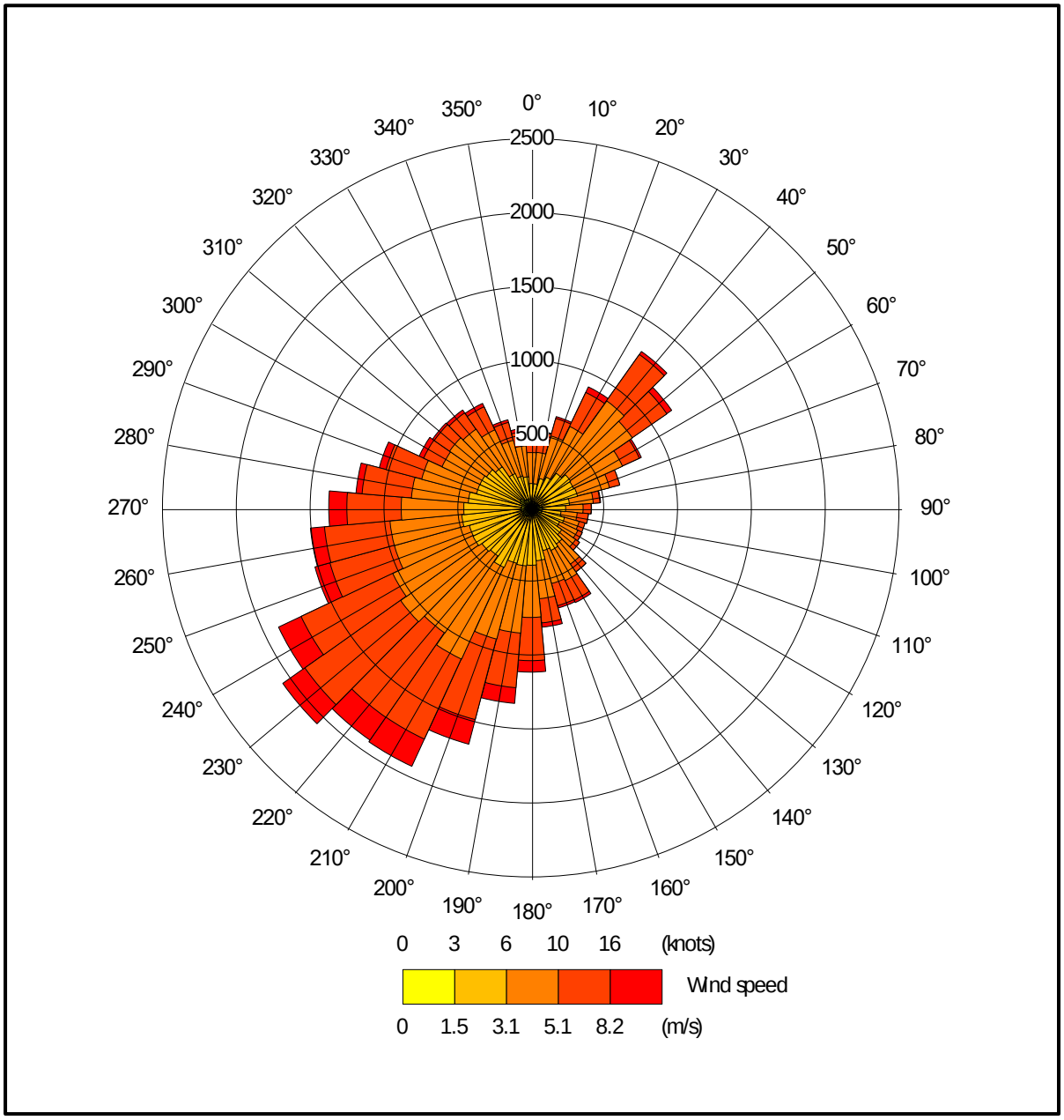


Figure 3b. The wind rose. modified GFS derived data for NGR 348100, 444100, 2020-2023



4.2 Emission sources

Emissions from the chimneys of the capped fans and uncapped high-speed ridge fans that would be used for the ventilation of the poultry houses are represented by three point sources per house within ADMS (H1 to H12; 1, 2 & 3).

Emissions from the gable end fans that would be used to supplement the primary ventilation of the poultry houses have been represented by volume sources within ADMS (H1to6_GAB and H7to12_GAB).

The emissions from the gable end fans are assumed to be zero unless the ventilation requirement within the poultry houses, which is a function of the age/weight of the flock and ambient temperature, exceeds the capacity of the high-speed ridge fans. In this case, as a precautionary measure, it is assumed that gable end fans provide 50% of the ventilation whenever ambient temperature exceeds 24 Celsius. It should be noted that particularly with 30 kg/m^2 maximum stocking densities, gable end fans would be used less frequently.

Details of the point source parameters are shown in Table 1a and details of the volume source parameters are shown in Table 1b. The positions of the emission sources used are shown in Figure 4 (the point sources are marked by green circles and the volume sources are marked by red shaded rectangles).

Table 1a. Point source parameters

Source ID	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (˚C)	Emission rate per source (ou_E/s)
H1 to H6 1, 2 & 3	7.0	0.8	11	Variable [1]	Variable [1 & 2]
H7 to H12 1, 2 & 3	7.0	0.8	11	Variable [1]	Variable [1 & 2]

Table 1b. Volume source parameters

Source ID	Length (m)	Width (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate (ou_E/s)
H1to6_GAB	184.0	10.0	3.0	1.5	Ambient	Variable [1 & 3]
H7to12_GAB	184.0	10.0	3.0	1.5	Ambient	Variable [1 & 3]

1. Dependent on crop stage and ambient temperature.
2. Reduced by 50% when ambient temperature equals or exceeds 24 Celsius.
3. 50% of total emitted only when ambient temperature equals or exceeds 24 Celsius.

4.3 Modelled buildings

The structure of the poultry houses and nearby farm buildings may affect the odour plumes from the point sources that would be used to ventilate the poultry houses. Therefore, these buildings are modelled within ADMS. The positions of the modelled buildings may be seen in Figures 4 (marked by grey rectangles).

4.4 Discrete receptors

Sixteen discrete receptors have been defined at a selection of nearby residences and commercial properties. The receptors are defined at 1.5 m above ground level within ADMS and their positions may be seen in Figure 5 (marked by enumerated pink rectangles).

4.5 Nested Cartesian grid

To produce the contour plots presented in Section 5 of this report, a nested Cartesian grid has been defined within ADMS. The grid receptors are defined at 1.5 m above ground level within ADMS. The positions of the grid receptors may be seen in Figure 5 (marked by green crosses).

4.6 Terrain data

Terrain height is not modelled, but surface roughness is modelled over a 6.4 km by 6.4km domain at 50m resolution. The resolution of the wind field over this domain is 100m.

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 0.064 m (arithmetic average of the spatially varying roughness over the modelling domain). The sample of the central area of the spatially varying roughness length field is shown in Figure 6.

Figure 4. The positions of modelled buildings and sources

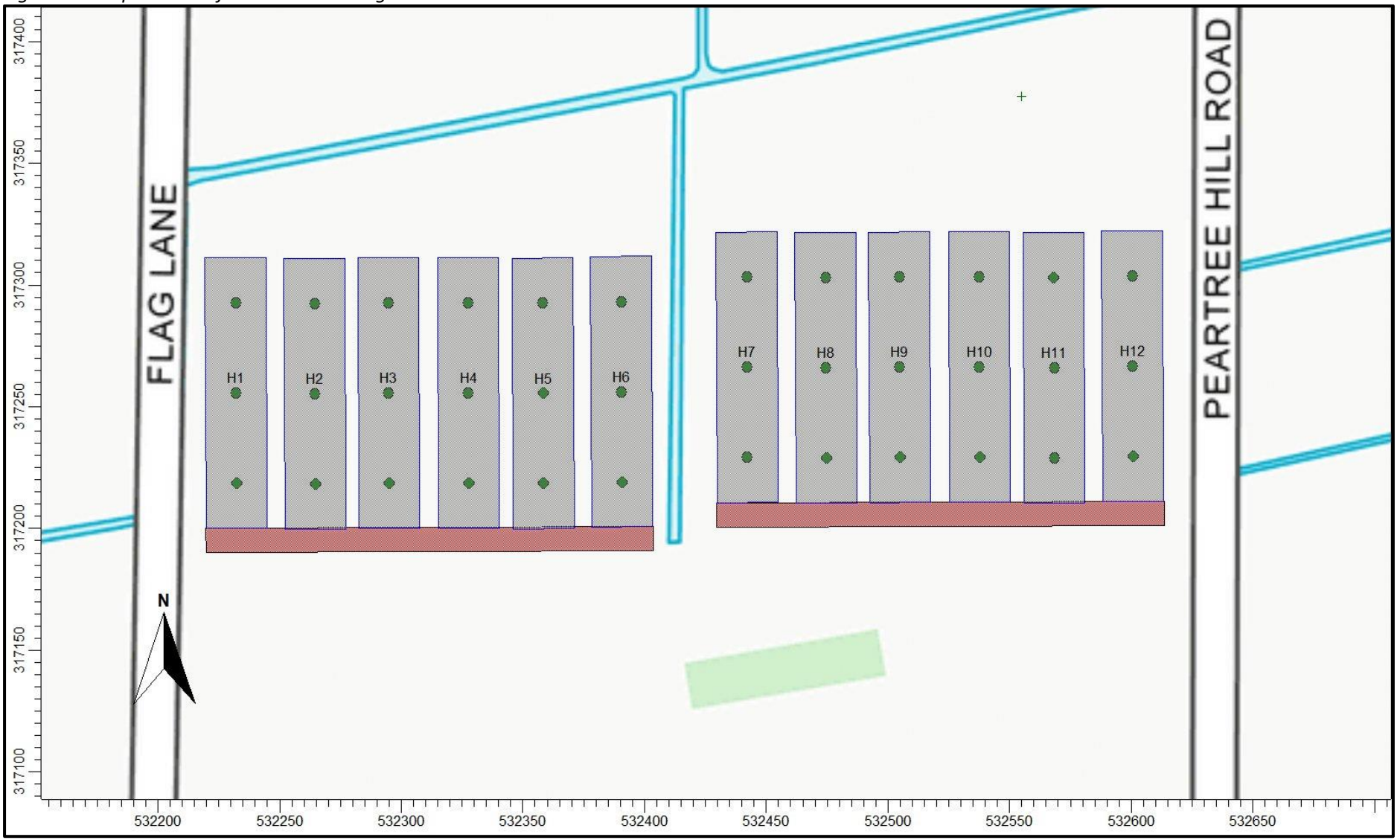


Figure 5. The discrete receptors and nested Cartesian grid receptors

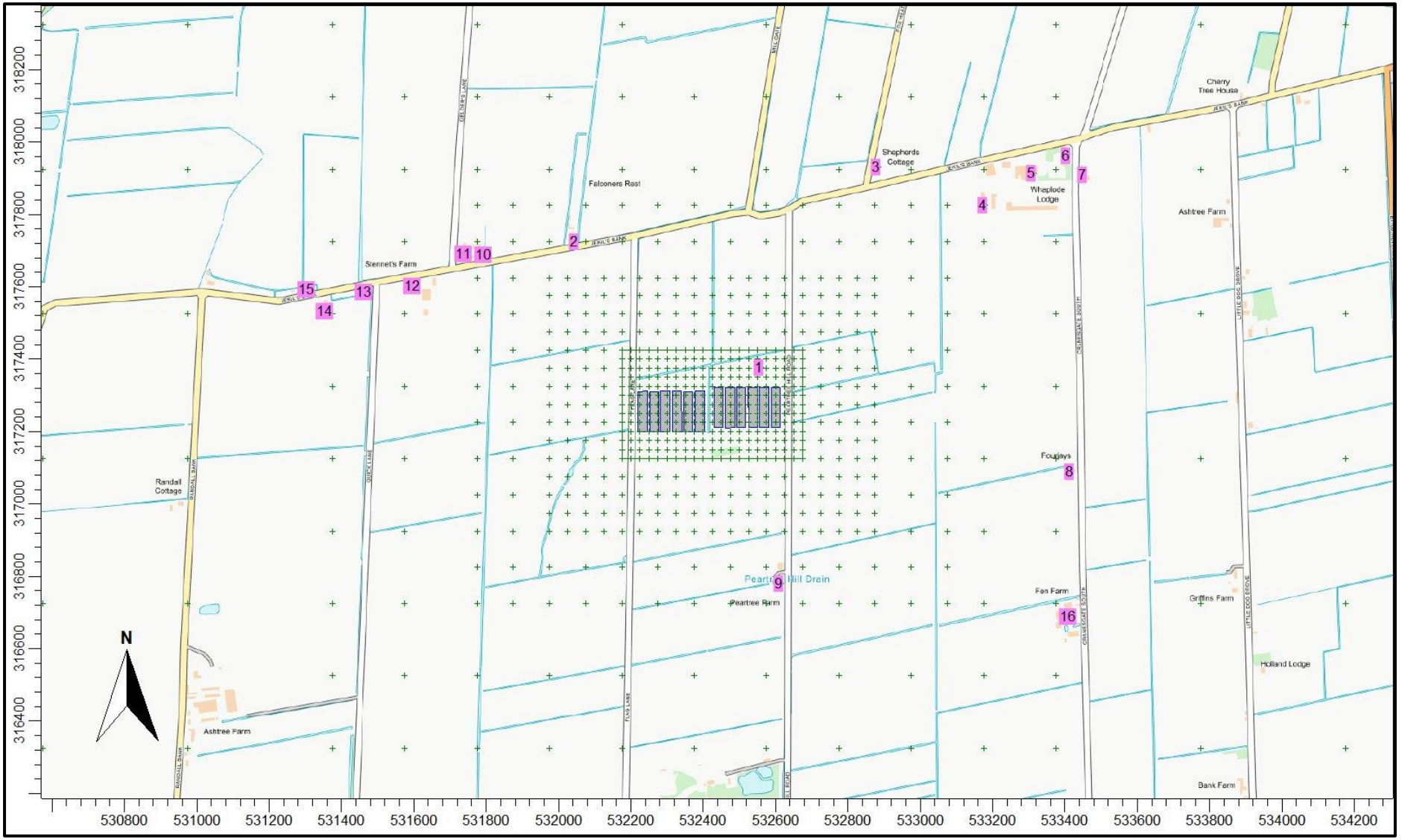
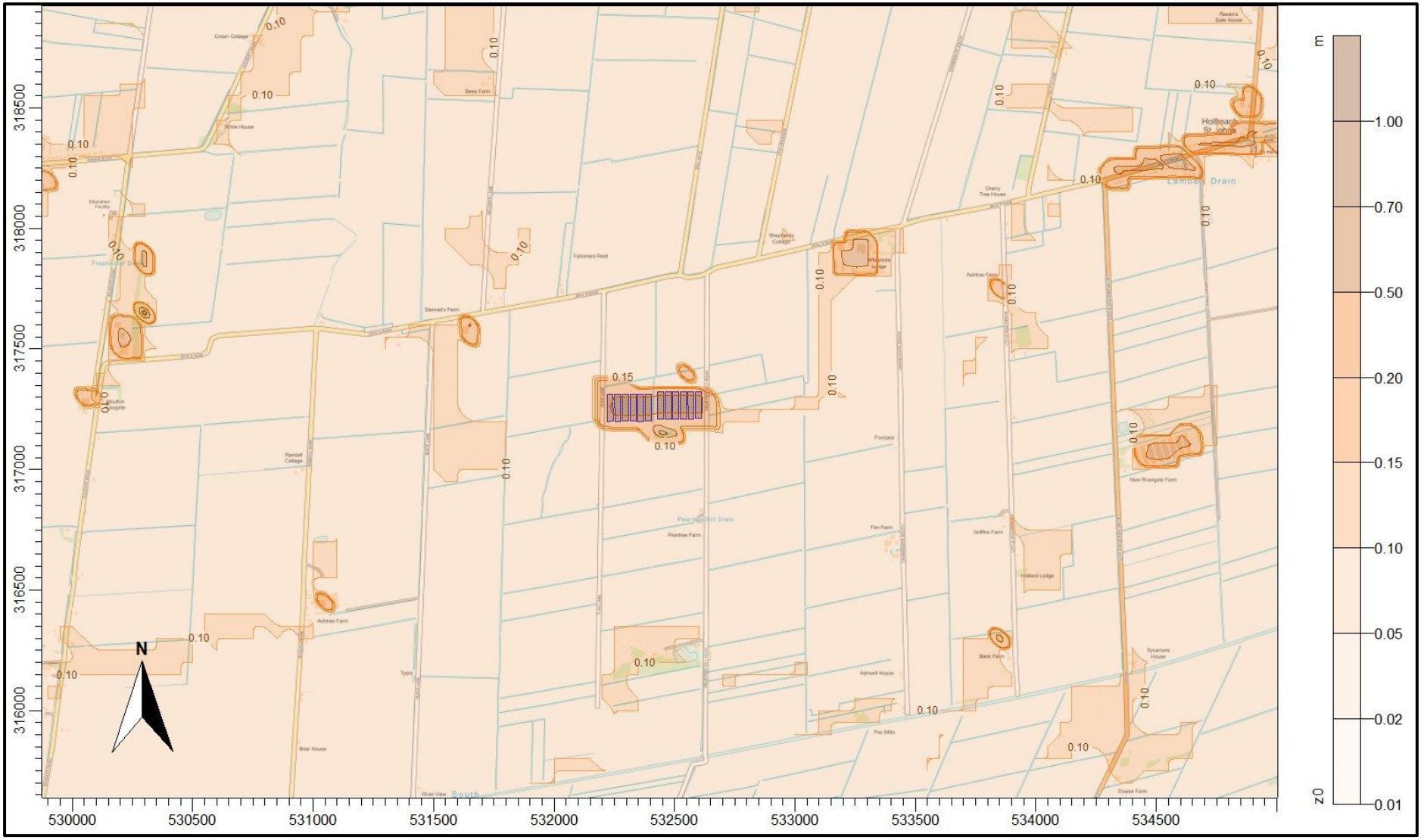


Figure 6. The spatially varying surface roughness field (central area)



5. Details of the Model Runs and Results

For this study, the model was run with the calms and terrain (roughness length only) modules in ADMS.

ADMS was effectively run twelve times, once for each year of the four year meteorological record and for each of the three crop cycles. Statistics for the annual 98th percentile hourly mean odour concentration at each receptor were compiled for each of the runs.

A summary of the results at the discrete receptors is provided in Table 2, where the maximum annual 98th percentile hourly mean odour concentration is shown.

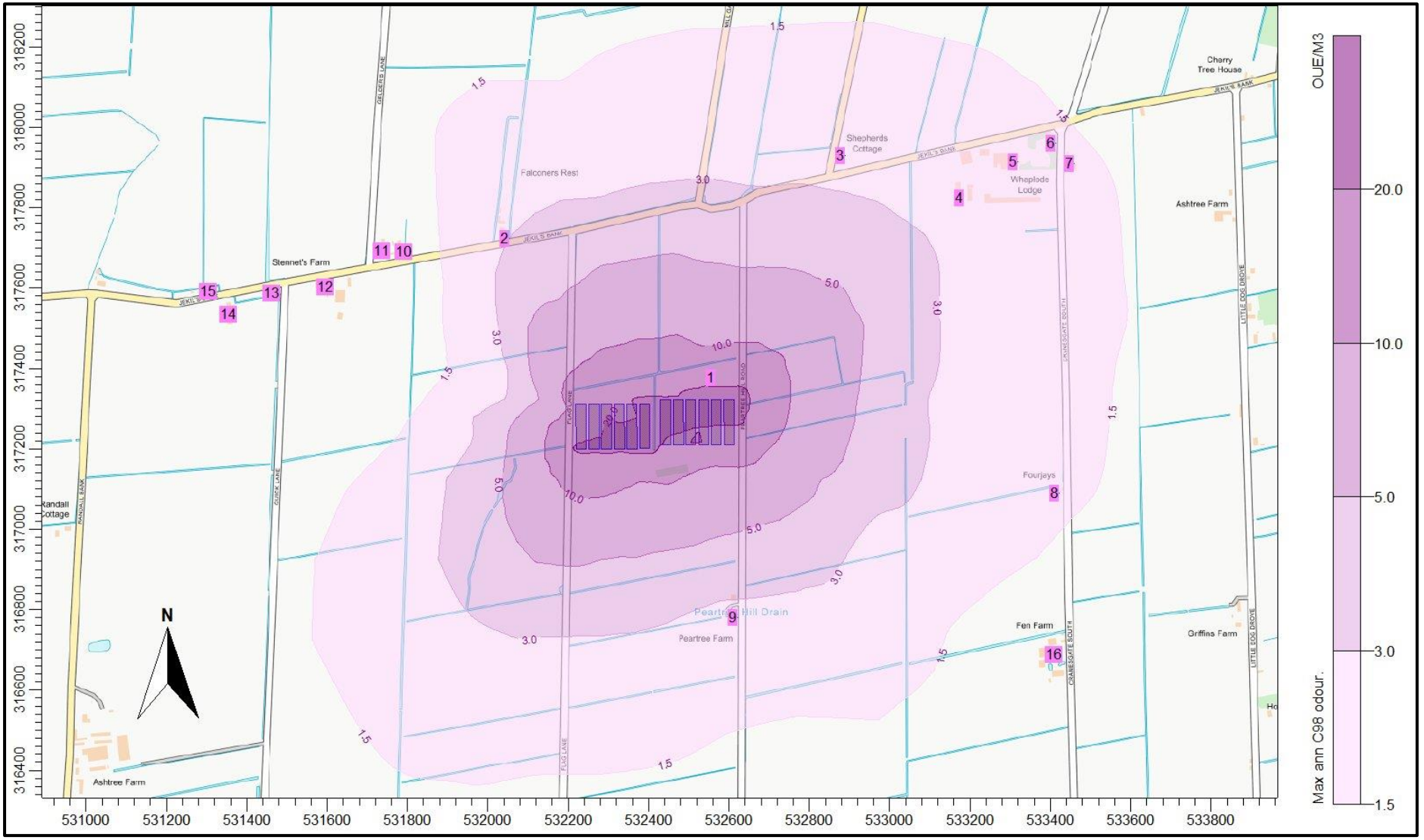
In Table 2, predicted odour exposures in excess of the Environment Agency's benchmark of 3.0 ou_E/m^3 as an annual 98th percentile hourly mean are coloured blue; those in the range that UKWIR research suggests gives rise to a significant proportion of complaints, 5.0 ou_E/m^3 to 10.0 ou_E/m^3 as an annual 98th percentile hourly mean, are coloured orange and predicted exposures likely to cause annoyance and complaint are coloured red.

A contour plot of the maximum annual 98th percentile hourly mean odour concentrations is shown in Figure 7.

Table 2. Predicted maximum annual 98th percentile hourly mean odour concentrations at the discrete receptors

Receptor	X(m)	Y(m)	Name/Location	Maximum annual mean odour concentration - (ou_E/m^3)
				GFS Calms Terrain
1	532555	317377	Pear Tree Hill Farm	**15.6**
2	532042	317724	Falconer's Rest	2.9
3	532878	317930	Shepherds Cottage	2.6
4	533173	317825	Whalpole Lodge	2.4
5	533308	317913	Whalpole Lodge	1.9
6	533402	317961	Whalpole Lodge	1.6
7	533448	317909	Whalpole Lodge	1.7
8	533411	317090	Fourjays	1.7
9	532610	316781	Peartree Farm	2.5
10	531791	317690	Jekil's Bank	1.0
11	531736	317692	Jekil's Bank	0.8
12	531596	317603	Stennet's Farm	0.6
13	531461	317587	Jekil's Bank	0.4
14	531353	317534	Jekil's Bank	0.4
15	531304	317592	Jekil's Bank	0.3
16	533410	316689	Fen Farm	1.0

Figure 7. Predicted maximum annual 98th percentile hourly mean odour concentration



6. Summary and Conclusions

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Odour emission rates from the proposed poultry houses have been assessed and quantified based upon an emissions model that takes into account the likely internal odour concentrations and ventilation rates of the poultry houses. The odour emission rates so obtained have then been used as inputs to an atmospheric dispersion model which calculates odour exposure levels in the surrounding area.

The modelling predicts that, should the poultry unit at Pear Tree Hill Road be developed, as proposed:

- There would be exceedances of the Environment Agency's benchmark for moderately offensive odours, which is a maximum annual 98th percentile hourly mean concentration of 3.0 ou_E/m^3 at receptor 1 (the proposed workers residences at Pear Tree Hill Farm itself).

- At all other residences considered, the odour exposure would be below the Environment Agency's benchmark for moderately offensive odours.

7. References

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