# A Dispersion Modelling Study of the Impact of Odour from the Existing and Proposed Broiler Chicken Rearing Houses at Boiling Wells Farm, Grantham Road, South Rauceby near Sleaford

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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 Bellamy of Greylees Ltd. to use computer modelling to assess the impact of odour emissions from the existing and proposed broiler chicken rearing houses at Boiling Wells Farm, Grantham Road, South Rauceby, Sleaford. NG34 8QX.

Odour emission rates from the existing and 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 broiler rearing unit at Boiling Wells Farm is in an isolated rural area. The surrounding land is used primarily for arable farming although there are some wooded areas nearby. The site is at an altitude of between 25 m and 30 m, with the land falling towards level drained fenland to the south-east and rising towards low hills to the north-west.

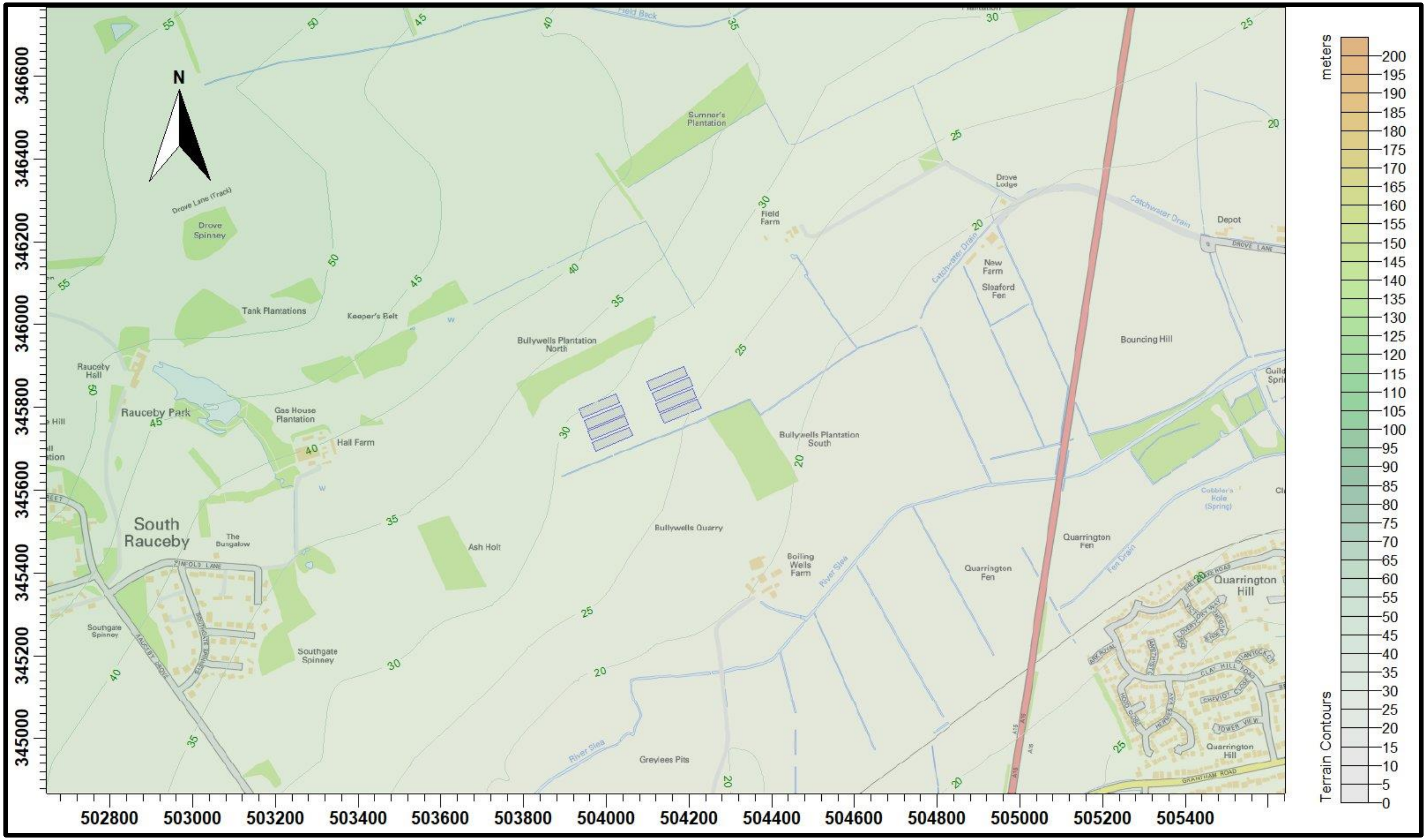
There are currently six broiler chicken rearing houses at Boiling Wells Farm. These houses are used to rear up to 198,900 broiler chickens and are primarily ventilated by uncapped high speed ridge mounted fans, each with a short chimney, with gable end fans which provide supplementary ventilation in hot weather conditions. The chickens are reared from day old chicks to up to around 38 days old and there are approximately 7.5 flocks per annum.

It is proposed that two new broiler rearing houses be constructed to the west of the existing houses. These two houses would provide accommodation for up to 66,300 additional broiler chickens and would be primarily ventilated by uncapped high speed ridge mounted fans, each with a short chimney, with gable end fans which would provide supplementary ventilation in hot weather conditions. The chickens would be reared from day old chicks to up to around 38 days old and there would be approximately 7.5 flocks per annum.

There are isolated residences and commercial properties in the area surrounding the site of the existing and proposed poultry houses. Excluding the farmhouse at Boiling Wells Farm, the closest of these are at: Field Farm, approximately 430 m to the north-east; New Farm, approximately 770 m to the east-north-east; Hall Farm approximately 660 m to the west and Drove Lodge, approximately 850 m to the east-north-east.

A map of the surrounding area is provided in Figure 1; the positions of the existing and proposed poultry rearing houses at Boiling Wells Farm are outlined in blue.

*Figure 1. The area surrounding the site of the poultry houses at Boiling Wells Farm*



# 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 98$^{th}$ 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 98$^{th}$ 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 98$^{th}$ 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 98$^{th}$ 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 98$^{th}$ 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 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 is usually 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 obtained from a review of available literature and olfactometric measurements[1] available to AS Modelling & Data Ltd. and are based primarily on Robertson *et al.* (2002).

1. These olfactometric measurements are contained in commercial reports and therefore cannot be published; however, they 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. 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. If the calculated ventilation rate is below the capacity of the ridge/roof fans (48 $m^3/s$), then all emissions are assumed to be from the ridge/roof fans. If the calculated ventilation rate is greater the capacity of the ridge/roof fans proportional emissions from both ridge/roof fans and the gable end fans are assumed. It should be noted that the use of the gable end fans is relatively rare and for example, the gable end fans were only used three times in the exceptionally hot summer of 2022. Additionally, as a precautionary measure, the gable end fans are assumed to operate during clearing out of the houses.

At high ventilation rates, it is likely 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. The birds at Boiling Wells are now stocked at low density so there is no thinning of the flocks. 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. The odour emission rates for a single house over the first year of the meteorological record for each of the three crop cycles is shown in Figure 2a; the emission rates for the exceptional year of 2022 are shown in Figure 2b.

*Figure 2a. Emission rates in 2019 for each of the three crop cycles - single house, 33,150 birds stocked*

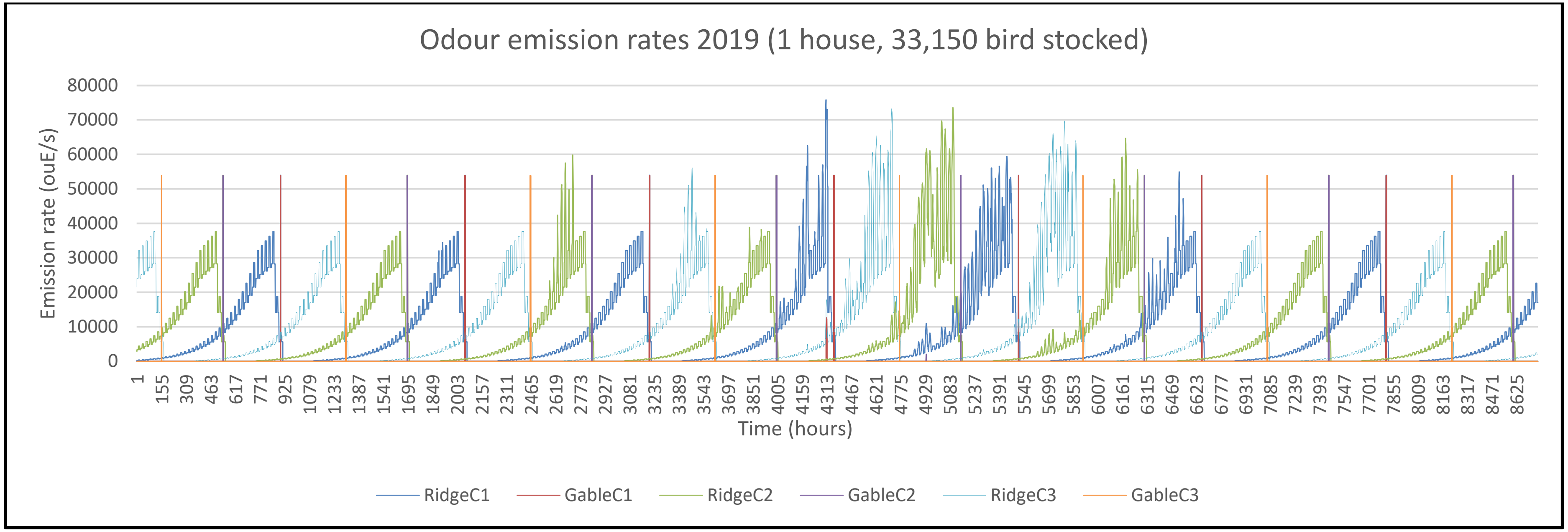
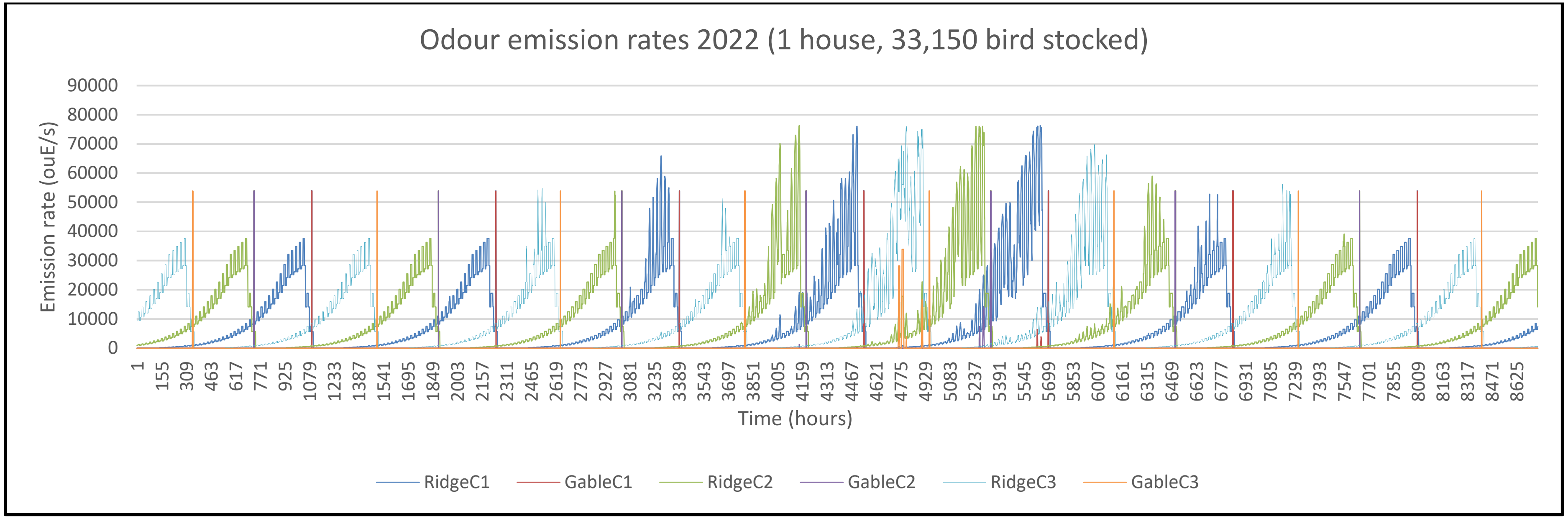


*Figure 2b. Emission rate in 2022 for each of the three crop cycles - single house, 33,150 birds stocked*



# 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 (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) and where terrain data is included in the modelling, the raw GFS wind speeds and directions will be modified. The terrain and roughness length modified wind rose for the site is shown in Figure 3b. The resolution of the wind field in terrain runs is 100 m. Please also note that FLOWSTAR[2] 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 amended [3].

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 53.00 N, 0.45 W, 2019-2022*

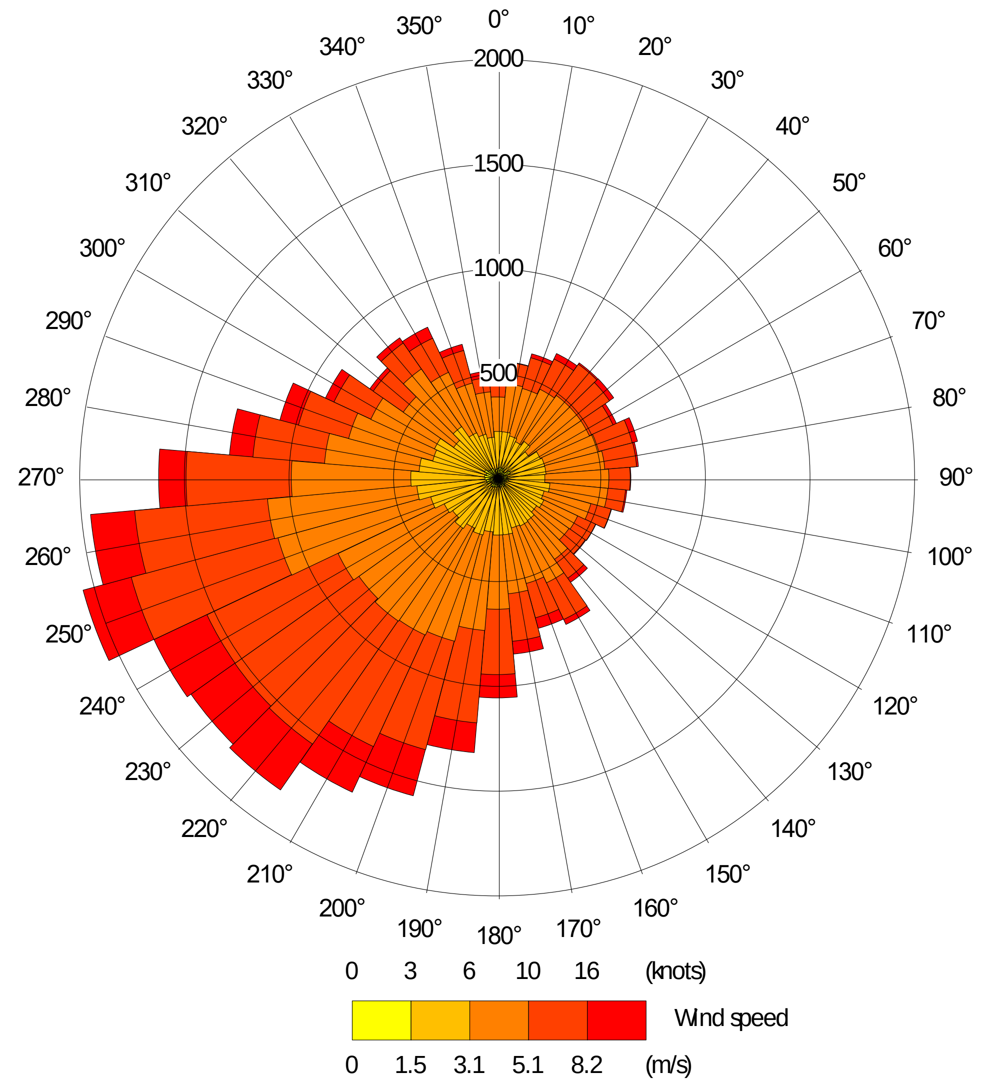
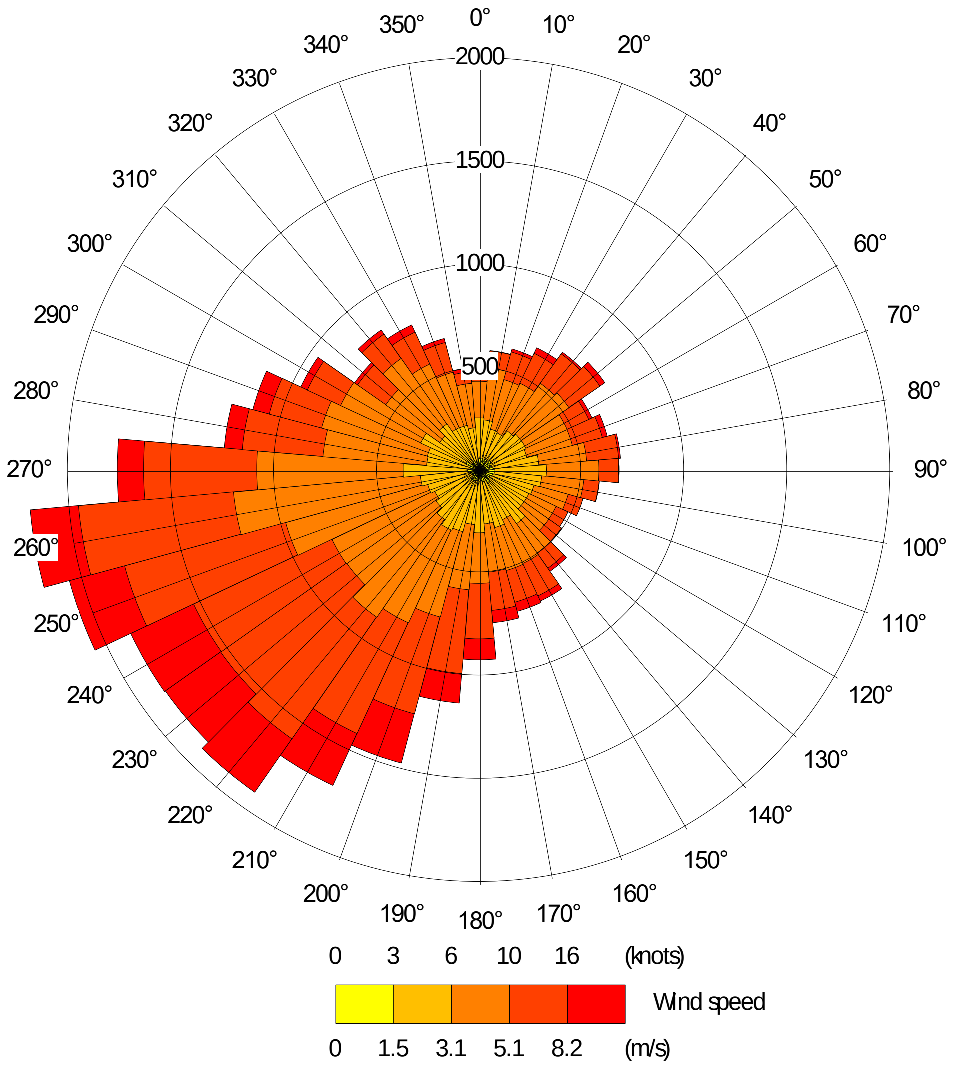


*Figure 3b. The wind rose. FLOWSTAR modified GFS derived data for NGR 504100, 345800, 2019-2022*



## 4.2 Emission sources

Emissions from the chimneys of the uncapped high speed ridge fans that are/would be used for the ventilation of the existing and proposed poultry houses are represented by three point sources per house within ADMS (H1 to H8; 1, 2 & 3).

Emissions from the gable end fans that would be used to supplement the primary ventilation have been represented by two volume sources within ADMS (H1toH4_GAB and H5toH8_GAB).

The emissions from the gable end fans are assumed to be zero unless the ventilation requirement within the poultry houses exceeds the capacity of the high speed ridge fans, taken to be 48 $m^3$/h, which is determined as a function of the age/weight of the flock and ambient temperature. Once this threshold has been reached, the total house emissions are assigned to the high speed ridge fans depending on the proportion that the capacity of these fans represents to the ventilation requirement for the poultry house, with the remainder being assigned to the gable end fans.

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 point sources used are shown in Figure 4 (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 H8; 1, 2 & 3 | 6.0 | 0.8 | 12.0 | Variable [1] | Variable [1 & 2] |

1. Dependent on crop stage and ambient temperature.
2. Reduced, when ambient conditions and age of the flock requires it, to the proportion the high speed fan capacity represents of the total house ventilation requirement.

*Table 1b. Volume source parameters*

| Source ID | Length (m) | Width (m) | Depth (m) | Base height (m) | Emission temperature (°C) | Emission rate ($ou_E$/s) |
|---|---|---|---|---|---|---|
| H1toH4_GAB | 109.0 | 10.0 | 3.0 | 0.5 | Ambient | Variable [3] |
| H5toH8_GAB | 109.0 | 10.0 | 3.0 | 0.5 | Ambient | Variable [3] |

3. Proportion of emissions determined by ventilation requirement above the roof fan capacity, when ambient conditions and age of the flock requires it.

## 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 4 (marked by grey rectangles).

*Figure 4. The positions of modelled buildings and sources*

## 4.4 Discrete receptors

Twelve 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 has been considered in the modelling. The terrain data are based upon the Ordnance Survey 50 m Digital Elevation Model. A 6.4 km x 6.4 km domain has been resampled at 50 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 100 m.

## 4.7 Other model parameters

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 0.2 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 5. The discrete receptors and nested Cartesian grid receptors*

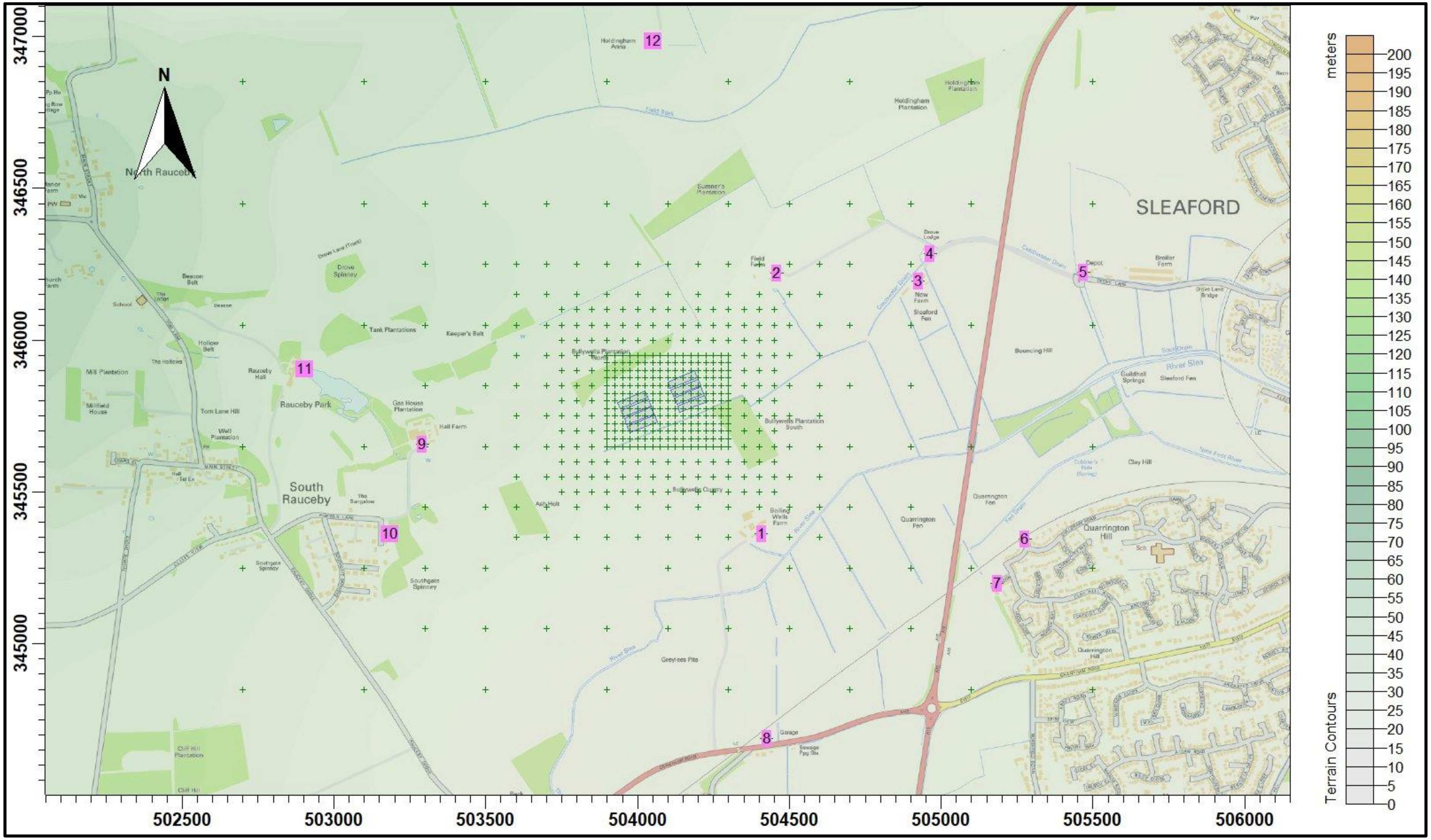
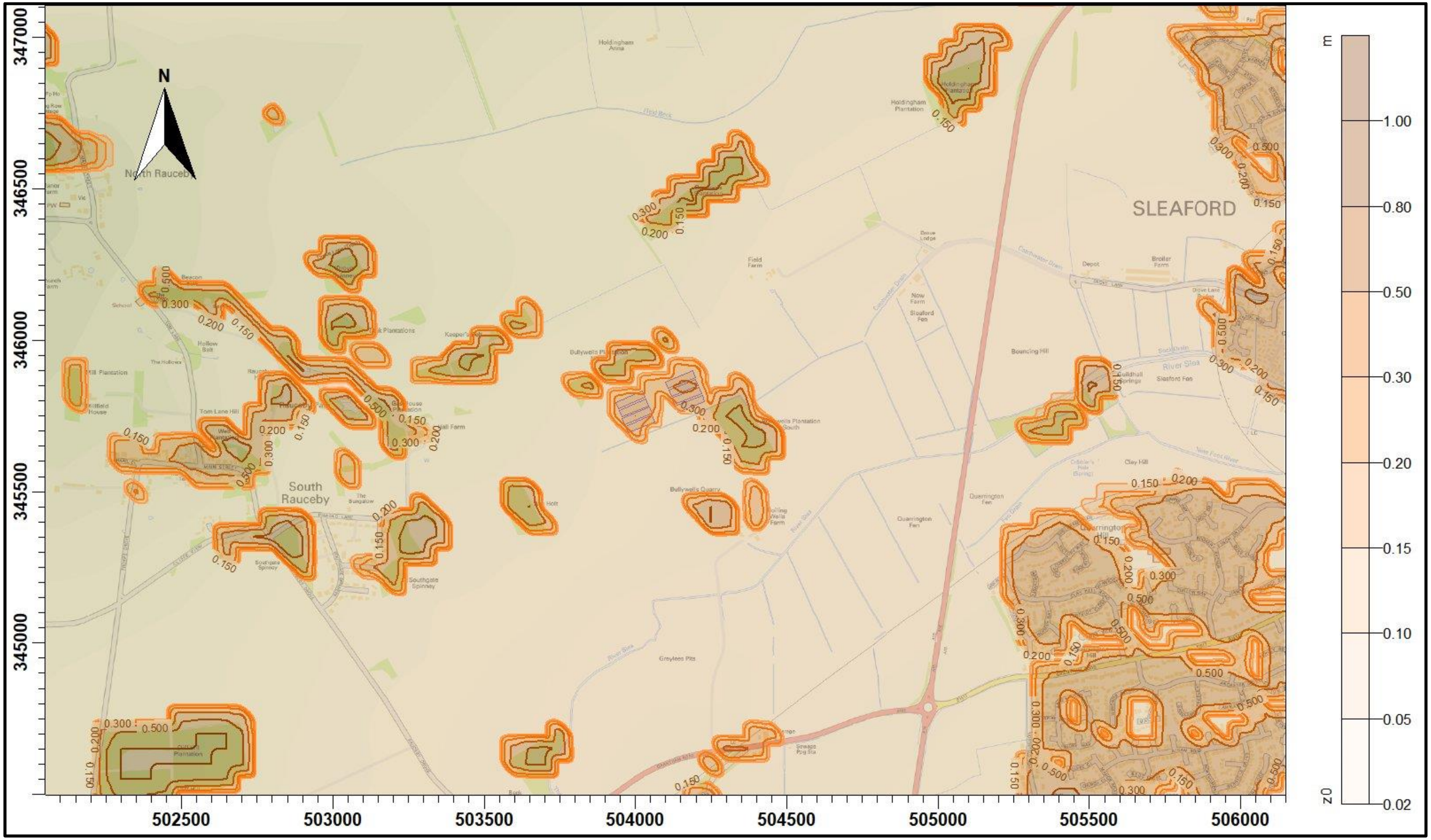


*Figure 6. The spatially varying surface roughness field*

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# 5. Details of the Model Runs and Results

For this study, the model was run with the calms and terrain 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 twelve runs.

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

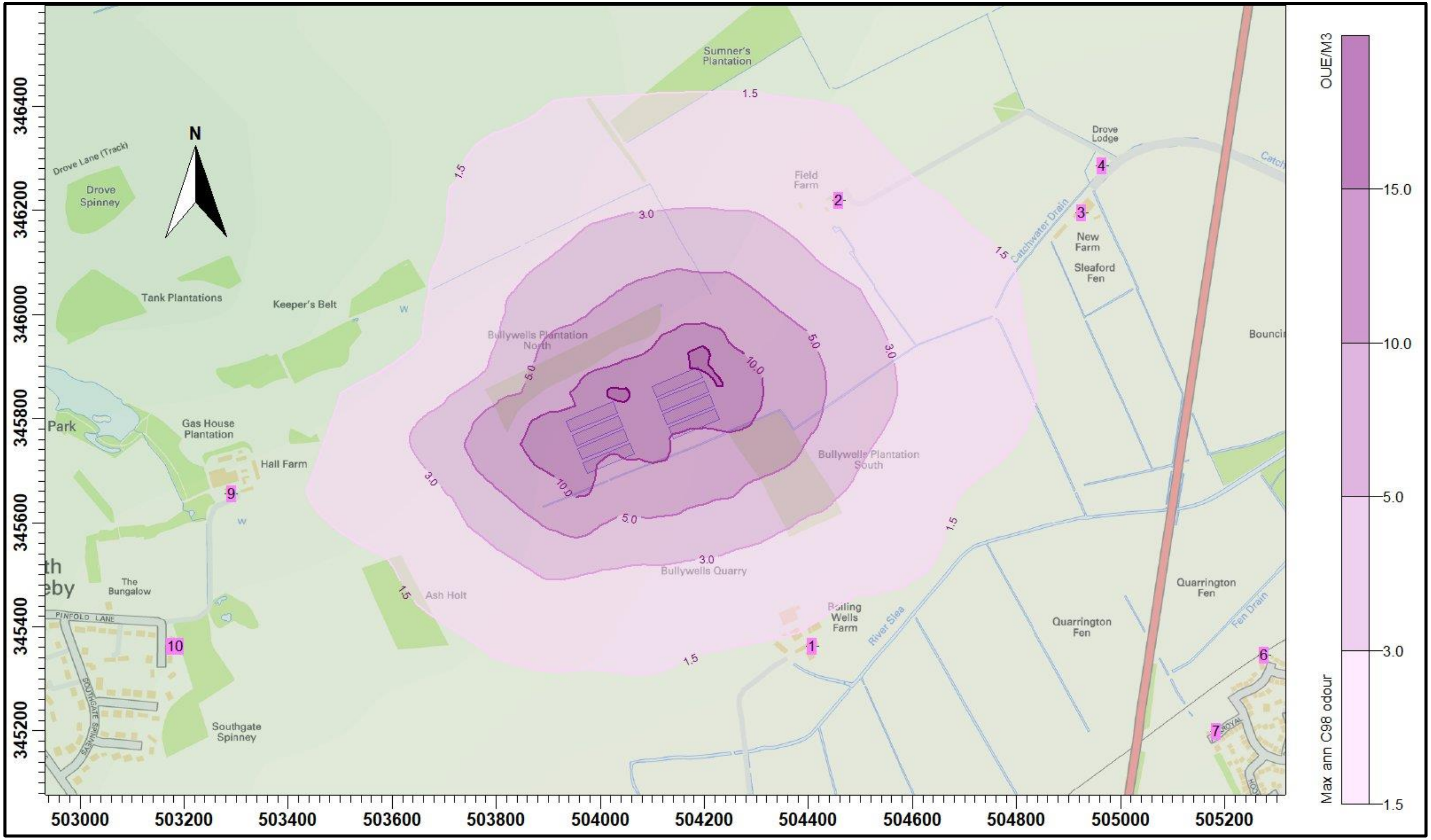
In Table 2, predicted odour exposures in excess of the Environment Agency's benchmark of 3.0 $ou_E/m^3$ as an annual 98th percentile hourly mean are coloured blue; those in the range that UKWIR research suggests gives rise to a significant proportion of complaints, 5.0 $ou_E/m^3$ to 10.0 $ou_E/m^3$ as 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 number | X(m) | Y(m) | Site | Maximum annual 98th percentile hourly mean odour concentration ($ou_E/m^3$) |
|---|---|---|---|---|
| | | | | GFS Calms Terrain |
| 1 | 504408 | 345363 | Boiling Wells Farm | 1.33 |
| 2 | 504459 | 346220 | Field Farm | 2.13 |
| 3 | 504925 | 346196 | New Farm | 1.02 |
| 4 | 504964 | 346285 | Drove Lodge | 0.90 |
| 5 | 505469 | 346225 | Depot, Drove Lane | 0.53 |
| 6 | 505284 | 345345 | Residence, Sheldrake Road | 0.45 |
| 7 | 505183 | 345197 | Ark Royal | 0.46 |
| 8 | 505286 | 344916 | Grantham Road | 0.33 |
| 9 | 505239 | 344664 | Hall Farm | 1.11 |
| 10 | 505322 | 344424 | South Rauceby | 0.52 |
| 11 | 505611 | 344701 | Rauceby Park | 0.39 |
| 12 | 505681 | 345044 | Holdingham Anne | 0.52 |

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



## 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 Bellamy of Greylees Ltd. to use computer modelling to assess the impact of odour emissions from the existing and proposed broiler chicken rearing houses at Boiling Wells Farm, Grantham Road, South Rauceby, Sleaford. NG34 8QX.

Odour emission rates from the existing and 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:

- At all nearby residences considered, the odour exposure surrounding the proposed poultry unit would be below the Environment Agency's benchmark for moderately offensive odours, which is a maximum annual 98$^{th}$ percentile hourly mean concentration of 3.0 $ou_E/m^3$.

# 7. References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