A Dispersion Modelling Study of the Impact of Odour from the Proposed Broiler Chicken Rearing Houses at West End Farm, near Shadingfield in Suffolk.

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1. Introduction

AS Modelling & Data Ltd. has been instructed by Charlie Davidson of C. E. Davidson Ltd., on behalf of A. W. Merrells & Sons, to use computer modelling to assess the impact of odour emissions from the proposed broiler chicken rearing houses at West End Farm, near Shadingfield in Suffolk. NR34 8DL.

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

West End Farm is in a rural area approximately 550 m to the west of the villages of Willingham and Shadingfield in Suffolk. The surrounding land is used primarily for arable farming, although there are some isolated wooded areas. The site of the proposed poultry houses is at an altitude of around 33 m, with the land falling towards the south.

It is proposed that three broiler chicken rearing houses be constructed at West End Farm. The poultry houses would have capacity for up to 150,000 broiler chickens and would be ventilated by uncapped high speed ridge mounted fans, each with a short chimney, with gable end fans to provide supplementary ventilation in hot weather conditions. The chickens would be reared from day old chicks up to around 38 days old and there would be approximately 7.5 flocks per annum.

There are some isolated residences and commercial properties in the area surrounding the site of the proposed poultry houses at West End Farm. The closest residences are at: Moat Farm, approximately 185 m to the north-west; West End Farm, approximately 370 m to the west-north-west; Park Farm Bungalow, approximately 330 m to the south-east and residences in Willingham, the closest of which is approximately 470 m to the east.

A map of the surrounding area is provided in Figure 1; the positions of the proposed poultry houses at West End Farm is outlined in blue.

Figure 1. The area surrounding West End 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 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 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 houses. 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 available to AS Modelling & Data Ltd. and are based primarily on Robertson *et al.* (2002).

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.

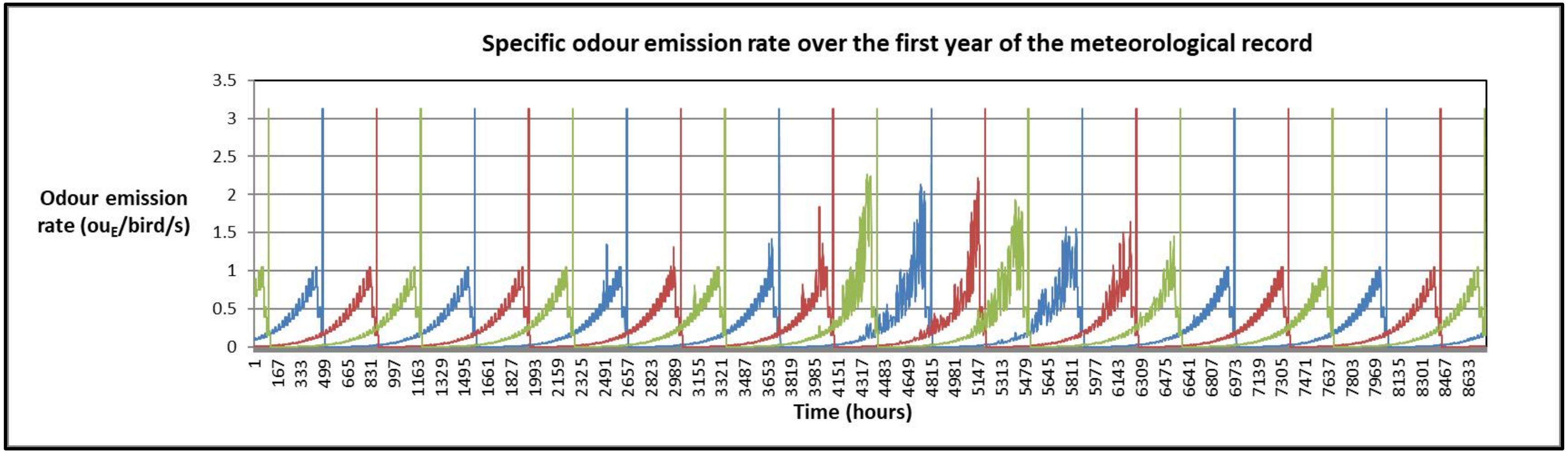
At high ventilation rates, it is likely that internal odour concentrations fall because odour is extracted much faster than it is created. Therefore, if the calculated ventilation rate exceeds that required to replace the volume of air in the house every 5 minutes, internal concentrations are reduced (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. It is also assumed that there is a 25% thinning of the birds at day 31 of the 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 15 of the crop and the third coinciding with day 30 of the crop. A summary of the emission rates used in this study are provided in Table 1. It should be noted that the figures in this table refer to the whole of the crop length whilst most figures quoted in literature are figures obtained from the latter stages of the crop cycle and therefore should not be compared directly to these AS Modelling & Data Ltd. figures. The specific odour emission rate used for the clearing process is approximately 3.10 ou_E/bird/s and the 98th percentile emission rate is approximately 1.15 ou_E/bird/s. As an example, a graph of the specific emission rate over the first year of the meteorological record for each of the three crop cycles is shown in Figure 2.

Table 1. Summary of odour emission rates (average of all 3 cycles)

Emission rate (ou_E/s per bird as stocked during crop)				
Season	Average	Night-time Average	Day-time Average	Maximum
Winter	0.226	0.203	0.271	1.046
Spring	0.256	0.206	0.305	2.082
Summer	0.330	0.230	0.391	2.278
Autumn	0.239	0.203	0.276	1.916

Figure 2. Specific emission rate over the first year of each of the three crop cycles



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 including: 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).

The GFS is a spectral model (the physics/dynamics model has an equivalent resolution of approximately 13 km and terrain is resolved at a resolution of approximately 2 km with sub-13 km processes parameterised). 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). 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 wind rose for the raw GFS data at the site of the poultry unit is shown in Figure 3a.

Wind speeds are modified by the treatment of roughness lengths (see Section 4.7) and because 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 location of the proposed poultry houses is shown in Figure 3b; it should be noted that although there is little modification in this case, elsewhere in the modelling domain the modified wind roses may differ more markedly, reflecting the local flow in that part of the domain. The resolution of the wind field in terrain runs is 100 m. Please also note that FLOWSTAR 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.

Figure 3a. The wind rose. Raw GFS derived data for 52.408 N, 1.572 E, 2015 – 2018

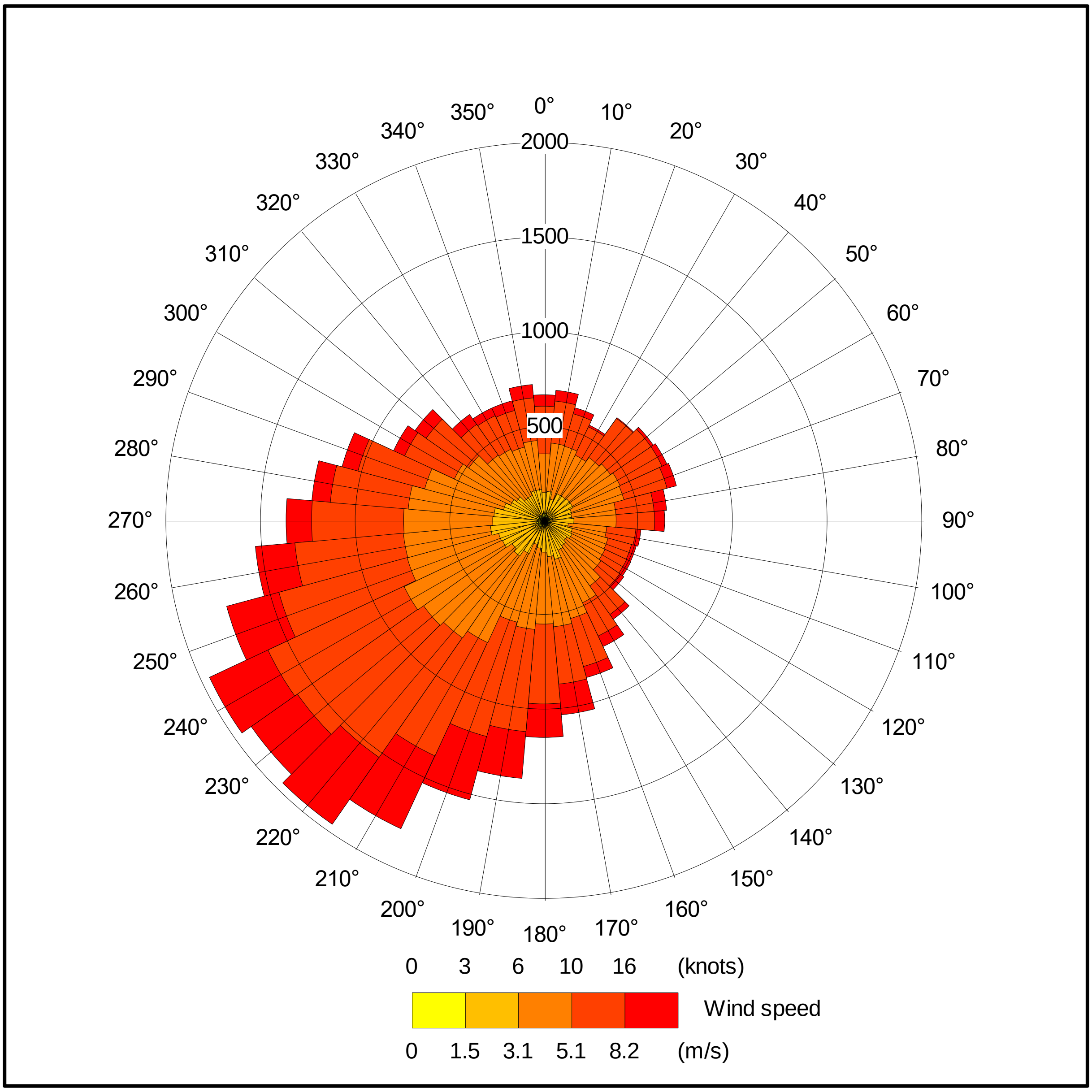
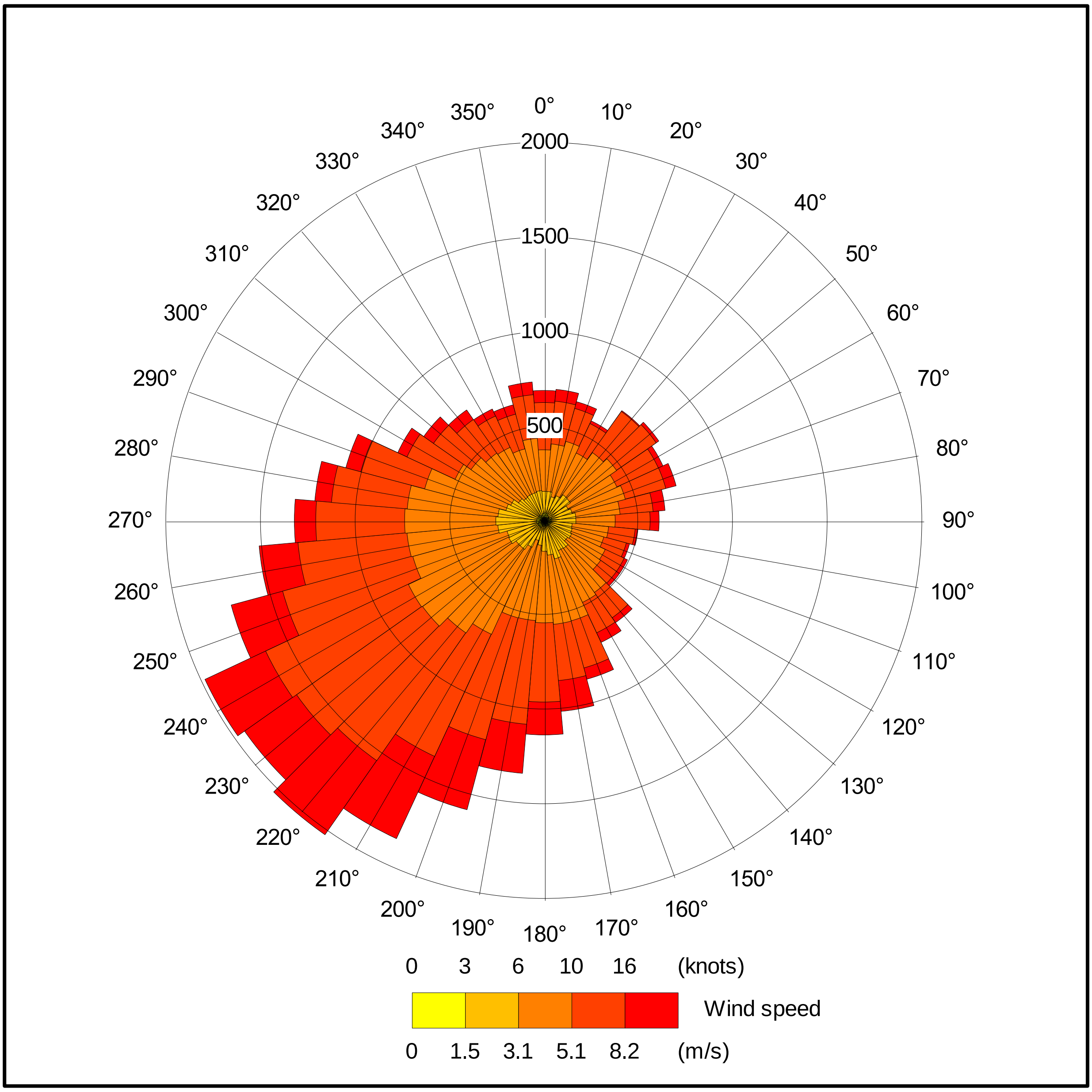


Figure 3b. The wind rose. FLOWSTAR modified GFS derived data for NGR 642950, 284900 - 2015–2018



4.2 Emission sources

Emissions from the high speed ridge fans that would be used to ventilate the proposed poultry houses are represented by three point sources per house within ADMS (PR1 a, b & c to PR3 a, b & c).). Emissions from the gable end fans are represented by a single volume sources within ADMS (PR1_3_GAB).

Details of the point and volume source parameters are shown in Tables 2a and 2b. The positions of the sources may be seen in Figure 4.

Table 2a. Point source parameters – proposed scenario

Source ID	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (˚C)	Emission rate per source (ou_E/s)
PR1 a, b & c to PR3 a, b & c	6.0	0.8	11.0	Variable [1]	Variable [1 & 2]

Table 2b. Volume source parameters

Source ID	Length Y (m)	Width X (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate (ou_E/s)
PR1_3_GAB	83.0	10.0	3.0	0.0	Ambient	Variable [1 & 3]

1. Dependent on crop stage and ambient temperature.
2. Reduced by 50% when the ambient temperature equals or exceeds 21 Celsius.
3. 50% of the total emission emitted only when the ambient temperature equals or exceeds 21 Celsius.

4.3 Modelled buildings

The structure of the poultry houses may affect the odour plumes from the point sources. Therefore, the proposed buildings are modelled within ADMS. The positions of the modelled buildings may be seen in Figure 4, where they are marked by grey rectangles.

4.4 Discrete receptors

Twenty 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, where they are 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, where they are 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

A fixed surface roughness length of 0.25 m has been applied over the entire modelling domain. As a precautionary measure, the GFS meteorological data is assumed to have a roughness length of 0.225 m. The effect of the difference in roughness length is precautionary as it increases the frequency of low wind speeds and the stability and therefore increases predicted ground level concentrations.

Figure 4. The positions of the modelled buildings and sources

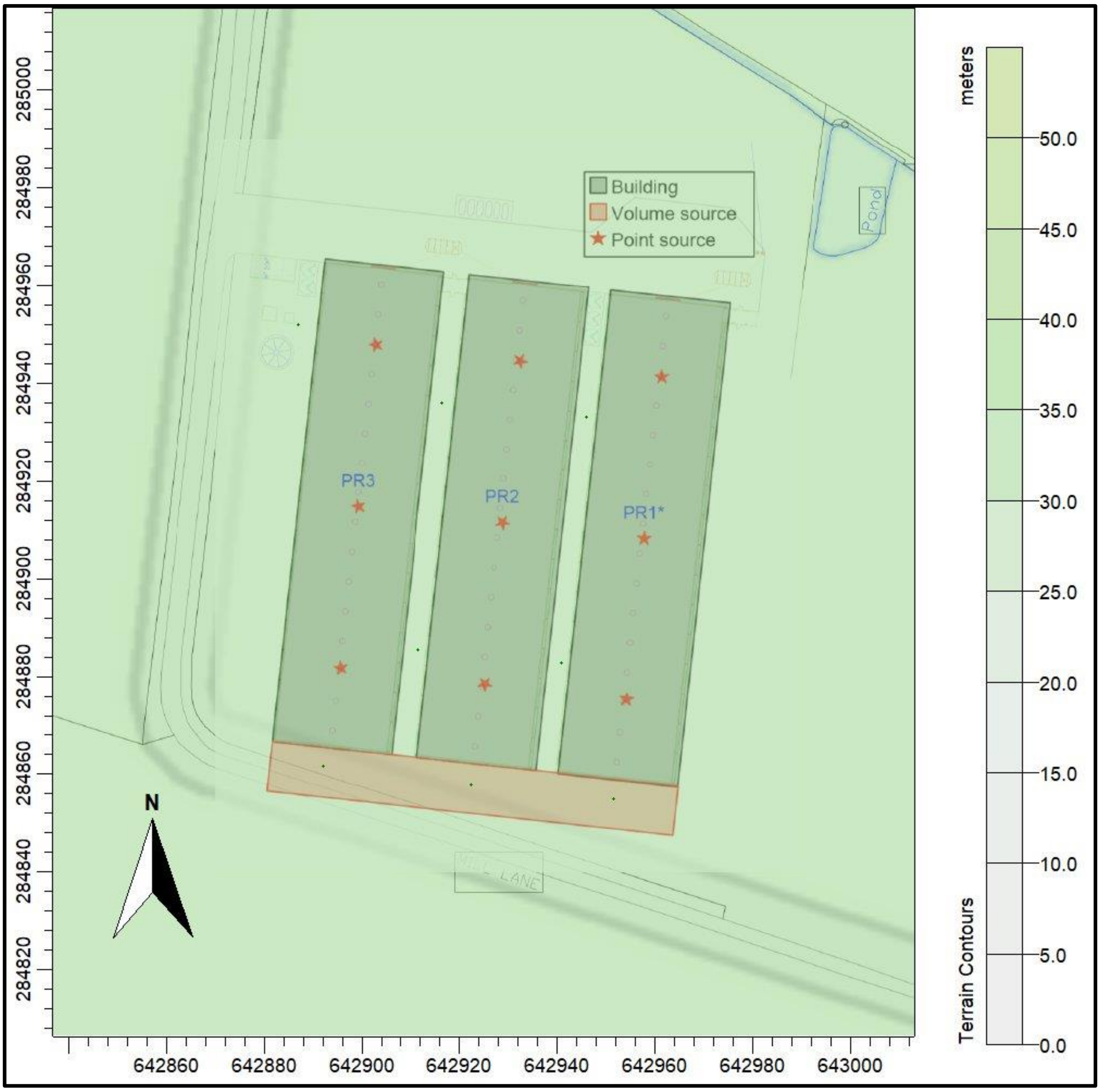
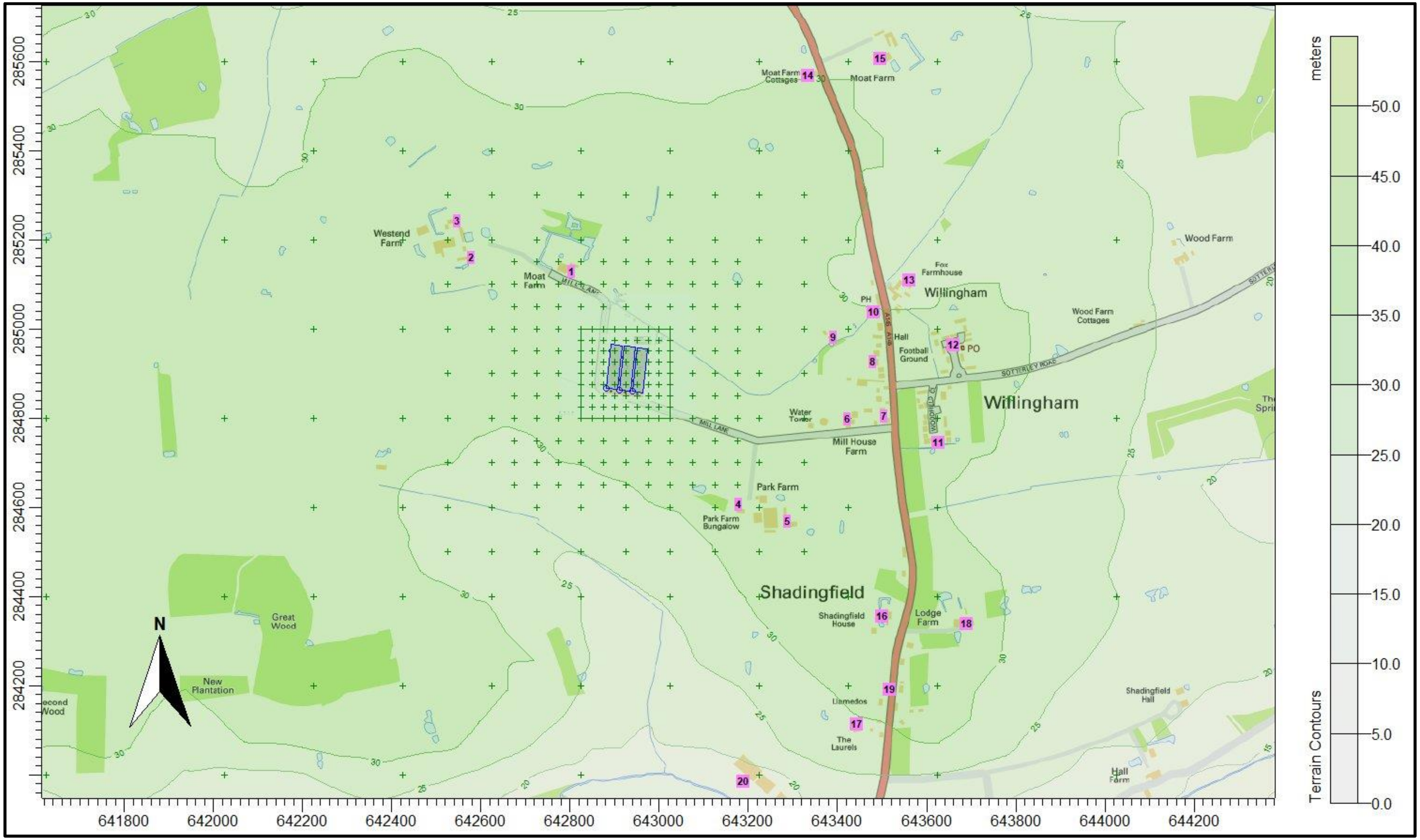


Figure 5. The discrete receptors and nested Cartesian grid receptors



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.

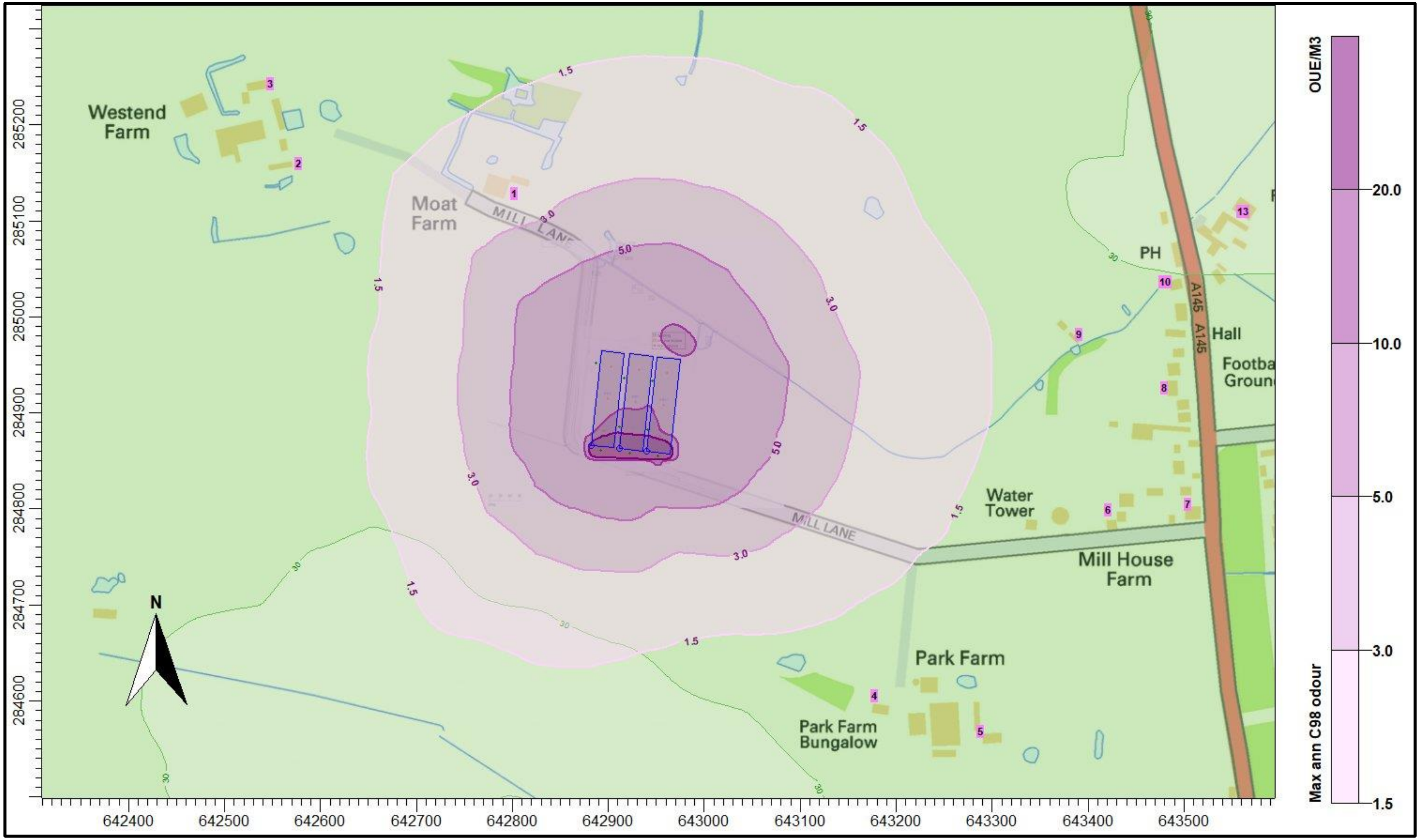
A summary of the results of these twelve runs at the discrete receptors is provided in Table 3, where the maximum annual 98th percentile hourly mean odour concentration is shown. A contour plot of the maximum annual 98th percentile hourly mean odour concentrations is shown in Figure 6.

In Table 3, 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.

Table 3. Predicted maximum annual 98th percentile hourly mean odour concentrations at the discrete receptors

Receptor number	X(m)	Y(m)	Location/Name	Maximum annual 98th percentile hourly mean odour concentration (ou_E/m^3)
				GFS Calms Terrain
1	642802	285128	Moat Farm	2.41
2	642577	285159	West End Farm	0.88
3	642548	285242	West End Farm	0.79
4	643177	284605	Park Farm Bungalow	0.86
5	643288	284568	Park Farm	0.62
6	643421	284798	Willingham	0.82
7	643504	284805	Willingham	0.64
8	643479	284925	Willingham	0.80
9	643391	284981	Willingham	1.06
10	643480	285036	Willingham	0.77
11	643626	284746	Willingham	0.47
12	643659	284964	Willingham	0.49
13	643562	285109	Willingham	0.58
14	643334	285567	Moat Farm Bungalow	0.45
15	643495	285605	Moat Farm 2	0.33
16	643500	284355	Shadingfield	0.27
17	643443	284114	Shadingfield	0.18
18	643690	284338	Shadingfield	0.21
19	643517	284191	Shadingfield	0.19
20	643188	283984	Works	0.15

Figure 6. Predicted maximum annual 98th percentile hourly mean odour concentration



6. Summary and Conclusions

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The modelling predicts that, at all nearby residences and commercial premises, the odour exposure would be below the Environment Agency's benchmark for moderately offensive odours, which is an annual 98th percentile hourly mean concentration of 3.0 ou_E/m^3.

7. References

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