A Report on the Modelling of the Dispersion and Deposition of Ammonia from the Existing and Proposed Broiler Chicken Rearing Houses at Haveringland, School Road, Broadland in Norfolk

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1. Introduction

AS Modelling & Data Ltd. has been instructed by Mr. Simon Akrill of Amber Real Estate Investments (Agriculture) Ltd., to use computer modelling to assess the impact of ammonia emissions from the existing and proposed poultry rearing houses at Haveringland, School Road, Broadland, Norfolk. NR10 4QL.

Ammonia emission rates from the existing and proposed poultry rearing houses have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors or emission factors that AS Modelling & Data Ltd. understands are agreed with the Environment Agency. The ammonia emission rates have then been used as inputs to an atmospheric dispersion and deposition model which calculates ammonia exposure levels and nitrogen and acid deposition rates in the surrounding area.

This report is arranged in the following manner:

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

2. Background Details

The poultry houses at Haveringland, School Lane, are in a rural area approximately 5.6 km to the east-south-east of the town of Reepham and 5.5 km to the north of the town of Thorpe Marriott, both in Norfolk. The setting for the poultry houses is a gently rolling landscape with arable agriculture or fodder production predominating as land uses along with some woodlands.

There are twenty-one poultry rearing houses at Haveringland in varying conditions, all of which are ventilated by side extraction fans. One of these poultry houses has been condemned previously and others are to be replaced in 2022. The site currently provides accommodation for up to 200,000 stag turkeys.

Under the proposal, twelve of the existing poultry houses would be refurbished or replaced. The houses would accomodate a total of 396,000 broiler chickens and would be ventilated by high speed ridge fans, each with a short chimney (scenario 1). A second proposed scenario is presented in which the twelve refurbished houses ventilated by high speed ridge fans are also fitted with heat exchanger units (scenario 2).

There are five areas designated as County Wildlife Sites (CWSs) and one area designated as an Ancient Woodland (AW) within 2 km of Haveringland (the normal screening distance for non-statutory sites). There are six areas that have been designated as Sites of Special Scientific Interest (SSSIs) within 5 km of the farm (the normal screening distance for SSSIs), three of which are also designated as Special Areas of Conservation (SACs). Beyond these, there are a further three SSSIs within 10 km of Haveringland. Some further details of these statutory sites that are sensitive to ammonia emissions and nitrogen deposition are provided below:

- **Swannington Upgate Common SSSI** - approximately 1.2 km to the north-west. Supports a wide variety of habitat types in a small area as a result of variations in soils and wetness and topography. Dry acidic heathland, wet heathland, fen, woodland, scrub, bracken, grassland and ponds.
- **Alderford Common SSSI** - approximately 2.6 km to the south. A variety of habitats include scrub, woodland, bracken heath, marshy grasslands and ponds. Also noted for bats and breeding birds.
- **Cawston And Marsham Heaths SSSI** - approximately 6.6 km to the west. A large area of heather dominated heathland with a rich assemblage of lichens. Also of ornithological interest.
- **Whitwell Common SSSI** - approximately 7.2 km to the north-west. A range of wetland communities characteristics of peat soil and calcareous flushes in low-lying hollows. There are fen, woodlands, and unimproved grasslands.
- **Foxley Wood SSSI** - approximately 10 km to the west-north-west. The largest ancient woodland in Norfolk. A species rich woodland and there is also entomological interest.
- **Hockering Wood SSSI** - approximately 9 km to the south-south-east. An ancient woodland with noted rare bryophytes and there are some ponds containing newts.
- **Buxton Heath SSSI/SAC** - approximately 7.2 km to the north-west. A floristically rich valley mire and there is also dry acidic heathland. Some invertebrates are present and there are some woodlands.
- **Booton Common SSSI/SAC** - approximately 7.2 km to the north-west. Comprises a mosaic of wet calcareous fen grassland and acid heathland and a strip of woodland.
- **River Wensum SSSI/SAC** - approximately 7.2 km to the north-west. An enriched, calcareous lowland river that supports over 100 species of plants and invertebrate fauna.

Maps of the surrounding area showing the positions of the poultry unit and nearby wildlife sites are provided in Figures 1a and 1b. In these figures, the CWSs are shaded in yellow, the AWs are shaded in olive, the SSSIs are shaded in green, the SACs are is shaded in purple and the position of the poultry unit is outlined in blue.

Figure 1a. The area surrounding the site of the poultry unit at Haveringland – concentric circles radii 2.0 km (olive) 5 km (green) and 10 km (purple)

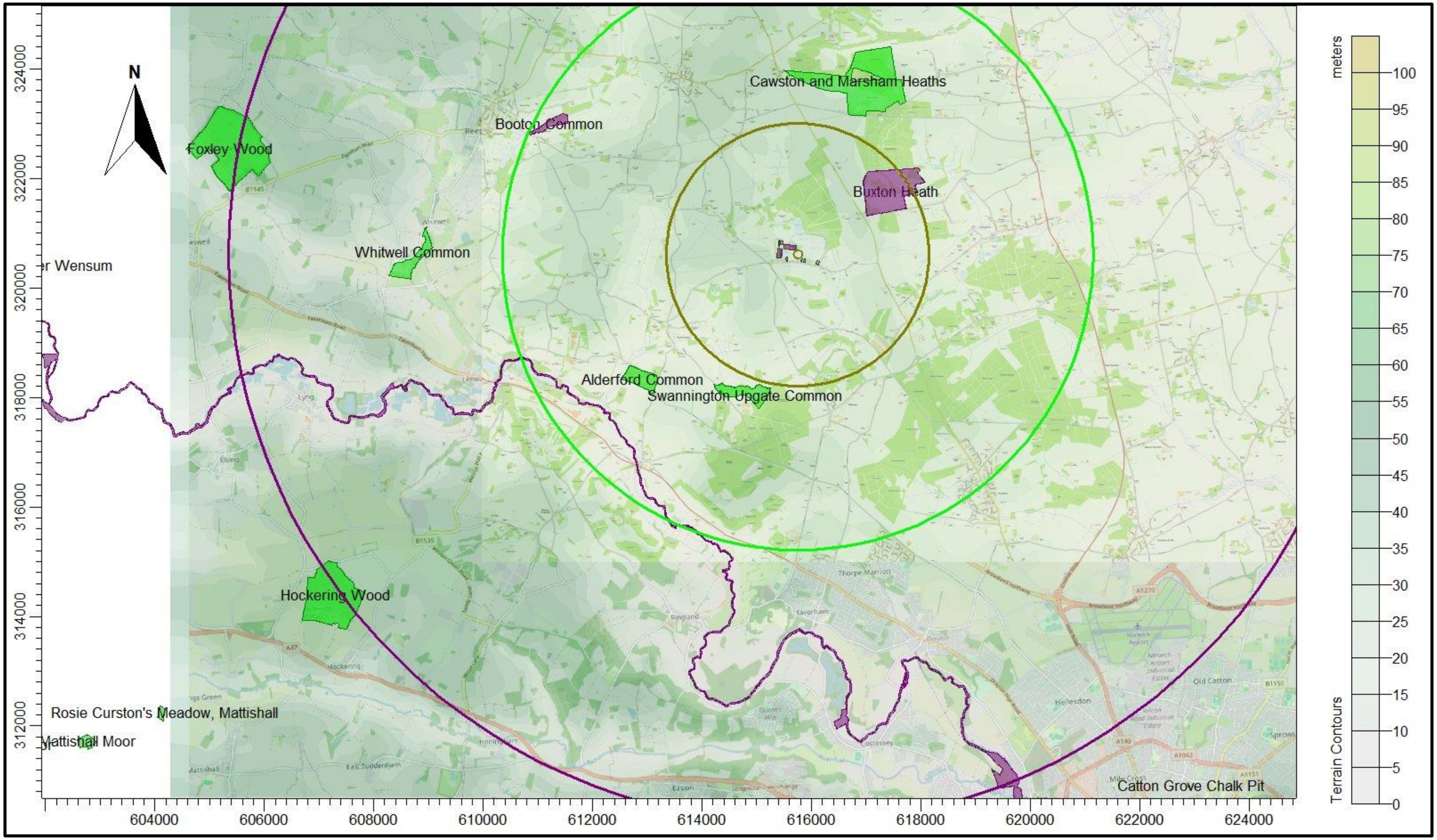
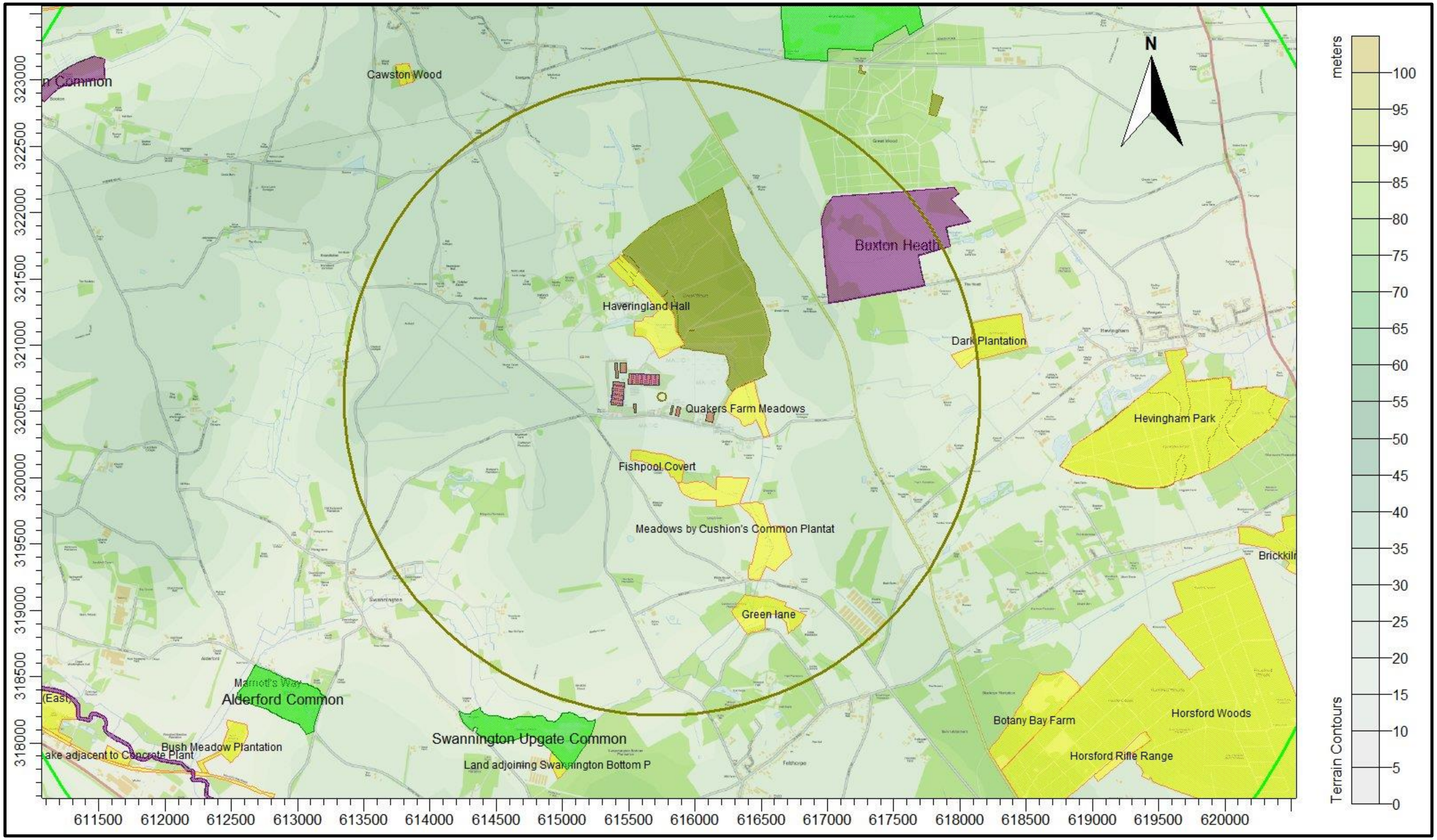


Figure 1b. The area surrounding the site of the poultry unit at Haveringland - with concentric circle radius at 2 km (olive)



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

3.1 Ammonia concentration and nitrogen and acid deposition

When assessing potential impact on ecological receptors, ammonia concentration is usually expressed in terms of micrograms of ammonia per metre cubed of air (µg-NH_3/m^3) as an annual mean. Ammonia in the air may exert direct effects on the vegetation, or indirectly affect the ecosystem through deposition which causes both hyper-eutrophication (excess nitrogen enrichment) and acidification of soils. Nitrogen deposition, specifically in this case the nitrogen load due to ammonia deposition/absorption, is usually expressed in kilograms of nitrogen per hectare per year (kg-N/ha/y). Acid deposition is expressed in terms of kilograms equivalent (of H^+ ions) per hectare per year (keq/ha/y).

3.2 Background ammonia levels and nitrogen and acid deposition

The source of the background figures is the Air Pollution Information System (APIS, February 2024). It should be noted that the 1 km APIS database background levels are extrapolated from 5 km modelled data. Ammonia levels may vary markedly over relatively short distances and the APIS website itself notes that, the background values should be used only to assist the user in obtaining a broad indication of the likely pollutant impact at a specific location and cannot be considered representative of any particular location within the 5 km grid square; extrapolation to a 1 km grid does not alter this.

The APIS figures for background ammonia concentration in the area around the farm is 2.64 µg-NH_3/m^3. The background nitrogen deposition rate to woodland is 34.7 kg-N/ha/y and to short vegetation is 20.05 kg-N/ha/y. The background acid deposition rate to woodland is 2.54 keq/ha/y and to short vegetation is 1.47 keq/ha/y.

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

3.3 Critical Levels and Critical Loads

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

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

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

For ammonia concentration in air, the Critical Level for higher plants is 3.0 µg-NH_3/m^3 as an annual mean. For sites where there are sensitive lichens and bryophytes present, or where lichens and bryophytes are an integral part of the ecosystem, the Critical Level is 1.0 µg-NH_3/m^3 as an annual mean.

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

The Critical Levels and Critical Loads at the wildlife sites assumed in this study are provided in Table 1. N.B. Where the Critical Level of 1.0 µg-NH_3/m^3 is assumed, it is usually unnecessary to consider the Critical Load as the Critical Level provides the stricter test. Normally, the Critical Load for nitrogen deposition provides a stricter test than the Critical Load for acid deposition.

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

Site	Critical Level (µg-NH_3/m^3)	Critical Load - Nitrogen Deposition (kg-N/ha/y)	Critical Load - Acid Deposition (keq/ha/y)
Non-statutory wildlife sites	1.0 [1]	10.0 [1]	-
Buxton Heath SSSI/SAC	1.0 [1]	5.0 [2 & 3]	-
Swannington Upgate Common SSSI, Cawston And Marsham Heaths SSSI, Whitwell Common SSSI, Foxley Wood SSSI, Hockering Wood SSSI	1.0 [1]	10.0 [2 & 3]	-
Booton Common SSSI/SAC	1.0 [1]	15.0 [2 & 3]	-
River Wensum SSSI/SAC	3.0 [2]	15.0 [2 & 3]	-
Aldeford Common SSSI	3.0 [2]	20.0 [2 & 3]	-

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

3.4 Guidance on the Significance of Ammonia Emissions

3.4.1 Environment Agency Criteria

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

If the predicted process contributions to Critical Level or Critical Load are below the lower threshold percentage, the impact is usually deemed acceptable.

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

3.4.2 Natural England advisory criteria

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

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

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

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

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

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

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

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

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

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

3.5 Quantification of Ammonia Emissions

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

The Environment Agency provides an Intensive farming guidance note which lists standard ammonia emission factors for a variety of livestock, including turkeys and broiler chickens. The emission factor given for broiler chickens is 0.034 kg-NH_3/bird place/y. The emission factor for stag turkeys is 0.45 kg-NH_3/bird place/y; however, this figure assumes that birds are bred from day old chicks to fully grown and that there is no thinning of the crop and in this case, the stag turkeys are reared from day old chicks for approximately 19 weeks with 60% thinning of crop at week 6. Therefore, an emission factor specific to the birds at the Haveringland poultry unit has been provided to AS Modelling & Data Ltd., this figure is 0.138 kg-NH_3/bird place/y.

For Scenario 2, it is proposed that heat exchangers be installed. Indirect heating systems such as heat exchangers have been found to reduce concentrations of ammonia in poultry houses and therefore help to mitigate against the potential for detrimental impacts at nearby wildlife sites. The An emission factor of 0.0221 kg-NH_3/bird place/y, has been assumed, which represents a 35% reduction in ammonia emissions from the standard emission factor. AS Modelling & Data Ltd. would note that decisions on the efficacy of heat exchangers in reducing ammonia emissions are usually made on a site by site basis and have the expectation that approval of reduced emission factors would be conditional on firm evidence of ammonia reductions from manufacturers of the heat exchangers and/or monitoring of ammonia emissions. It should also be noted that the modelling is a simple scaling of the results obtained using the standard emission factor and assumes that the efflux characteristics from the heat exchangers would be similar in height and velocity to standard ridge/roof mounted ventilation fans.

Details of the poultry numbers and types and emission factors used and calculated ammonia emission rates are provided in Table 2.

Table 2. Details of poultry numbers and ammonia emission rates

Source	Animal numbers	Type or weight	Emission factor (kg-NH_3/place/y)	Emission rate (g-NH_3/s)
Existing – stag turkeys	200,000	Stag turkeys	0.138	0.918321
Proposed – broiler chickens	396,000	Broiler chickens	0.034	0.426648
Proposed – broiler chickens	396,000	Broiler chickens (with heat exchangers)	0.0221	0.277321

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 2a. 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 2b. Although there is little modification in this case, elsewhere in the modelling domain 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 approximately 340 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 2a. The wind rose. Raw GFS derived data for 52.74 N, 1.193 E, 2020-2023

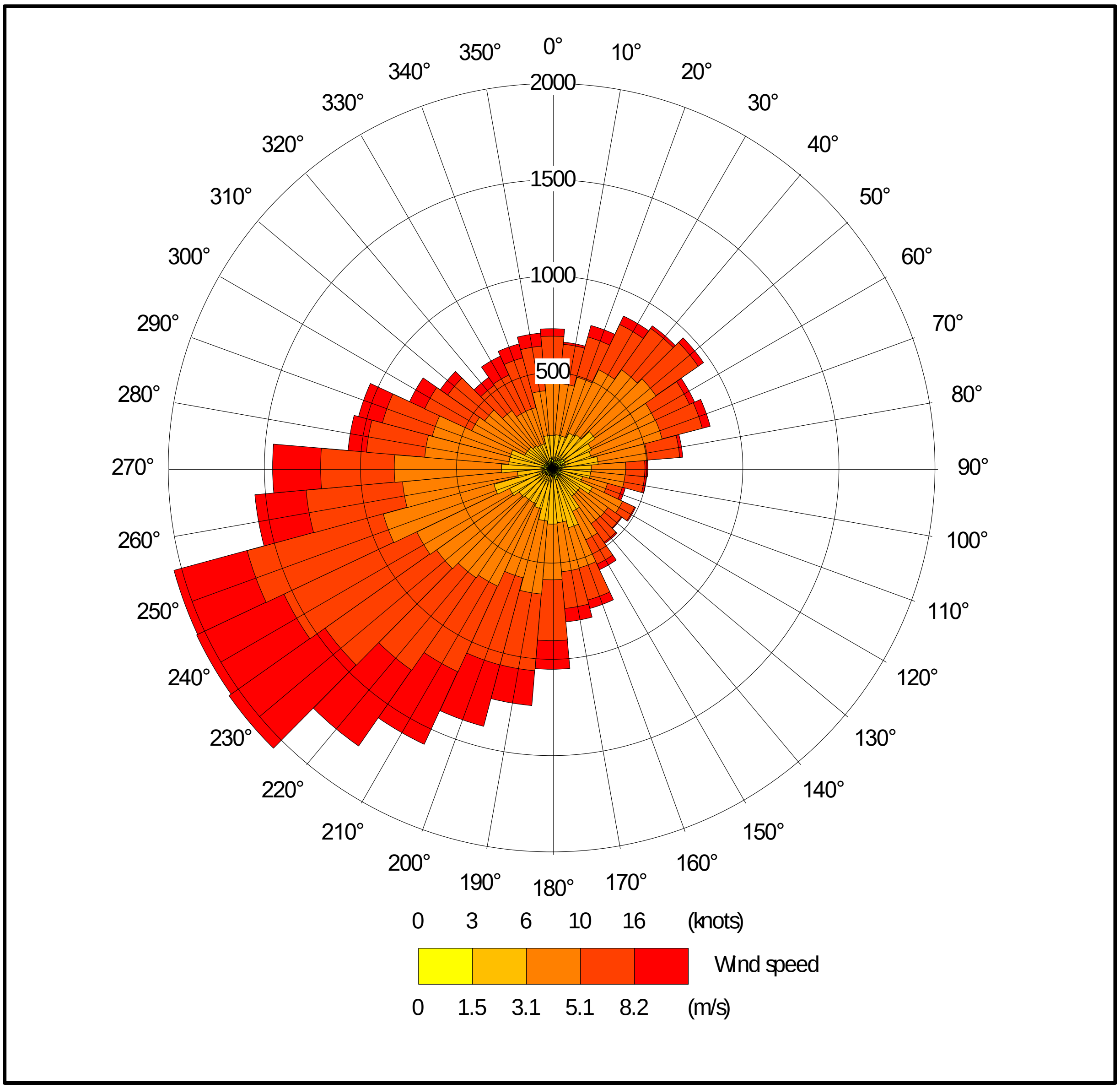
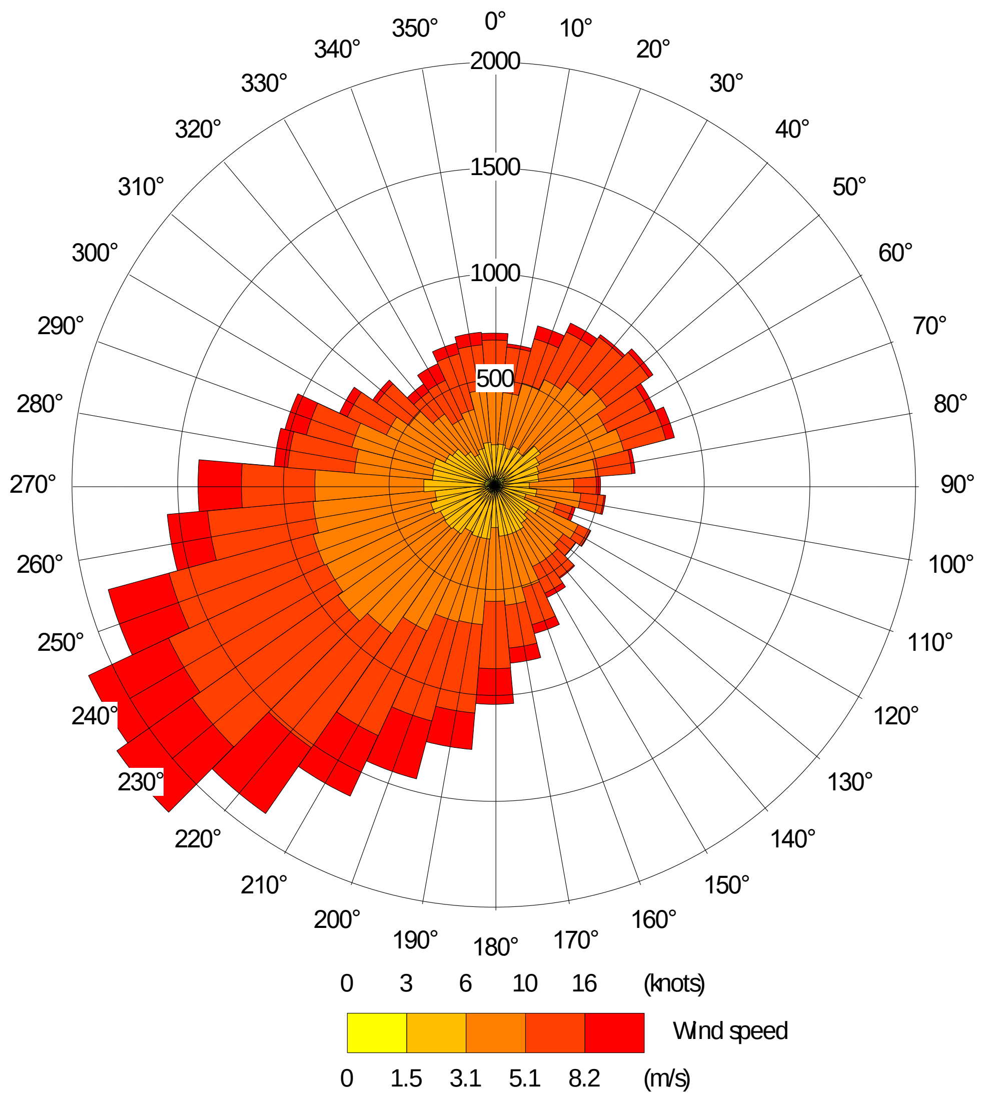


Figure 2b. The wind rose. FLOWSTAR modified GFS derived data for NGR 615500, 320650, 2020-2023



4.2 Emission sources

Emissions from the side fans that are used to ventilate the existing poultry houses are represented by volume sources within ADMS. Details of the volume source parameters are shown in Table 3a. The positions of the volume sources used are shown in Figure 3a, marked by red rectangles.

Table 3a. Volume source parameters

Source ID	Length (m)	Width (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission Rate (g-NH_3/s)
EX1TO6	89.9	175.3	3.0	0.5	Ambient	1.901285 [2]
EX7	21.5	112.4	3.0	0.5	Ambient	0.316881 [2]
EX8&9	48.5	72.9	3.0	0.5	Ambient	0.633762 [2]
EX10TO16	230.5	82.0	3.0	0.5	Ambient	2.218166 [2]
EX17	67.3	17.1	3.0	0.5	Ambient	0.316881 [2]
EX18	66.8	16.1	3.0	0.5	Ambient	0.316881 [2]
EX19	26.7	69.6	3.0	0.5	Ambient	0.316881 [2]
EX20&21	53.5	71.6	3.0	0.5	Ambient	0.633762 [2]

Emissions from the chimneys of the uncapped high speed ridge fans that would be used for the primary ventilation of the proposed poultry houses are represented by three point sources per house within ADMS (H1 1, 2 & 3 to H12 1, 2 & 3). Details of the point source parameters are shown in Table 3b. The positions of the point sources used are shown in Figure 3b (point sources are marked by green circles).

Table 3b. Point source parameters

Source ID	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (˚C)	Baseline Emission rate per source (g/s)
H1 to H12; 1, 2 & 3	6.2	0.8	9.0	Variable [1]	0.348569 [2]

1. Dependent on ambient temperature.
2. Assumes an emission factor of 1.0 kg-NH_3/bird-place/y, results are scaled by a factors of: 0.138 for the existing scenario; 0.034 for the standard broiler emission scenario and 0.0221 for the heat exchanger scenario.

4.3 Modelled buildings

The structure of the proposed poultry houses and other large 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 3b (marked by grey rectangles).

4.4 Discrete receptors

Thirty-eight discrete receptors have been defined at the nearby non-statutory and statutory wildlife sites. These receptors are defined at ground level within ADMS. The positions of the discrete receptors may be seen in Figure 4 (marked by enumerated pink rectangles).

4.5 Cartesian grid

To produce the contour plots presented in Section 5 of this report and to define the spatially varying deposition velocity field, regular Cartesian grids have been defined within ADMS. The individual grid receptors are defined at ground level within ADMS. The positions of the Cartesian grids may be seen in Figure 4 (marked by grey lines).

4.6 Terrain data

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

4.7 Roughness Length

In this case, a spatially varying roughness length file has been defined, this is based upon the Defra Living Landscapes land use database. The GFS meteorological data is assumed to have a roughness length of 0.241 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 5.

Figure 3a. The positions of the existing modelled sources

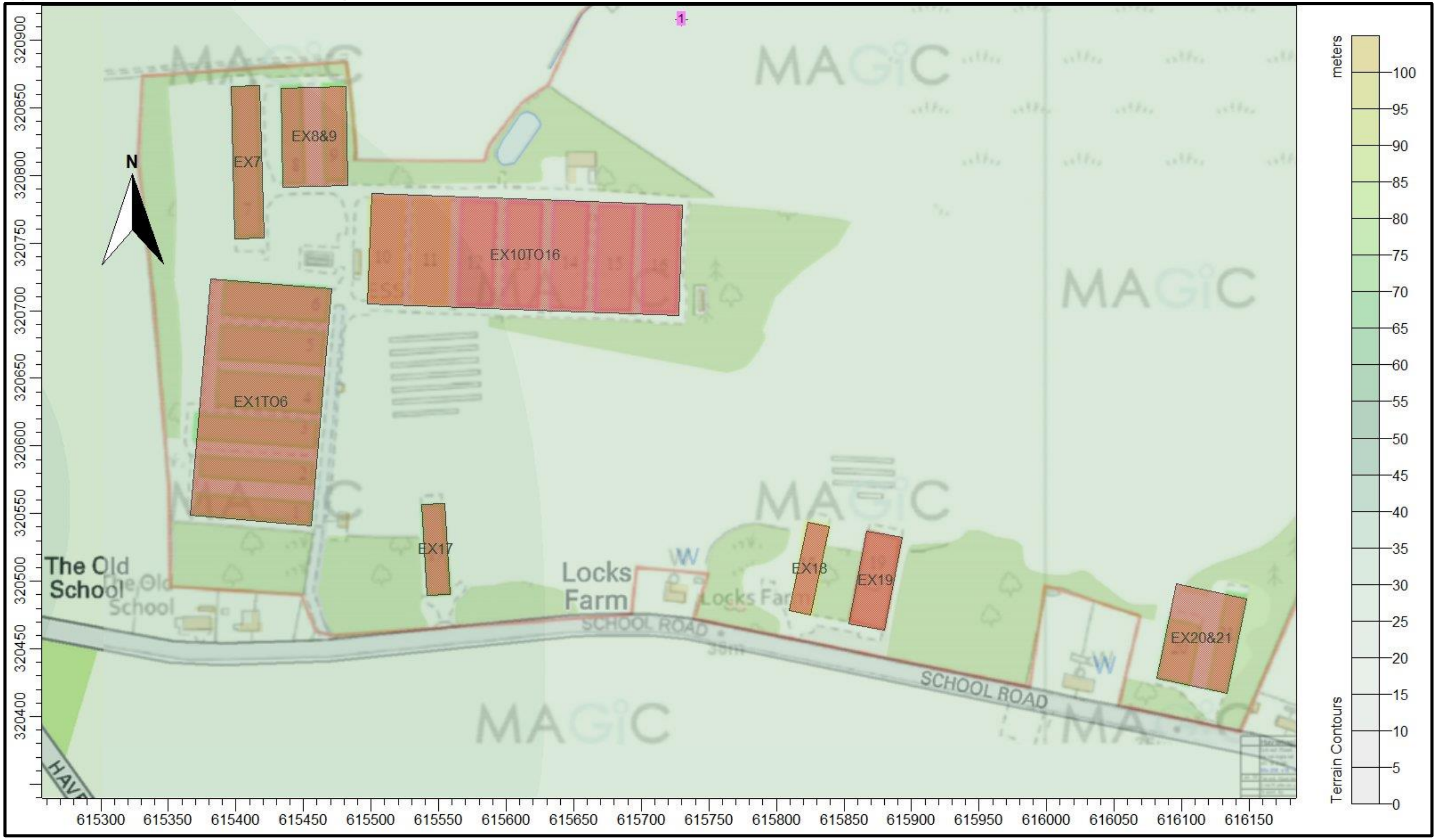


Figure 3b. The positions of the proposed modelled buildings and sources

Figure 4a. The discrete receptors and Cartesian grid

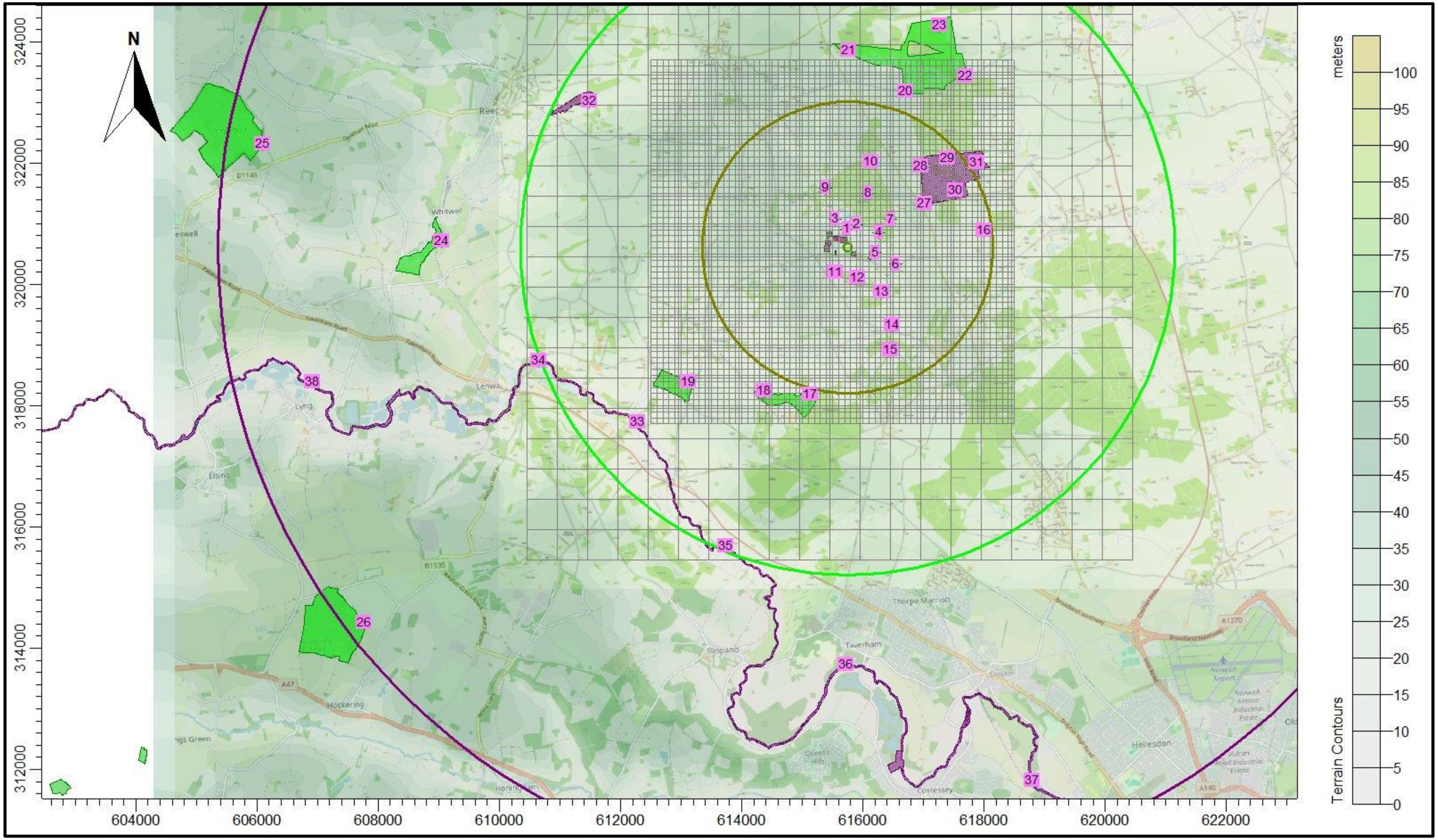


Figure 4b. The discrete receptors and Cartesian grid – a closer view

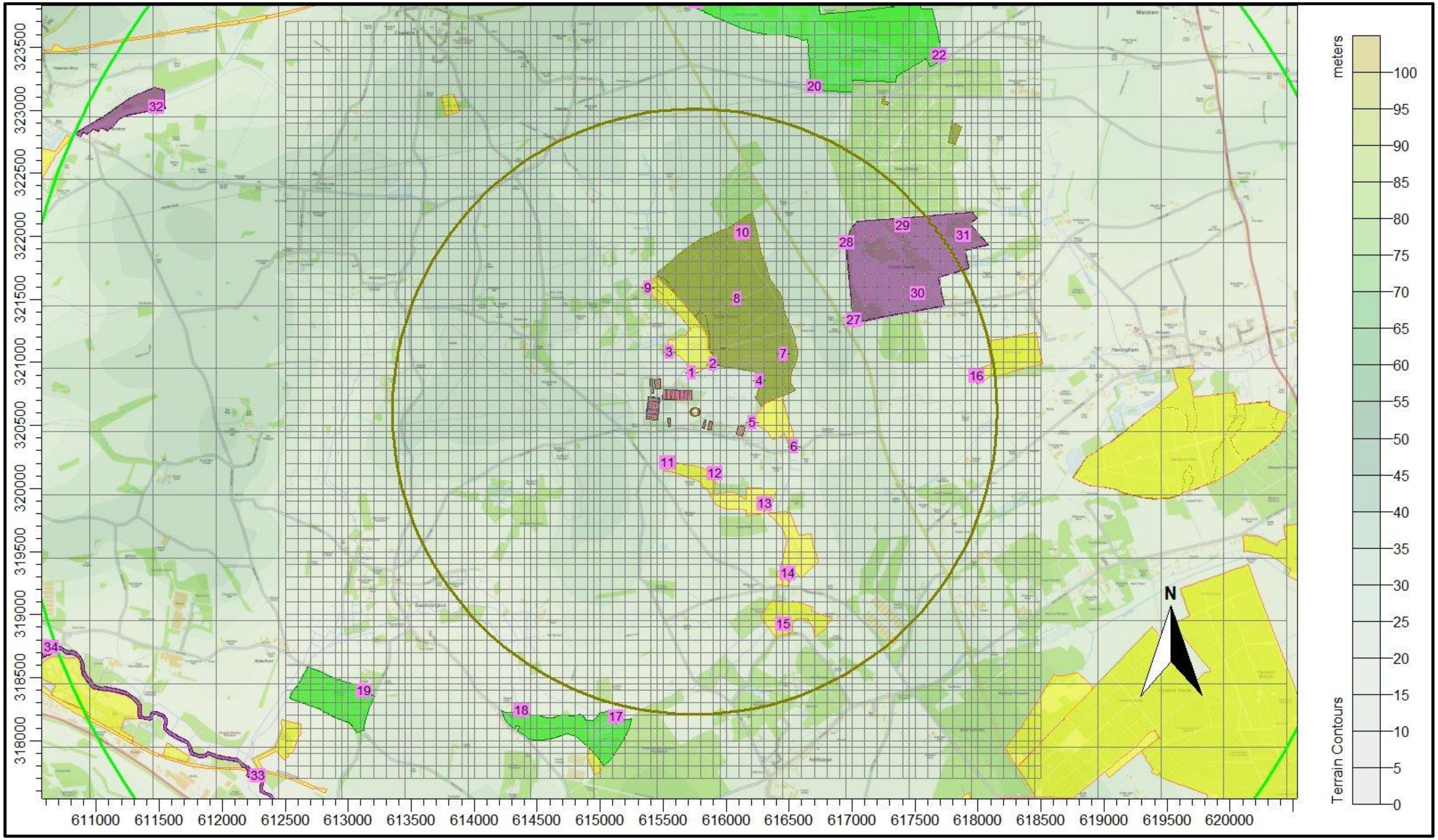
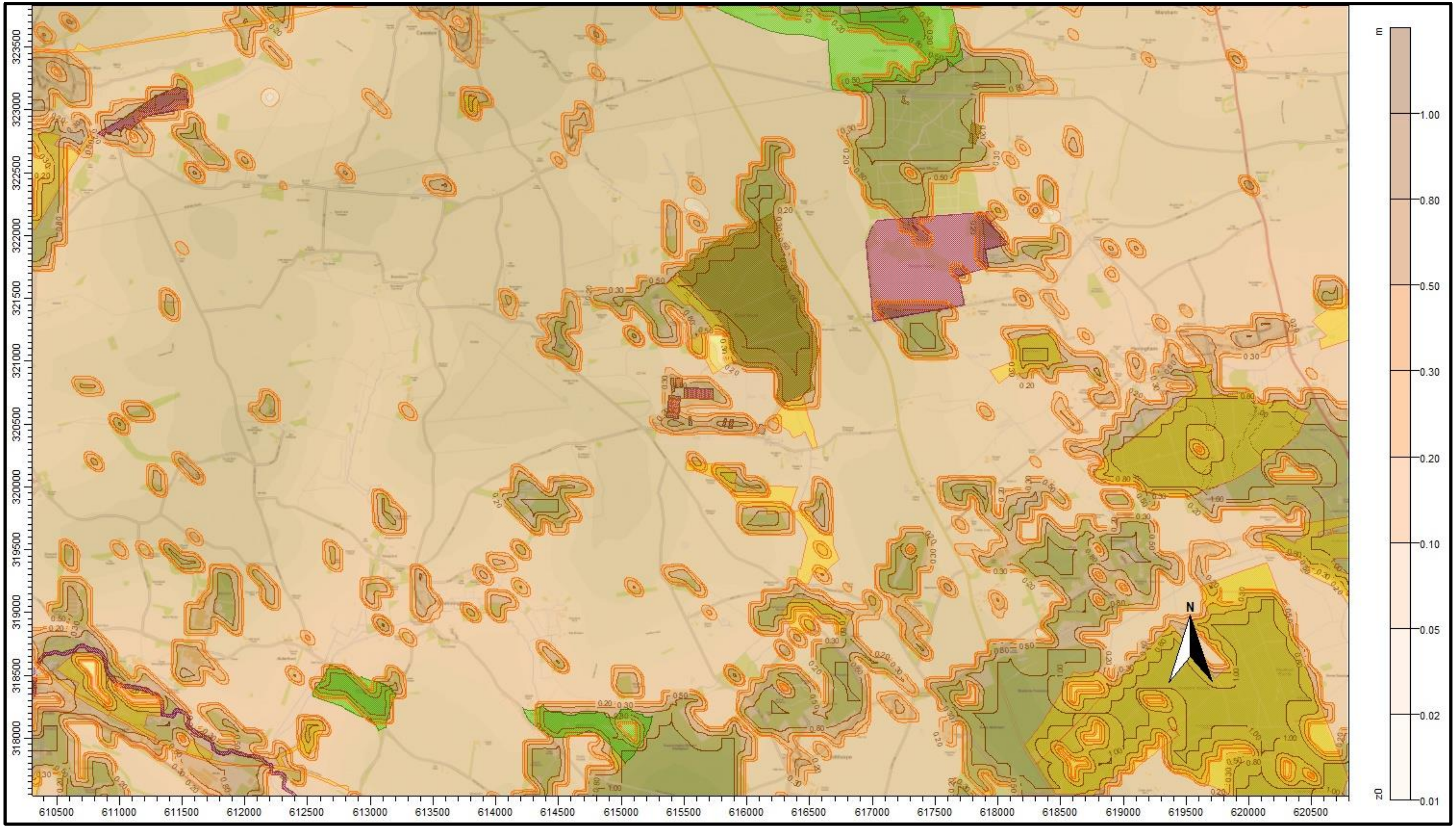


Figure 5. The spatially varying surface roughness field (central area)



4.8 Deposition

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

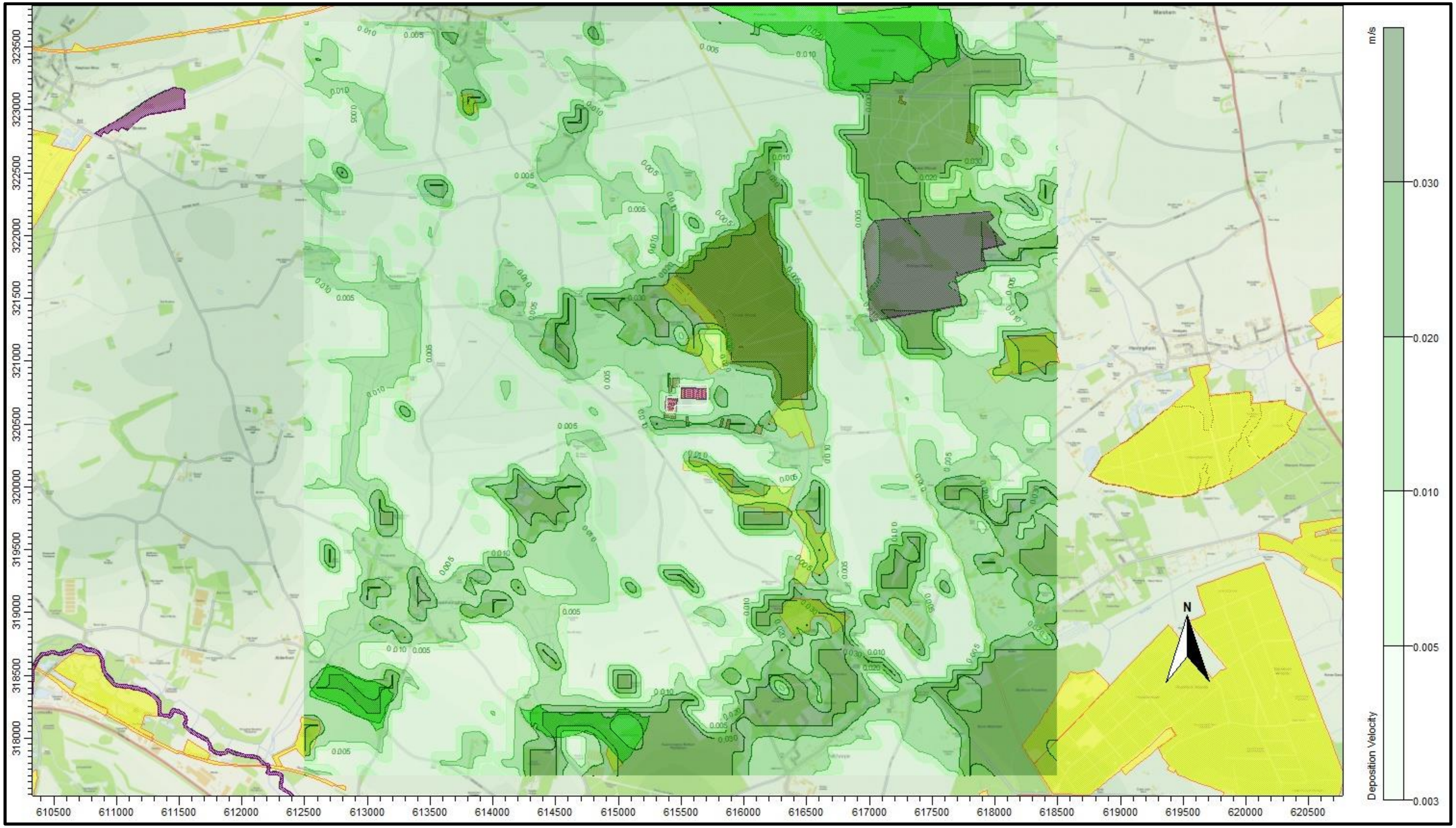
The deposition velocities used are provided in Table 4.

Table 4. Deposition velocities

NH_3 concentration (PC + background) (µg/m^3)	< 10	10 - 20	20 - 30	30 - 80	> 80
Deposition velocity - woodland (m/s)	0.03	0.015	0.01	0.005	0.003
Deposition velocity - short vegetation (m/s)	0.02 (0.010 to 0.015 over heavily grazed grassland)	0.015	0.01	0.005	0.003
Deposition velocity - arable farmland/rye grass (m/s)	0.005	0.005	0.005	0.005	0.003

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

Figure 6. The spatially varying deposition field



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5. Details of the Model Runs and Results

5.1 Preliminary modelling and model sensitivity tests

General sensitivities have been tested (tables available on request).

5.2 Detailed modelling

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

The predicted maximum annual mean ground level ammonia concentrations, nitrogen deposition and acid deposition rates at the discrete receptors are shown in Tables 5a, 5b and 5c for the existing and the two proposed scenarios, respectively. In the Tables, predicted ammonia concentrations and deposition rates that are in excess of the Environment Agency's upper threshold (100% of the precautionary Critical Level of 1.0 $\mu g\text{-}NH_3/m^3$ and Critical Load of 10.0 kg-N/ha/y for a non-statutory site, 20% of the relevant Critical Level or Load for a SSSI and 4% of the relevant Critical Level or Load for an internationally designated site) are coloured red. Concentrations or deposition rates in the range between the Environment Agency's lower and upper thresholds (100% and 100% for a non-statutory site, 20% and 50% for a SSSI and 4% and 20% for an internationally designated site) are coloured blue. Additionally, process contributions which exceed 1% of the relevant Critical Level or Critical Load at a statutory site are highlighted with bold text.

Contour plots of the predicted maximum annual mean ammonia concentration and the maximum annual nitrogen deposition rate are shown in Figures 7a and Figure 7b (existing scenario), Figures 8a and 8b (proposed scenario 1) and Figures 9a and 9b (proposed scenario 2).

Table 5a. Predicted maximum annual mean ammonia concentrations and nitrogen deposition rates – existing scenario

Receptor number	X(m)	Y(m)	Designation	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level (µg/m³)	Critical Load (kg/ha)	Process Contribution (µg/m³)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	615730	320915	LWS	0.03	1.0	10.0	8.716	**871.6**	67.91	**679.1**
2	615897	320985	LWS	0.03	1.0	10.0	3.507	**350.7**	27.32	**273.2**
3	615550	321077	LWS	0.03	1.0	10.0	4.109	**410.9**	32.01	**320.1**
4	616262	320852	AW	0.03	1.0	10.0	1.583	**158.3**	12.34	**123.4**
5	616210	320522	LWS	0.03	1.0	10.0	6.767	**676.7**	52.72	**527.2**
6	616540	320331	LWS	0.02	1.0	10.0	0.748	74.8	3.88	38.8
7	616459	321066	AW	0.03	1.0	10.0	0.765	76.5	5.96	59.6
8	616088	321500	AW	0.03	1.0	10.0	0.585	58.5	4.55	45.5
9	615382	321587	LWS	0.03	1.0	10.0	0.485	48.5	3.78	37.8
10	616129	322027	AW	0.03	1.0	10.0	0.227	22.7	1.77	17.7
11	615539	320197	LWS	0.03	1.0	10.0	2.264	**226.4**	17.64	**176.4**
12	615909	320116	LWS	0.03	1.0	10.0	1.528	**152.8**	11.91	**119.1**
13	616308	319873	LWS	0.02	1.0	10.0	0.470	47.0	2.44	24.4
14	616488	319323	LWS	0.02	1.0	10.0	0.167	16.7	0.87	8.7
15	616459	318924	LWS	0.02	1.0	10.0	0.109	10.9	0.56	5.6
16	617993	320886	LWS	0.02	1.0	10.0	0.134	13.4	0.70	7.0
17	615129	318183	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.081	**8.1**	0.63	**6.3**
18	614374	318235	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.082	**8.2**	0.64	**6.4**
19	613123	318391	Alderford Common SSSI	0.03	3.0	20.0	0.058	**1.9**	0.45	**2.3**
20	616705	323184	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.067	**6.7**	0.52	**5.2**
21	615767	323862	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.047	**4.7**	0.37	**3.7**
22	617695	323432	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.051	**5.1**	0.40	**4.0**
23	617265	324265	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.039	**3.9**	0.31	**3.1**
24	609043	320708	Whitwell Common SSSI	0.03	1.0	10.0	0.012	**1.2**	0.09	**0.9**
25	606087	322307	Foxley Wood SSSI	0.03	1.0	10.0	0.005	**0.5**	0.04	**0.4**
26	607760	314424	Hockering Wood SSSI	0.03	1.0	10.0	0.006	**0.6**	0.05	**0.5**
27	617011	321331	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.323	**32.3**	1.68	**33.5**
28	616960	321944	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.189	**18.9**	0.98	**19.6**
29	617403	322080	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.132	**13.2**	0.69	**13.7**
30	617522	321547	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.175	**17.5**	0.91	**18.2**
31	617882	322006	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.111	**11.1**	0.58	**11.6**
32	611481	323020	Booton Common SSSI/SAC	0.02	1.0	15.0	0.020	**2.0**	0.10	0.7
33	612282	317722	River Wensum SSSI/SAC	0.02	3.0	15.0	0.038	**1.3**	0.20	**1.3**
34	610647	318736	River Wensum SSSI/SAC	0.02	3.0	15.0	0.022	0.7	0.12	0.8
35	613738	315678	River Wensum SSSI/SAC	0.02	3.0	15.0	0.020	0.7	0.11	0.7
36	615724	313732	River Wensum SSSI/SAC	0.02	3.0	15.0	0.009	0.3	0.05	0.3
37	618790	311819	River Wensum SSSI/SAC	0.02	3.0	15.0	0.005	0.2	0.03	0.2
38	606919	318392	River Wensum SSSI/SAC	0.02	3.0	15.0	0.009	0.3	0.05	0.3

Table 5b. Predicted maximum annual mean ammonia concentrations and nitrogen deposition rates – proposed scenario 1

Receptor number	X(m)	Y(m)	Designation	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level (µg/m³)	Critical Load (kg/ha)	Process Contribution (µg/m³)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	615730	320915	LWS	0.03	1.0	10.0	2.573	**257.3**	20.05	**200.5**
2	615897	320985	LWS	0.03	1.0	10.0	1.175	**117.5**	9.16	91.6
3	615550	321077	LWS	0.03	1.0	10.0	0.948	94.8	7.38	73.8
4	616262	320852	AW	0.03	1.0	10.0	0.413	41.3	3.22	32.2
5	616210	320522	LWS	0.03	1.0	10.0	0.299	29.9	2.33	23.3
6	616540	320331	LWS	0.02	1.0	10.0	0.144	14.4	0.75	7.5
7	616459	321066	AW	0.03	1.0	10.0	0.269	26.9	2.10	21.0
8	616088	321500	AW	0.03	1.0	10.0	0.250	25.0	1.95	19.5
9	615382	321587	LWS	0.03	1.0	10.0	0.186	18.6	1.45	14.5
10	616129	322027	AW	0.03	1.0	10.0	0.102	10.2	0.79	7.9
11	615539	320197	LWS	0.03	1.0	10.0	0.472	47.2	3.68	36.8
12	615909	320116	LWS	0.03	1.0	10.0	0.214	21.4	1.66	16.6
13	616308	319873	LWS	0.02	1.0	10.0	0.101	10.1	0.52	5.2
14	616488	319323	LWS	0.02	1.0	10.0	0.050	5.0	0.26	2.6
15	616459	318924	LWS	0.02	1.0	10.0	0.035	3.5	0.18	1.8
16	617993	320886	LWS	0.02	1.0	10.0	0.047	4.7	0.24	2.4
17	615129	318183	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.029	**2.9**	0.23	**2.3**
18	614374	318235	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.033	**3.3**	0.26	**2.6**
19	613123	318391	Alderford Common SSSI	0.03	3.0	20.0	0.025	0.8	0.19	1.0
20	616705	323184	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.035	**3.5**	0.28	**2.8**
21	615767	323862	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.025	**2.5**	0.20	**2.0**
22	617695	323432	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.027	**2.7**	0.21	**2.1**
23	617265	324265	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.022	**2.2**	0.17	**1.7**
24	609043	320708	Whitwell Common SSSI	0.03	1.0	10.0	0.008	0.8	0.06	0.6
25	606087	322307	Foxley Wood SSSI	0.03	1.0	10.0	0.003	0.3	0.03	0.3
26	607760	314424	Hockering Wood SSSI	0.03	1.0	10.0	0.004	0.4	0.03	0.3
27	617011	321331	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.127	**12.7**	0.66	**13.1**
28	616960	321944	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.091	**9.1**	0.47	**9.4**
29	617403	322080	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.066	**6.6**	0.34	**6.8**
30	617522	321547	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.076	**7.6**	0.39	**7.8**
31	617882	322006	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.050	**5.0**	0.26	**5.2**
32	611481	323020	Booton Common SSSI/SAC	0.02	1.0	15.0	0.014	**1.4**	0.07	0.5
33	612282	317722	River Wensum SSSI/SAC	0.02	3.0	15.0	0.020	0.7	0.10	0.7
34	610647	318736	River Wensum SSSI/SAC	0.02	3.0	15.0	0.013	0.4	0.07	0.4
35	613738	315678	River Wensum SSSI/SAC	0.02	3.0	15.0	0.012	0.4	0.06	0.4
36	615724	313732	River Wensum SSSI/SAC	0.02	3.0	15.0	0.005	0.2	0.02	0.2
37	618790	311819	River Wensum SSSI/SAC	0.02	3.0	15.0	0.003	0.1	0.02	0.1
38	606919	318392	River Wensum SSSI/SAC	0.02	3.0	15.0	0.005	0.2	0.03	0.2

Table 5c. Predicted maximum annual mean ammonia concentrations and nitrogen deposition rates – pro[posed scenario 2

Receptor number	X(m)	Y(m)	Designation	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level ($\mu g/m^3$)	Critical Load (kg/ha)	Process Contribution ($\mu g/m^3$)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	615730	320915	LWS	0.03	1.0	10.0	1.673	**167.3**	13.03	**130.3**
2	615897	320985	LWS	0.03	1.0	10.0	0.764	76.4	5.95	59.5
3	615550	321077	LWS	0.03	1.0	10.0	0.616	61.6	4.80	48.0
4	616262	320852	AW	0.03	1.0	10.0	0.269	26.9	2.09	20.9
5	616210	320522	LWS	0.03	1.0	10.0	0.194	19.4	1.51	15.1
6	616540	320331	LWS	0.02	1.0	10.0	0.094	9.4	0.49	4.9
7	616459	321066	AW	0.03	1.0	10.0	0.175	17.5	1.36	13.6
8	616088	321500	AW	0.03	1.0	10.0	0.163	16.3	1.27	12.7
9	615382	321587	LWS	0.03	1.0	10.0	0.121	12.1	0.94	9.4
10	616129	322027	AW	0.03	1.0	10.0	0.066	6.6	0.52	5.2
11	615539	320197	LWS	0.03	1.0	10.0	0.307	30.7	2.39	23.9
12	615909	320116	LWS	0.03	1.0	10.0	0.139	13.9	1.08	10.8
13	616308	319873	LWS	0.02	1.0	10.0	0.066	6.6	0.34	3.4
14	616488	319323	LWS	0.02	1.0	10.0	0.032	3.2	0.17	1.7
15	616459	318924	LWS	0.02	1.0	10.0	0.023	2.3	0.12	1.2
16	617993	320886	LWS	0.02	1.0	10.0	0.031	3.1	0.16	1.6
17	615129	318183	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.019	**1.9**	0.15	**1.5**
18	614374	318235	Swannington Upgate Common SSSI	0.03	1.0	10.0	0.022	**2.2**	0.17	**1.7**
19	613123	318391	Alderford Common SSSI	0.03	3.0	20.0	0.016	0.5	0.12	0.6
20	616705	323184	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.023	**2.3**	0.18	**1.8**
21	615767	323862	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.017	**1.7**	0.13	**1.3**
22	617695	323432	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.018	**1.8**	0.14	**1.4**
23	617265	324265	Cawston and Marsham Heaths SSSI	0.03	1.0	10.0	0.014	**1.4**	0.11	**1.1**
24	609043	320708	Whitwell Common SSSI	0.03	1.0	10.0	0.005	0.5	0.04	0.4
25	606087	322307	Foxley Wood SSSI	0.03	1.0	10.0	0.002	0.2	0.02	0.2
26	607760	314424	Hockering Wood SSSI	0.03	1.0	10.0	0.003	0.3	0.02	0.2
27	617011	321331	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.082	**8.2**	0.43	**8.5**
28	616960	321944	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.059	**5.9**	0.31	**6.1**
29	617403	322080	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.043	**4.3**	0.22	**4.4**
30	617522	321547	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.049	**4.9**	0.26	**5.1**
31	617882	322006	Buxton Heath SSSI/SAC	0.02	1.0	5.0	0.032	**3.2**	0.17	**3.4**
32	611481	323020	Booton Common SSSI/SAC	0.02	1.0	15.0	0.009	0.9	0.05	0.3
33	612282	317722	River Wensum SSSI/SAC	0.02	3.0	15.0	0.013	0.4	0.07	0.4
34	610647	318736	River Wensum SSSI/SAC	0.02	3.0	15.0	0.008	0.3	0.04	0.3
35	613738	315678	River Wensum SSSI/SAC	0.02	3.0	15.0	0.007	0.2	0.04	0.3
36	615724	313732	River Wensum SSSI/SAC	0.02	3.0	15.0	0.003	0.1	0.02	0.1
37	618790	311819	River Wensum SSSI/SAC	0.02	3.0	15.0	0.002	0.1	0.01	0.1
38	606919	318392	River Wensum SSSI/SAC	0.02	3.0	15.0	0.003	0.1	0.02	0.1

Figure 7a. Maximum annual ammonia concentration – existing scenario

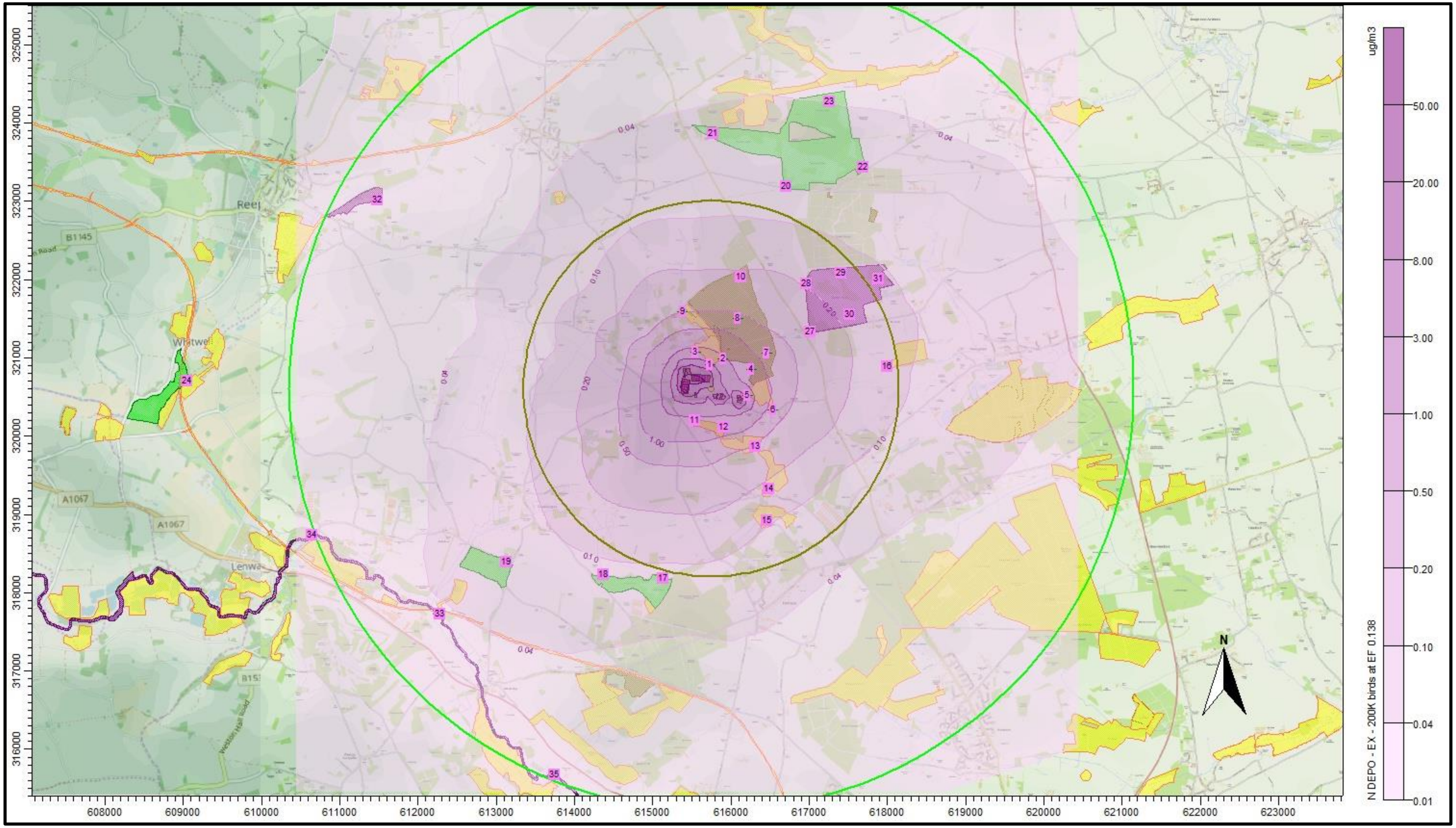


Figure 7b. Maximum annual nitrogen deposition rates – existing scenario

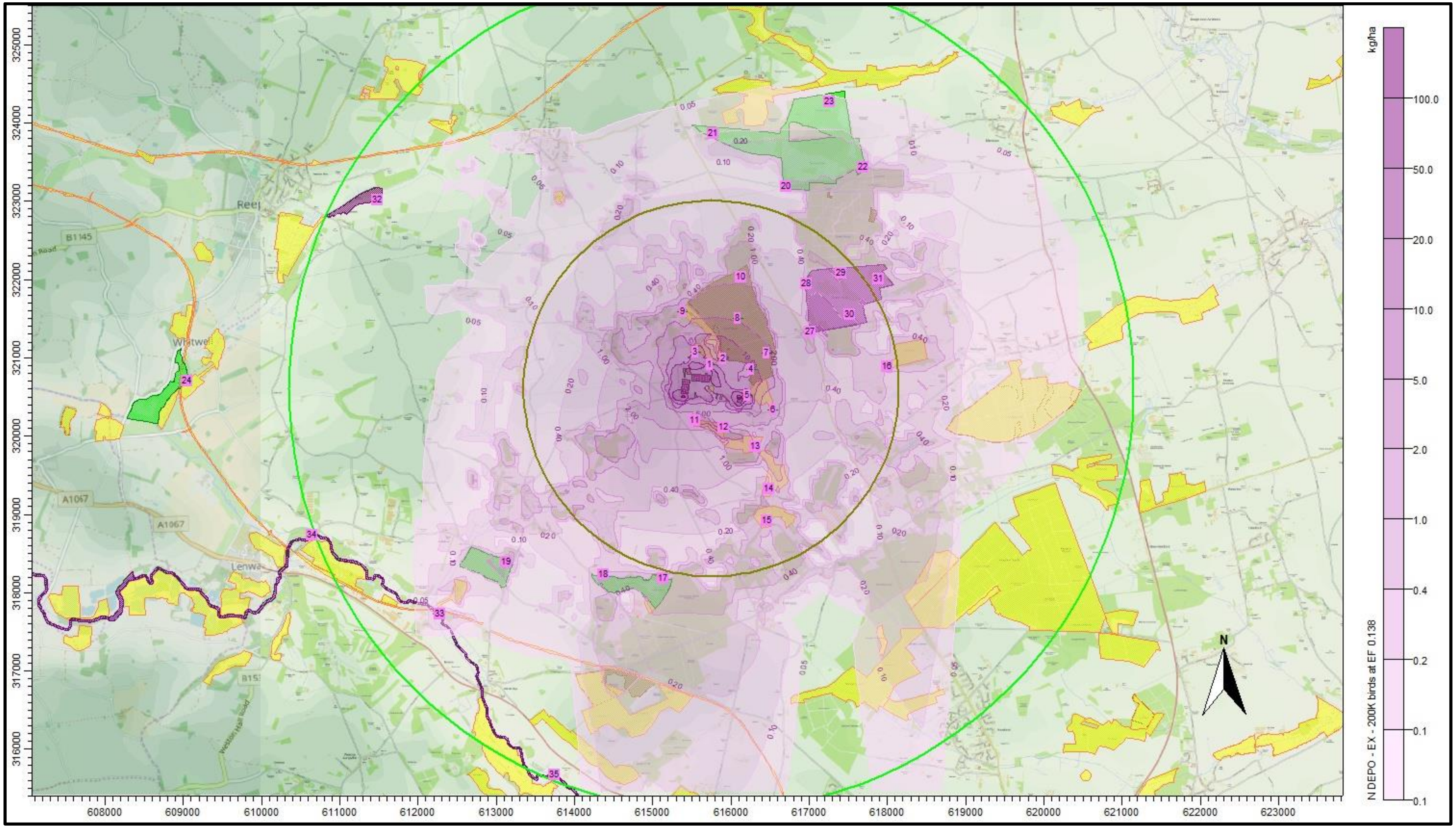


Figure 8a. Maximum annual ammonia concentration – proposed scenario 1

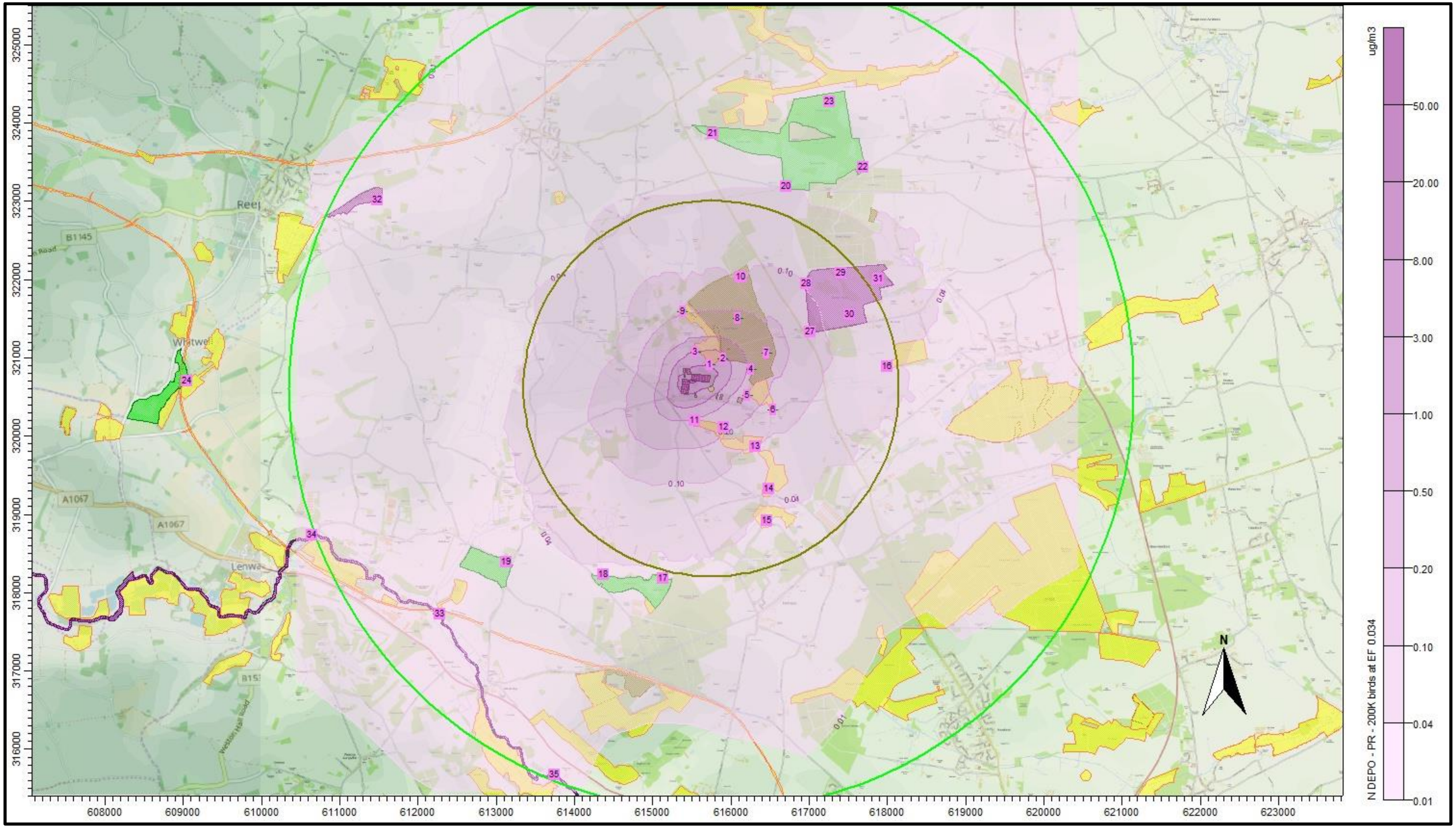


Figure 8b. Maximum annual nitrogen deposition rates – proposed scenario 1

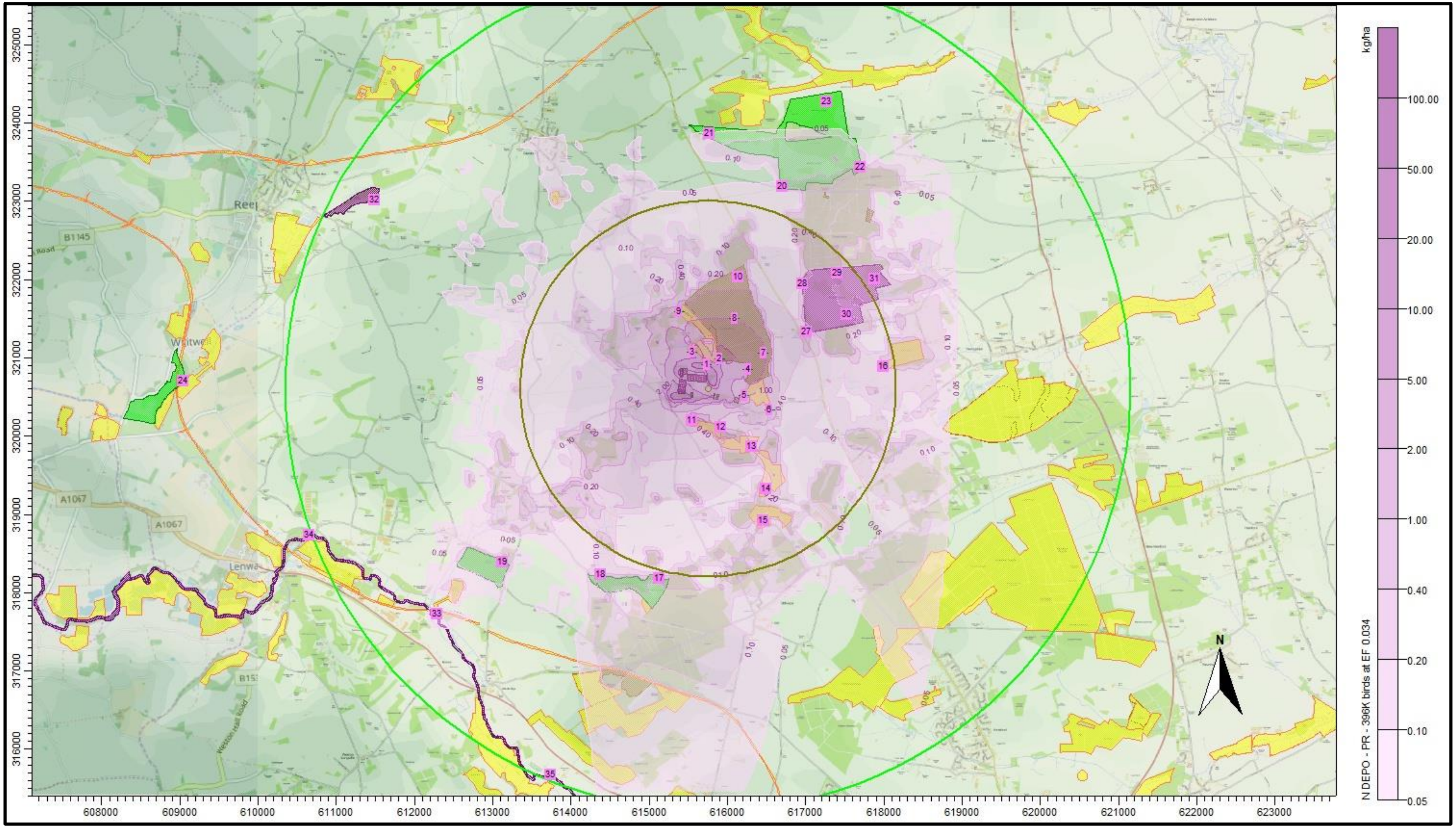


Figure 9a. Maximum annual ammonia concentration – proposed scenario 2

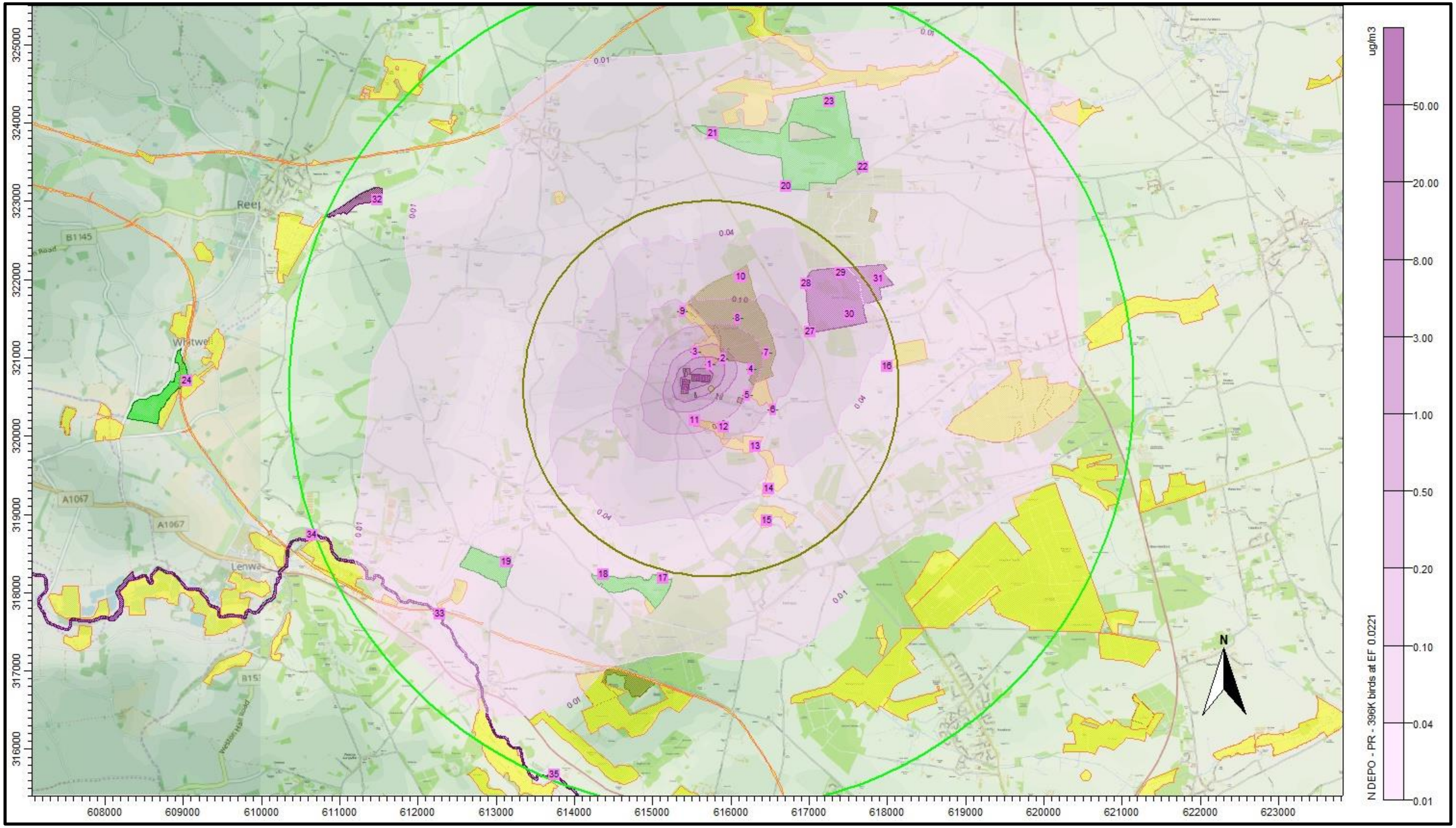
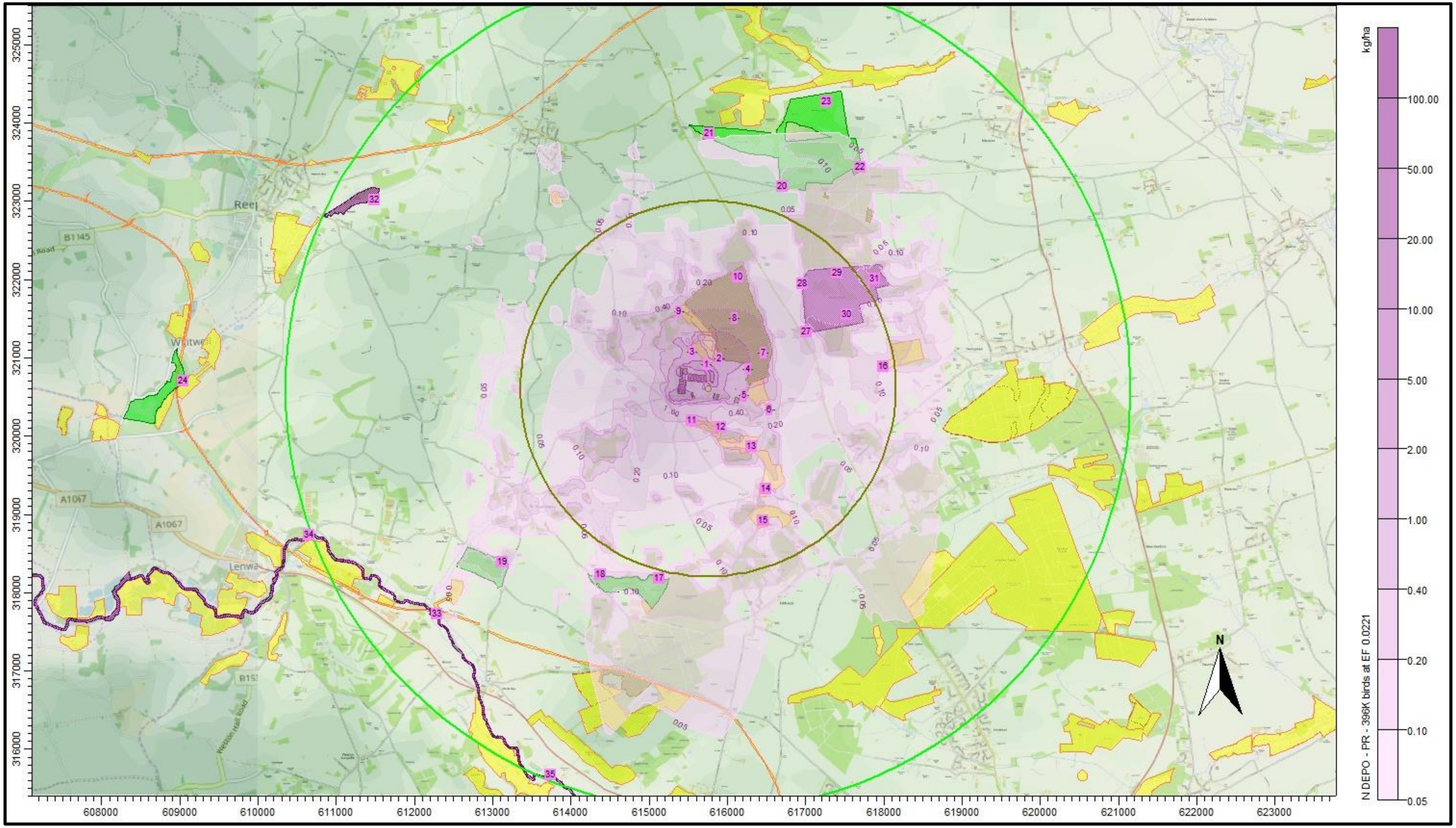


Figure 9b. Maximum annual nitrogen deposition rates – proposed scenario 2



6. Summary and Conclusions

AS Modelling & Data Ltd. has been instructed by Mr. Simon Akrill of Amber Real Estate Investments (Agriculture) Ltd., to use computer modelling to assess the impact of ammonia emissions from the existing and proposed poultry rearing houses at Haveringland, School Road, Broadland, Norfolk. NR10 4QL.

Ammonia emission rates from the existing and proposed poultry rearing houses have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors or emission factors that AS Modelling & Data Ltd. understands are agreed with the Environment Agency. The ammonia emission rates have then been used as inputs to an atmospheric dispersion and deposition model which calculates ammonia exposure levels and nitrogen and acid deposition rates in the surrounding area.

The modelling predicts that:

- The process contributions from the existing stag turkey rearing to ammonia concentrations and nitrogen deposition rates, exceedances of the Environment Agency's upper threshold percentage of the relevant Critical Level and Critical Load at a number of the nearby non-statutory sites and Buxton Heath SSSI/SAC. Elsewhere, there are exceedances of 1% of the relevant Critical Level/Load at several of the SSSIs and SACs.

- Under proposal scenario 1, the process contribution to ammonia concentrations and nitrogen deposition rates are reduced at all wildlife sites considered. At the closest LWS to the north of the farm, which is very close to the poultry houses, the Environment Agency's upper threshold percentage of the precautionary Critical Level of 1.0 μg-NH3/m3 and Critical Load of 10.0 kg-N/ha/y is exceeded. There would also be an exceedance of the lower threshold percentage of the Critical Level of 1.0 μg-NH3/m3 and Critical Load of 5.0 kg-N/ha/y at Buxton Heath SSSI/SAC. In addition, there would be exceedances of 1% of the relevant Critical Level or Critical Load at Swannington Upgate Common SSSI, Alderford Common SSSI, Cawston and Marsham Heaths SSSI and Booton Common SSSI/SAC.

- Should heat exchangers be utilised in the proposed refurbished poultry houses, in addition to the high speed roof fans (proposed scenario 2), the process contribution to ammonia concentrations and nitrogen deposition rates would be further reduced at all wildlife sites, although some exceedances would remain.

7. References

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