A Dispersion Modelling Study of the Impact of Odour from the Proposed Broiler Chicken Rearing Houses at land south of the A1066, Diss Road, near to Garboldisham, Thetford, Norfolk

Prepared by Phil Edgington

AS Modelling & Data Ltd.

Email: philedgington@asmodata.co.uk

Telephone: 01952 462500

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1. Introduction

AS Modelling & Data Ltd. has been instructed by Ian Pick of Ian Pick Associates Ltd., on behalf of B.J. and P.M. Gooderham, to use computer modelling to assess the impact of odour emissions from the proposed broiler chicken rearing houses at land south of the A1066, Diss Road near to Garboldisham, Thetford, in Norfolk. IP22 2HW.

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 methods 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.
- And Section 6 provides a discussion of the results and conclusions.

2. Background Details

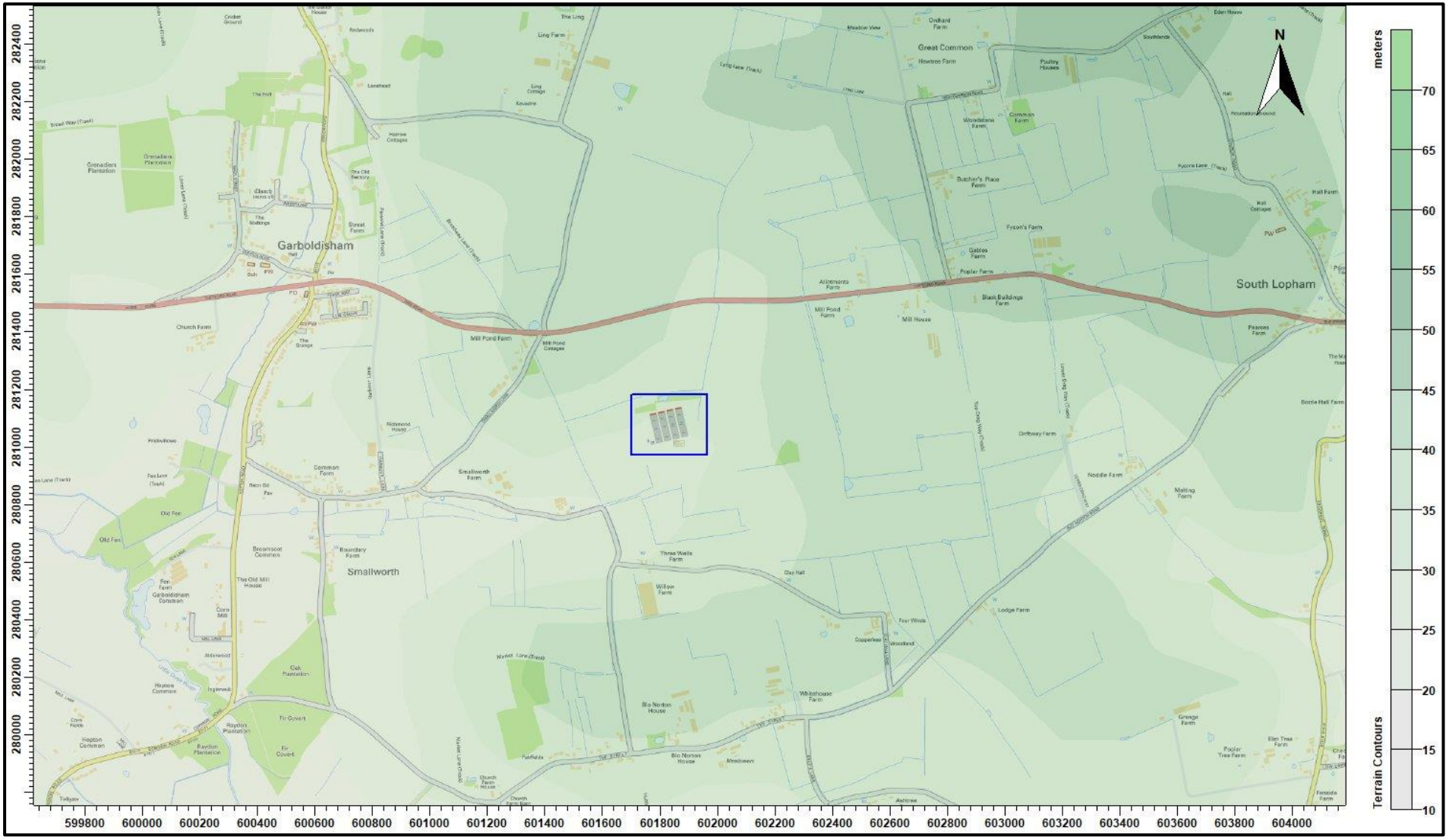
The site of the proposed poultry houses is approximately 1.0 km to the south-east of the village of Garboldisham in Norfolk. The site is at an altitude of around 35 m with the land falling to the south and west towards the Little Ouse River.

Under the proposal, four new poultry houses would be constructed on a green-field site to the south of the A1066, Diss Road. The proposed poultry houses would provide accommodation for up to 200,000 broiler chickens and would be ventilated by high speed ridge fans, each with a short chimney, with gable end fans providing supplementary ventilation during hot weather. The broiler chickens would be reared for up to 38 days and there would be approximately 7.6 flocks per annum.

There are isolated residences and commercial properties in the area surrounding the site of the proposed poultry houses at land south of the A1066, Diss Road. The closest residence is approximately 350 m to the south-west of the proposed poultry houses and there are further residences at Three Wells Farm, which is approximately 370 m to the south, Smallworth Farm, which is approximately 525 m to the east-south-east, the Mill Pond Cottages are approximately 470 m to the north-west and Mill Pond Farm is approximately 650 m to the north-east, from the proposed poultry houses. Beyond these, there are further isolated residences in the countryside around the site and the denser residential streets associated with Garboldisham, which is approximately 1 km to the west-north-west and South Lopham, which is approximately 2.2 km to the east.

A map of the surrounding area is provided in Figure 1; the position of the site of the proposed poultry houses at land south of the A1066, Diss Road is outlined in blue.

Figure 1. The area surrounding the site of the proposed poultry unit at land south of the A1066, Diss Road, near to Garboldisham



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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 models 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 rearing 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 house 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 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.

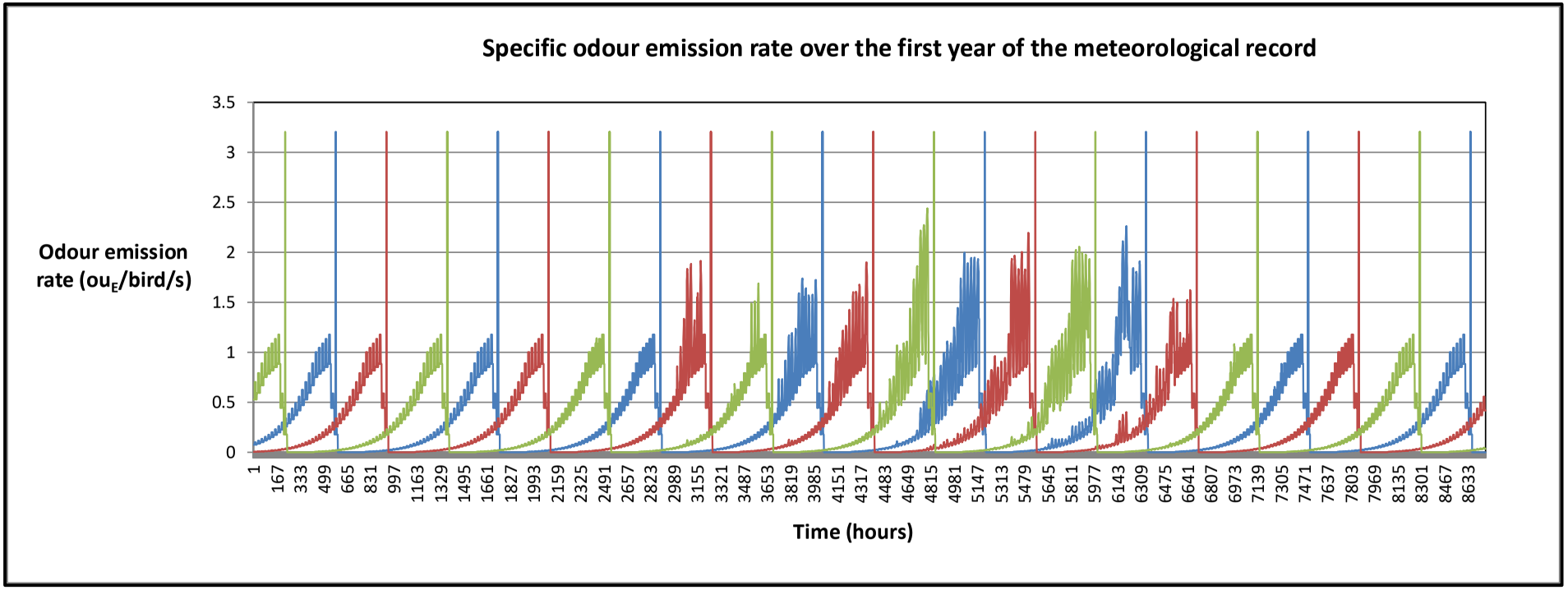
At high ventilation rates, it is likely that internal odour concentrations fall because odour is extracted much faster than it is created. Therefore, if the calculated ventilation rate exceeds that required to replace the volume of air in the house every 5 minutes, internal concentrations are reduced (by a factor of the square root of 7.5 times the house 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 15 of the crop and the third coinciding with day 30 of the crop. A summary of the emission rates used in this study is 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 3.2 ou_E/bird/s and the 98th percentile emission rate is approximately 1.5 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 AS Modelling & Data Ltd. Modelled odour emission rates

Emission rate (ou_E/s per bird as stocked, during crop)				
Season	Average	Night-time Average	Day-time Average	Maximum
Winter	0.284	0.255	0.341	1.832
Spring	0.330	0.258	0.402	2.457
Summer	0.411	0.279	0.491	2.718
Autumn	0.304	0.256	0.351	2.112

Figure 2. Specific emission rate over the first year of year of the meteorological data



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).

The GFS is a spectral model: the physics/dynamics model has an equivalent resolution of approximately 13 km (latterly 9km); terrain is understood to be resolved at a resolution of approximately 2 km, with sub-13/9 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). 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 3a and the terrain and roughness length modified wind rose for the site at land south of the A1066, Diss Road is shown in Figure 3b. Note that elsewhere in the modelling domain the modified wind rose may differ more markedly and that the resolution of the wind field 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 52.390 N, 0.963 E, 2016–2019

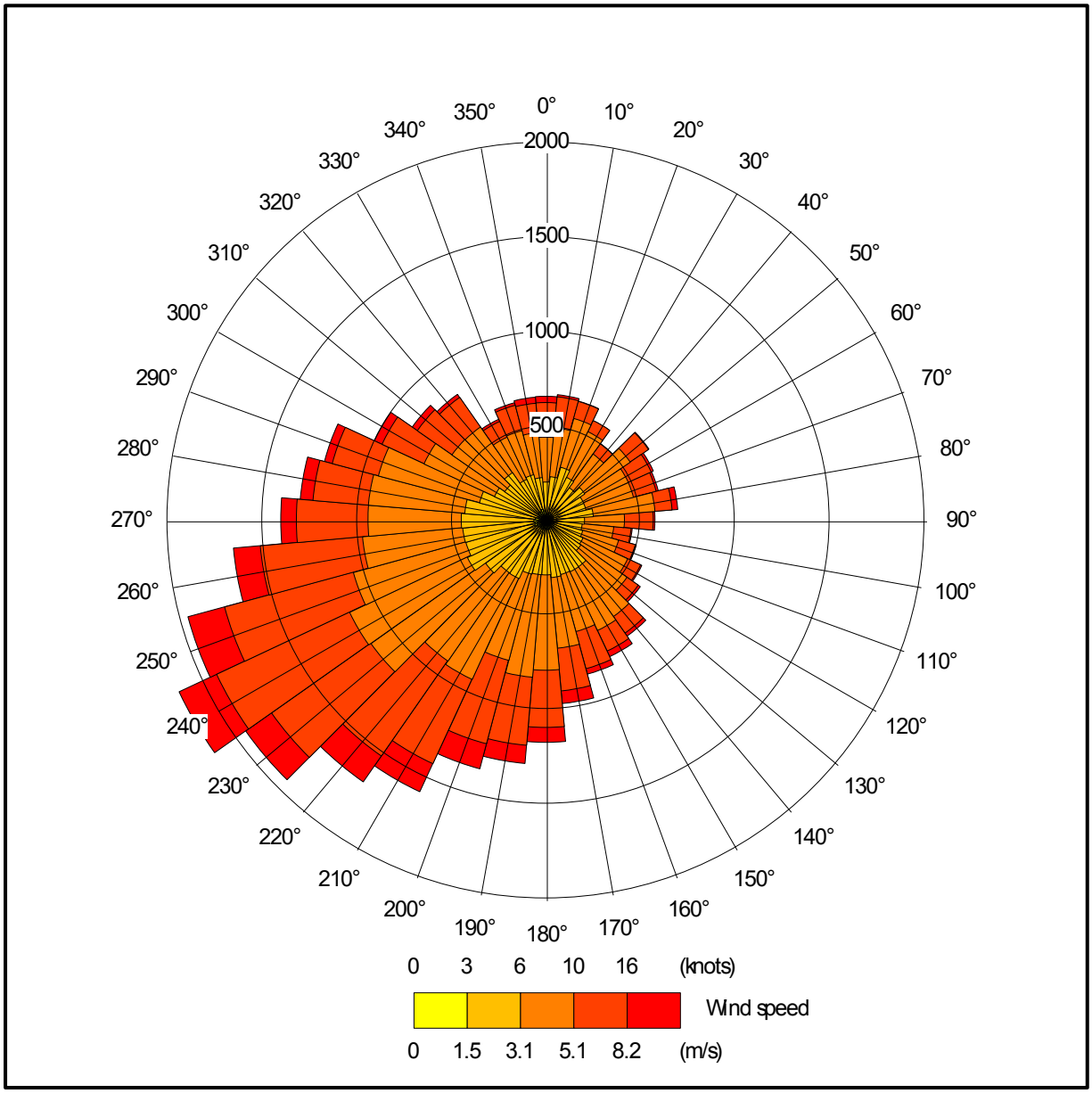
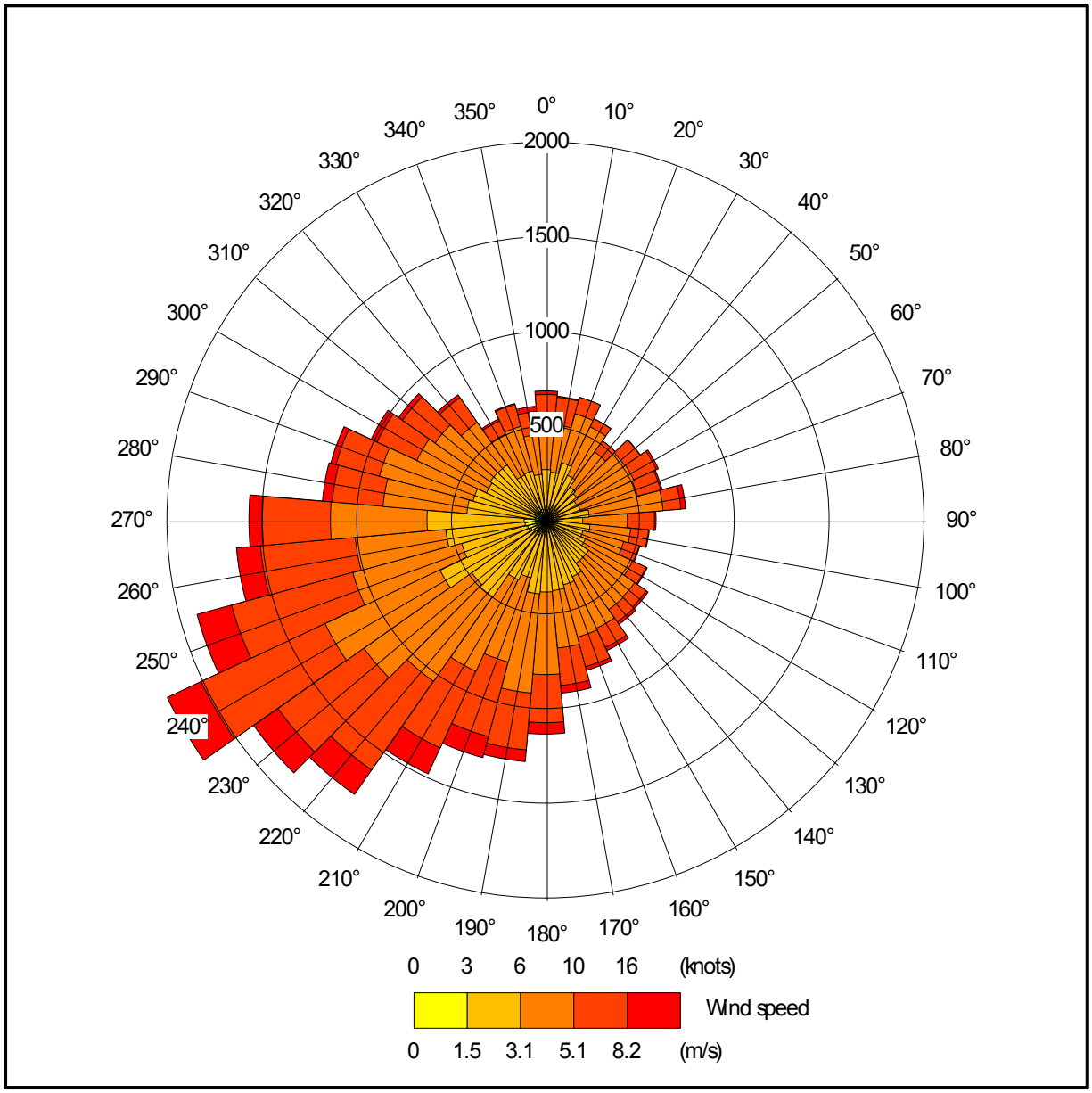


Figure 3b. The wind rose. FLOWSTAR modified GFS derived data for NGR 601750, 281050 2016–2019



4.2 Emission sources

Emissions from the chimneys of the uncapped high speed ridge fans that would be used as the primary form of ventilation for the poultry houses are represented by three point sources per house within ADMS (PR1 to PR4; a, b & c).

Details of the point source parameters are shown in Table 2a and their positions may be seen in Figure 4, where they are indicated by red star symbols.

Table 2a. Point source parameters

Source ID	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (˚C)	Emission rate per source (ou_E/s)
PR1 to PR4; a, b & c	5.5	0.8	11.0	Variable [1]	Variable [1]

1. Dependent on ambient temperature.

The proposed poultry houses would be fitted with gable end fans which would be used to provide supplementary ventilation in hot weather conditions. The emissions from the gable end fans are represented by a single volume source per house within ADMS (PR1_gab to PR4_gab). These volume sources are assumed to emit 50% of the total emission only when the ambient temperature equals or exceeds 21 Celsius; when the volume sources are emitting, emissions from the associated point sources are reduced by 50%.

Details of the volume source parameters are shown in Table 2b and their positions may be seen in Figure 4, where they are marked by red rectangles.

Table 2b. Volume source parameters

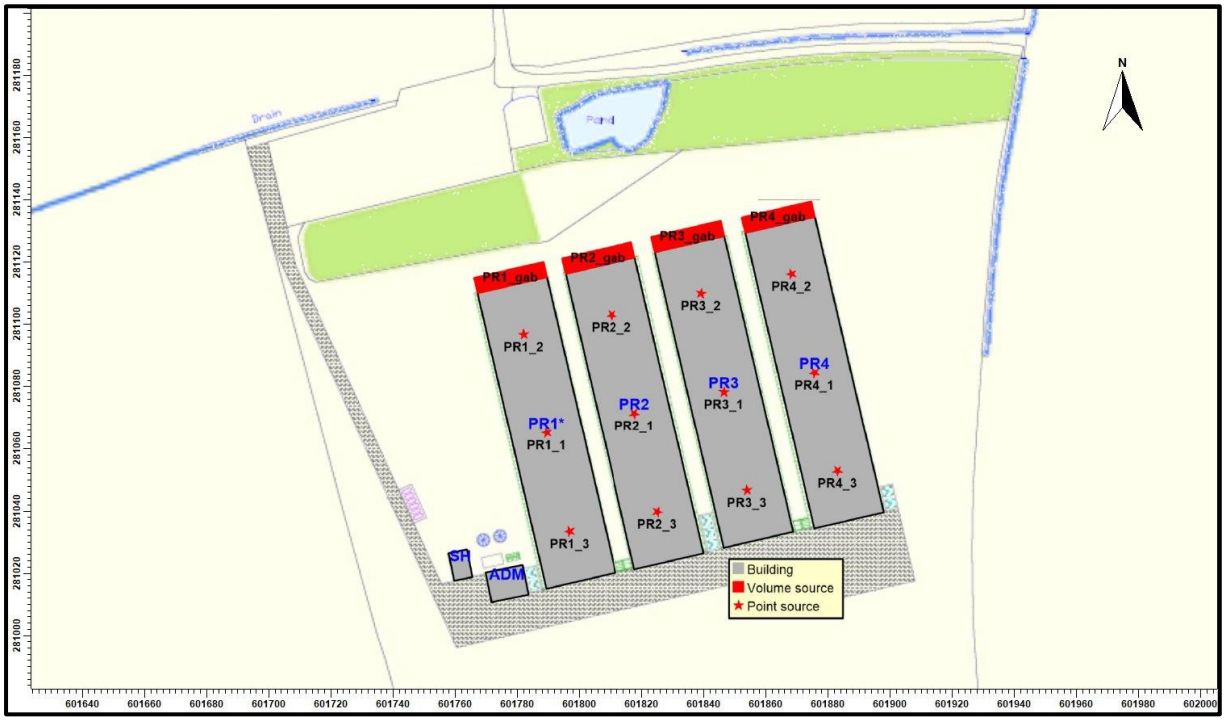
Source ID	Length Y (m)	Width X (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate (ou_E/s)
PR1_gab to PR4_gab	23.0	5.0	3.0	0.5	Ambient	Variable [1]

1. Dependent on ambient temperature.

4.3 Modelled buildings

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

Figure 4. The positions of the modelled buildings and sources



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4.4 Discrete receptors

Eighteen 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 receptors may be seen in Figure 5, where they are marked by green crosses bounded by a purple rectangle.

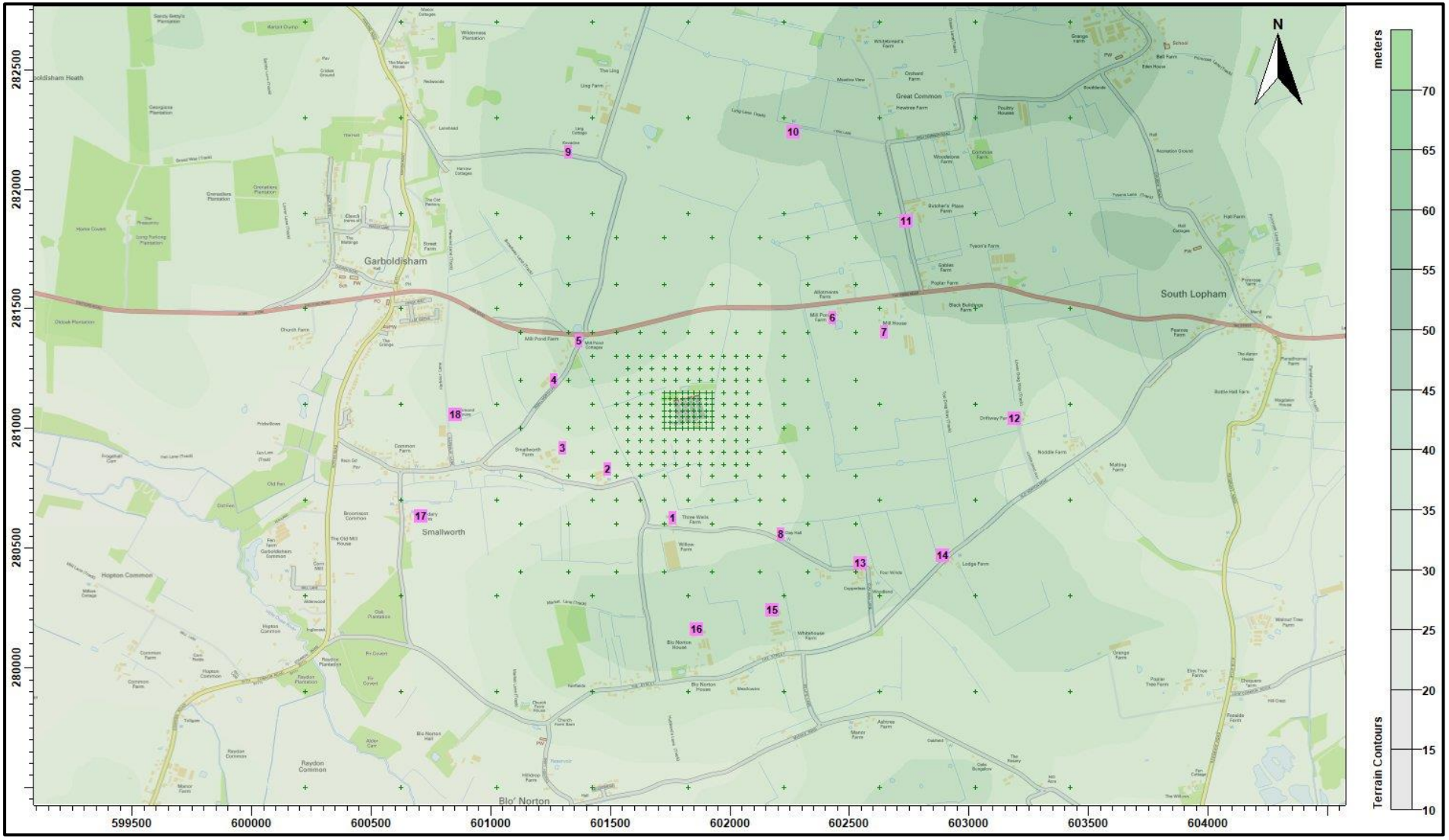
4.6 Terrain data

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 by 6.4 km domain has been resampled at 50 m horizontal resolution for use within ADMS. N.B. The resolution of FLOWSTAR is 64 by 64 grid points; therefore, the effective resolution of the wind field for the terrain runs is 100 m.

4.7 Other model parameters

A fixed surface roughness length of 0.3 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 0.275 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 5. The discrete receptors and nested Cartesian grid receptors



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5. Details of the Model Runs and Results

For this study, ADMS was run with the calms module and with terrain. ADMS was effectively run a total of four times, once for each year of the four year meteorological record.

Statistics for the annual 98th percentile hourly mean odour concentration at each receptor were compiled for each of the four runs.

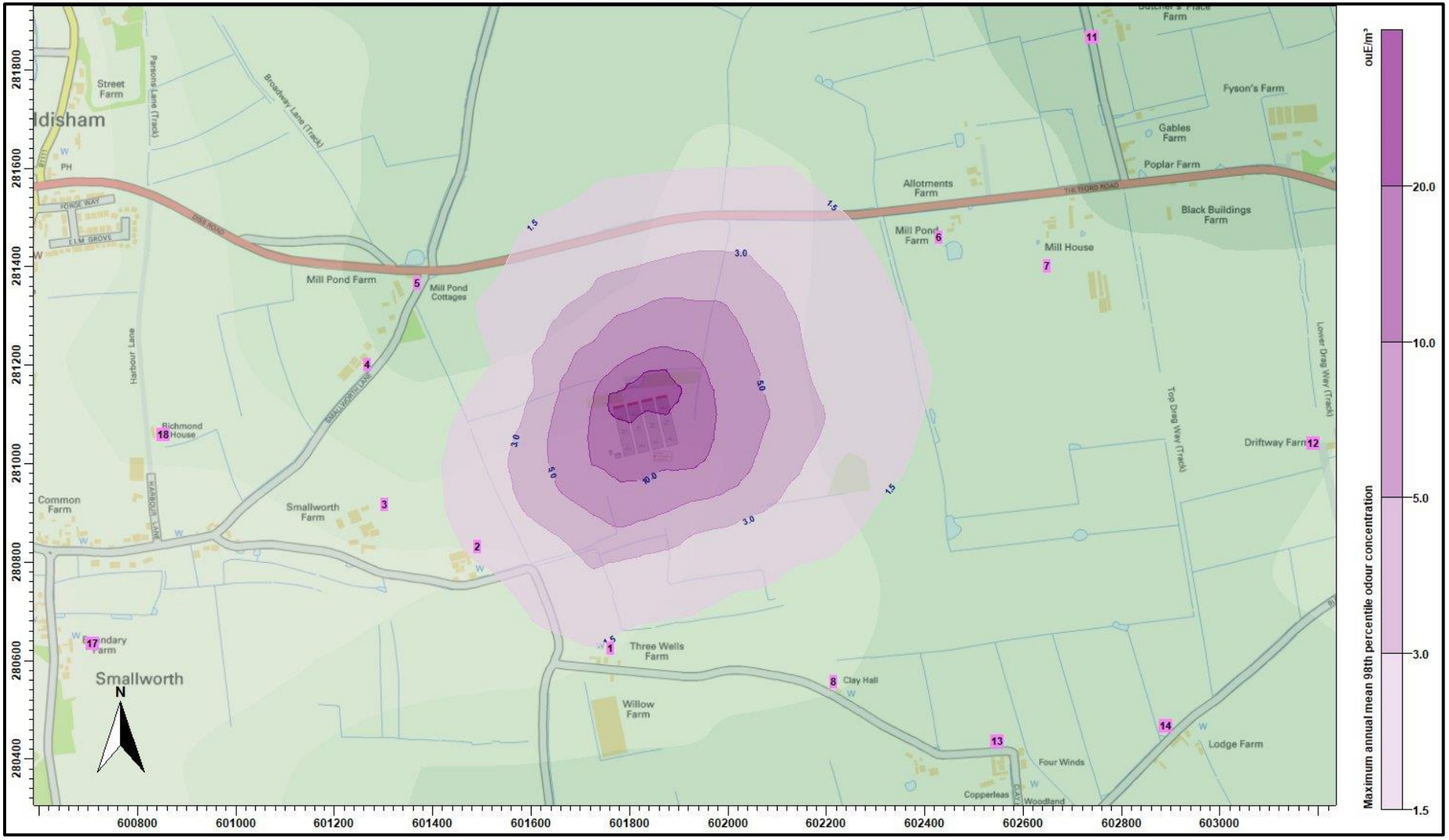
A summary of the results at the discrete receptors is shown in Table 3, where the maximum annual 98th percentile hourly mean odour concentrations are shown for odour emissions from the proposed poultry houses. A contour plot of the maximum annual 98th percentile hourly mean odour concentrations is shown 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, namely 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, namely those in excess of 10.0 ou_E/m^e as an annual 98th percentile hourly mean, are coloured red.

Table 3. 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	601761	280625	Three Wells Farm	1.36
2	601491	280830	Farmstead	1.64
3	601302	280915	Smallworth Farm	0.98
4	601267	281200	Commercial, Smallworth Lane	0.72
5	601369	281365	Mill Pond Cottages	0.91
6	602429	281460	Mill Pond Farm	1.05
7	602648	281400	Mill House	0.69
8	602214	280556	Clay Hall	0.65
9	601325	282155	Kevadne	0.28
10	602266	282237	Residence, Lyng Lane	0.43
11	602740	281866	Butcher's Place Farm	0.43
12	603190	281040	Driftway Farm	0.39
13	602547	280436	Four Winds	0.38
14	602890	280467	Lodge Farm	0.28
15	602178	280240	Whitehouse Farm	0.34
16	601860	280159	Blo Norton House	0.36
17	600709	280634	Boundary Farm, Smallworth	0.26
18	600853	281059	Richmond House	0.40

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



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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 proposed development at land south of the A1066 Diss Road proceed, at all discrete receptors considered, the odour exposures from the proposed poultry houses would be well below the Environment Agency's benchmark for moderately offensive odours, which is a 98th percentile hourly mean odour concentration of 3.0 ou_E/m^3 over a one year period.

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