A Report on the Modelling of the Dispersion and Deposition of Ammonia from the Existing and Proposed Piggeries at Old Hall Farm, near Burston in Norfolk

AS Modelling & Data Ltd.

www.asmodata.co.uk

Prepared by Steve Smith

stevesmith@asmodata.co.uk
07523 993370
24th July 2025

Reviewed by Sally Young

sally@asmodata.co.uk
07483 345124
31st July 2025

This report has been prepared by AS Modelling & Data Ltd. on behalf of the Client, based on the information provided by the client and/or agent. In preparing this report, AS Modelling & Data Ltd. has exercised all reasonable skill and care, taking into account the agreed scope of works with the Client. AS Modelling & Data Ltd. does not accept any liability in negligence for any matters arising outside of the agreed scope of works, or for changes that may be required due to omissions in the information provided.

1. Introduction

AS Modelling & Data Ltd. has been instructed by Mr. Karl Kollett of Green Inc Solutions Ltd, on behalf of Calton Brothers, to use computer modelling to assess the impact of ammonia emissions from the existing and proposed piggeries at Old Hall Farm, Burston, Diss, Norfolk. IP22 5TF.

Ammonia emission rates from the existing and proposed pig rearing buildings at Old Hall Farm have been assessed and quantified based upon bespoke ammonia emission factors provided by 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 piggeries at Old Hall Farm are in a rural area approximately 1.2 km to the west-north-west of the village of Burston in Norfolk. The surrounding land is used primarily for arable cultivation, although there are some isolated wooded areas. The farm is at an altitude of around 50 m with the land rising gently towards higher ground to the north and falling towards a tributary of the River Waveney to the south.

Three scenarios are considered in this report:

- **Existing Scenario** – The existing farm, with up to 3,000 <30 kg pigs and 3,000 >30 kg pigs, housed in a variety of naturally ventilated buildings. Spent litter and manure are stored in two middens and a covered slurry lagoon.
- **Proposed Scenario** – The proposed farm, with up to 4,500 <30 kg pigs and 6,320 >30 kg pigs, housed in a variety of naturally ventilated buildings which includes some of the existing houses and two newly constructed houses. Spent litter and manure would continue to be stored in two middens and a covered slurry lagoon.
- **Proposed Houses Only** (for planning purposes) – The two newly constructed naturally ventilated buildings housing up to 3,600 >30 kg pigs.

Further details of housing type/ventilation, pig numbers and manure management for both scenarios are provided in Section 3.5 of this report.

AS Modelling & Data Ltd. have identified four areas designated as Local Wildlife Sites (LWSs) within 2 km (the normal screening distance for a non-statutory site) of Old Hall Farm (Local Authority policies/constraints mapping). There are no designated Ancient Woodland (AW) within 2 km. There are eleven SSSIs within 10 km (the screening distance for a SSSI/internationally designated site - Defra/Natural England, Impact Risk Zone Mapping). One of the SSSIs are also designated as a Special Areas of Conservation (SAC) and a Ramsar site. Further details of the statutory wildlife sites are provided below:

- **Shelfanger Meadows SSSI** - Approximately 2.4 km to the south-west - One of the most important areas of unimproved grassland in Norfolk, forming an outstanding example of traditionally managed, herb-rich, hay meadows. In addition, diverse marshy grassland has developed in seepage zones where springs emerge on the valley-side. Epiphytic lichens are present on trees at the site (site inspection).
- **Wortham Ling SSSI** - Approximately 6.0 km to the south-west - Important for its lowland dry heath and acid grassland communities which have developed on a sandy, glaciofluvial drift deposit. In the open areas within the stands of heather the ground is occupied by carpets of mosses, mainly *Polytrichum* spp. and lichens, particularly *Cladonia* spp. which are present in good numbers.
- **Gypsy Camp Meadows, Thrandeston SSSI** - Approximately 7.2 km to the south-south-west - One of the few remaining species rich wet meadow sites in Suffolk. A system of drainage ditches runs through the site and adds further diversity to the plant communities present.
- **Burgate Wood SSSI** - Approximately 9.9 km to the south-west - A particularly good example of the type of oak-hornbeam woodland characteristic of this part of north Suffolk. Many giant coppiced stools are present which indicate its great antiquity. The ground flora is diverse and includes several species that are indicators of ancient woodland, including one rarity.
- **Hoxne Brick Pit SSSI** - Approximately 8.6 km to the south-south-east - Geological.

- **Pulham Market Big Wood SSSI** - Approximately 8.8 km to the north-east - An ancient woodland site on heavy boulder clays, overlain in places by acidic sandy loams. The site is probably of primary origin and appears to be the sole remaining fragment of a once much larger area of woodland. The structure is coppice with standards and the wood is notable for the exceptional range of stand-types. A rare variant of plateau alderwood is present and there are also stands of lowland birch–pedunculate oak woodland and the uncommon birch–hazel variant of pedunculate oak–hornbeam woodland. The ground flora is fairly diverse and contains a few uncommon species.
- **Aslacton Parish Land SSSI** - Approximately 7.4 km to the north-north-east - A characteristic example of a type of unimproved spring-line meadow which at one time was widely distributed in the valley of the River Tas. A range of inter-grading wet and dry grassland types are present and the flora which is rich and contains a number of uncommon and declining species.
- **Forncett Meadows SSSI** - Approximately 8.6 km to the north-north-east - One of only three examples of unimproved meadow now remaining in the valley of the River Tas. An interesting mosaic of grassland types has developed in response to natural variation in soil type and wetness and to a long period of stable non-intensive grazing management.
- **New Buckenham Common SSSI** - Approximately 7.0 km to the north-north-west - A large area of unimproved grassland with a traditional management of light grazing by cattle. A variety of grassland types are present which reflect the alkalinity/acidity and drainage of the underlying soils. A number of uncommon plant species occur including the Green-winged Orchid *Orchis morio* which is present in some abundance.
- **Kenninghall & Banham Fens with Quidenham Mere SSSI** - Approximately 9.2 km to the west-north-west - Consists of areas of tall fen, species-rich fen and calcareous grassland (Kenninghall Fen and Banham Great Fen) and a deep natural mere (Quidenham Mere). Additional interest is provided by areas of wet woodland and by an area of drier unmanaged fen.
- **Redgrave and Lopham Fens SSSI/SAC/Ramsar site** - Approximately 8.2 km to the south-west - An extensive area of spring-fed valley fen at the headwaters of the River Waveney. It supports several distinct fen vegetation types, ranging from *Molinia*-based grasslands, mixed Sedge fen to Reed-dominated fen. There are small areas of wet heath, Sallow carr and Birch woodland. The invertebrate fauna is extensive and well studied and the site is the only British locality for the Fen Raft Spider *Dolomedes plantarius*.

Maps of the surrounding area showing the location of the piggeries, the LWSs, the SSSIs, the SAC and the Ramsar site are provided in Figures 1a and 1b. In these figures: the LWSs are shaded in yellow; the SSSIs are shaded in green; the Ramsar Site is shaded in blue; the SAC is shaded in purple and the site of the piggeries is outlined in blue. Where there are multiple designations, the higher designation is shown.

Figure 1a. The area surrounding Old Hall Farm - concentric circles radii 2.2 km (olive), 5.2 km (green) and 10.2 km (purple)

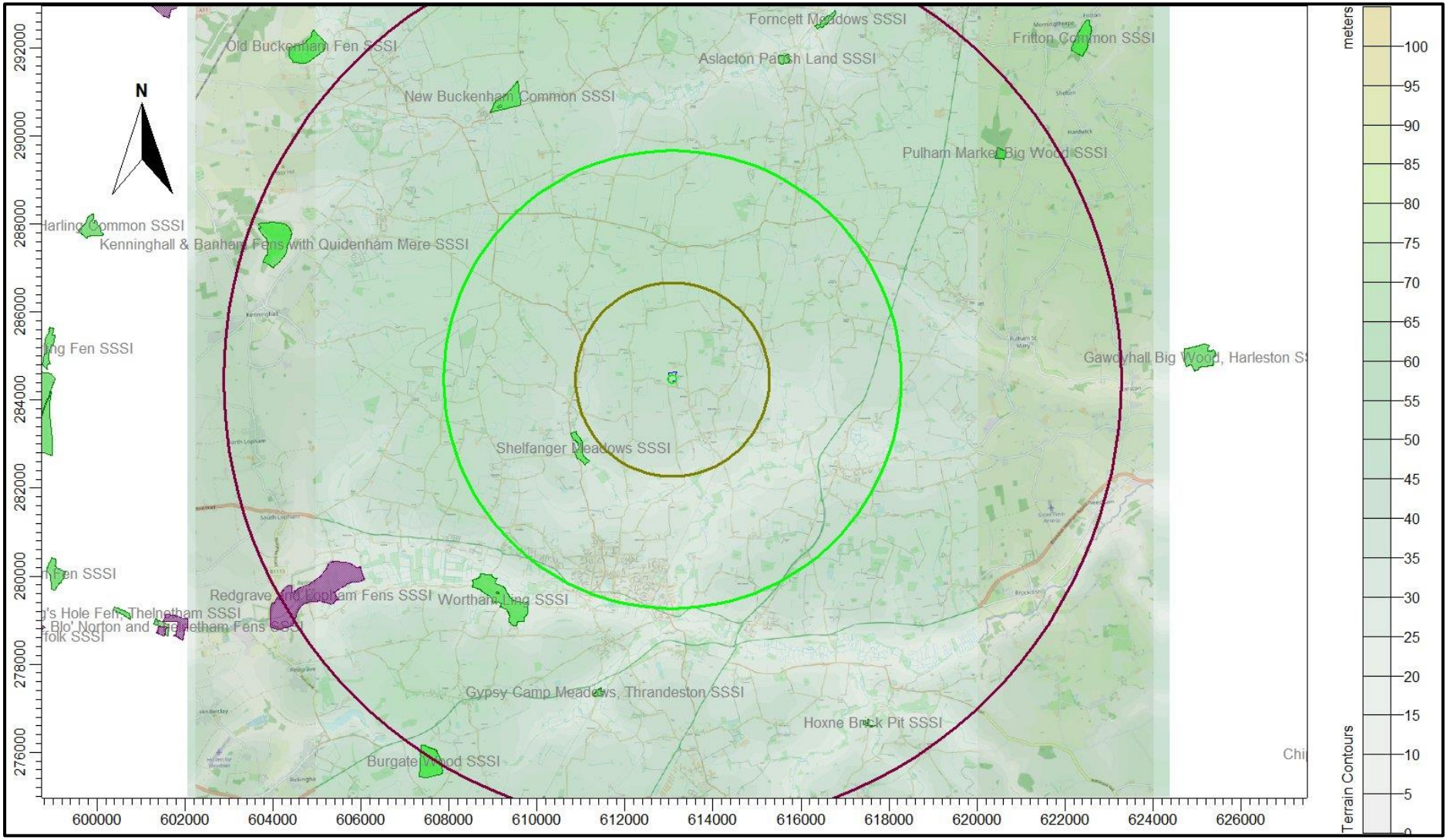
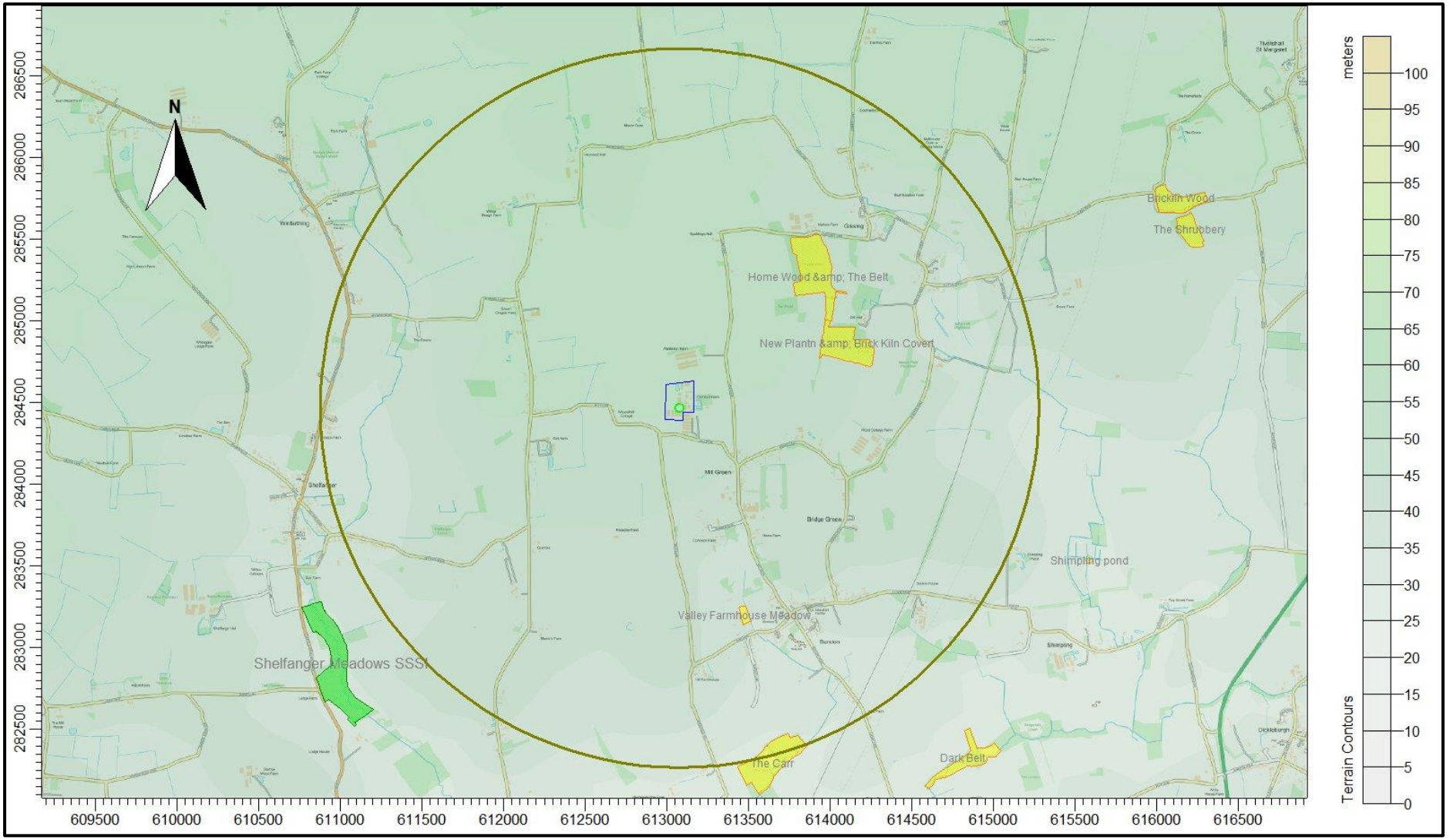


Figure 1b. The area surrounding Old Hall Farm – a closer view with LWSs and a SSSI



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, July 2025). 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 (2021) in the area around Old Hall Farm is 2.83 µg-NH_3/m^3. The background nitrogen deposition rate to woodland is 40.17 kg-N/ha/y and to short vegetation is 21.39 kg-N/ha/y. The background acid deposition rate to woodland is 2.94 keq/ha/y and to short vegetation is 1.57 keq/ha/y.

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

3.3 Critical Levels & 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 and for sites where there are sensitive lichens and bryophytes present, or 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. 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 does the Critical Load for acid deposition.

Please note that the assessment requirement is to use the lower bound of the range of Critical Loads for habitats that are present; however, the APIS database (https://www.apis.ac.uk/app) may contain Critical Levels and Critical Loads for species/habitats that are not present at the site, or not present at the parts of the site under consideration.

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)
LWSs	1.0 [1]	-	-
Wortham Ling SSSI and Redgrave and Lopham Fens SSSI/SAC/Ramsar site	1.0 [1 & 2]	5.0 [2 & 3]	-
Pulham Market Big Wood SSSI	1.0 [1 & 2]	10.0 [2 & 3]	-
Burgate Wood SSSI and Kenninghall & Banham Fens with Quidenham Mere SSSI and Shelfanger Meadows SSSI	1.0 [1 & 2]	15.0 [2 & 3]	-
Gypsy Camp Meadows, Thrandeston SSSI; Forncett Meadows SSSI and New Buckenham Common SSSI	3.0 [2]	10.0 [2 & 3]	-
Aslacton Parish Land SSSI	3.0 [2]	15.0 [2 & 3]	-
Hoxne Brick Pit SSSI	n/a [4]	n/a [4]	n/a [4]

1. A precautionary figure used where details of the site are entirely unknown, or where although citations do not explicitly mention lichens or bryophytes, they are likely to be present.
2. Based upon the citation for the site and APIS database. Please note that, in some cases, the APIS database may contain Critical Levels/Loads for habitats/species that are not present, or not present at the site/parts of the site within 10 km.
3. The lower bound of the range of Critical Loads for habitats present at the site (Review and revision of empirical critical loads of nitrogen for Europe 2022). Please note that, in some cases, the APIS database may contain entries for habitats/species that are not present at the site, or parts of the site within 10 km.
4. No Critical Loads for designated features.

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 and deposition rates are derived as an average for a 5 km by 5 km grid.

3.4.3 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.

Whilst this guidance is useful for decision makers it has not been used further in this report.

3.5 Quantification of ammonia emissions

Ammonia emission rates from piggeries 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 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 bespoke ammonia emission factors have been provided by the Environment Agency in the pre-application report (EPR/TP3130QY/P001).

Details of the pig numbers and types, emission factors used and the calculated ammonia emission rates are provided in Tables 2a (Existing Scenario) and 2c (Proposed Scenario). Details of the calculated emissions from the lagoon, storage tanks and manure storage area are provided in Tables 2b (Existing Scenario) and 2d (Proposed Scenario).

Table 2a. Details of pig numbers and ammonia emission rates – Existing Scenario

Name	Source ID	Type/Weight	Flooring	Ventilation	Pig numbers	Emission Factor (kg-NH_3/place/y)	Emission rate (g-NH_3/s)
Finisher 1 to 4	F1234	>30 kg	Straw	Natural	3,000	1.6048	0.152559
Growers in F5	F5	<30 kg	Straw	Natural	220	0.2032	0.001417
Grower 1	G1	<30 kg	Straw	Natural	310	0.2032	0.001996
Grower 2	G2	<30 kg	Straw	Natural	280	0.2032	0.001803
Grower 3	G3	<30 kg	Straw	Natural	480	0.2032	0.003091
Grower 4 and 5	G45	<30 kg	Straw	Natural	440	0.2032	0.002833
Weaner 1	W1	<30 kg	Straw	Natural	250	0.2032	0.001610
Weaner 2	W2	<30 kg	Straw	Natural	380	0.2032	0.002447
Weaner 3	W3	<30 kg	Straw	Natural	640	0.2032	0.004121

Table 2b. Details of manure storage – Existing Scenario

Name	Source ID	Area/Tonnage	Description	Emission Factor (kg-NH_3/place/y)	Emission rate (g-NH_3/s)
Muck Pad 1	MAN1	2000	Manure	0.85	0.053870
Muck Pad 2	MAN2	500	Manure	0.85	0.013467
Slurry Lagoon	DWLAG	944	Floating Cover	0.45	0.013461

Table 2c. Details of pig numbers and ammonia emission rates – Proposed Scenario

Name	Source ID	Type/Weight	Flooring	Ventilation	Pig numbers	Emission Factor (kg-NH_3/place/y)	Emission rate (g-NH_3/s)
Finisher 1 to 4	F1234	>30 kg	Straw	Natural	2,720	1.6048	0.138320
Growers in F5	F5	<30 kg	Straw	Natural	320	0.2032	0.002060
Finisher 6	F6	>30 kg	Straw	Natural	1,600	1.6048	0.081365
Grower 2	G2	<30 kg	Straw	Natural	420	0.2032	0.002704
Grower 3	G3	<30 kg	Straw	Natural	920	0.2032	0.005924
Grower 4 and 5	G45	<30 kg	Straw	Natural	700	0.2032	0.004507
Grower 6	G6	>30 kg	Straw	Natural	2,000	1.6048	0.101706
Weaner 1	W1	<30 kg	Straw	Natural	420	0.2032	0.002704
Weaner 2	W2	<30 kg	Straw	Natural	560	0.2032	0.003606
Weaner 3	W3	<30 kg	Straw	Natural	1,160	0.2032	0.007469

Table 2d. Details of manure storage – Proposed Scenario

Name	Source ID	Area/Tonnage	Description	Emission Factor (kg-NH_3/place/y)	Emission rate (g-NH_3/s)
Muck Pad	MAN1	2000	Manure	0.85	0.053870
Muck Pad	MAN2	500	Manure	0.85	0.013467
Slurry Lagoon	DWLAG	944	Floating cover	0.45	0.013461

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 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)[1].

The GFS is a discrete model. The physics/dynamics model has a resolution or had a resolution of approximately 7 km over the central 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 records may be overrepresented because the instrumentation used may not record wind speed 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 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 farm is shown in Figure 2b. Although there is little modification in this case, elsewhere in the modelling domain, the modified wind roses may differ more markedly. 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].

As discussed above, the use of NWP data (suitably processed and quality controlled), removes the usual uncertainties and gross errors associated with using “representative” data from a remote meteorological station.

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. GFS derived data, for 52.416 N, 1.134 E, 2021 – 2024

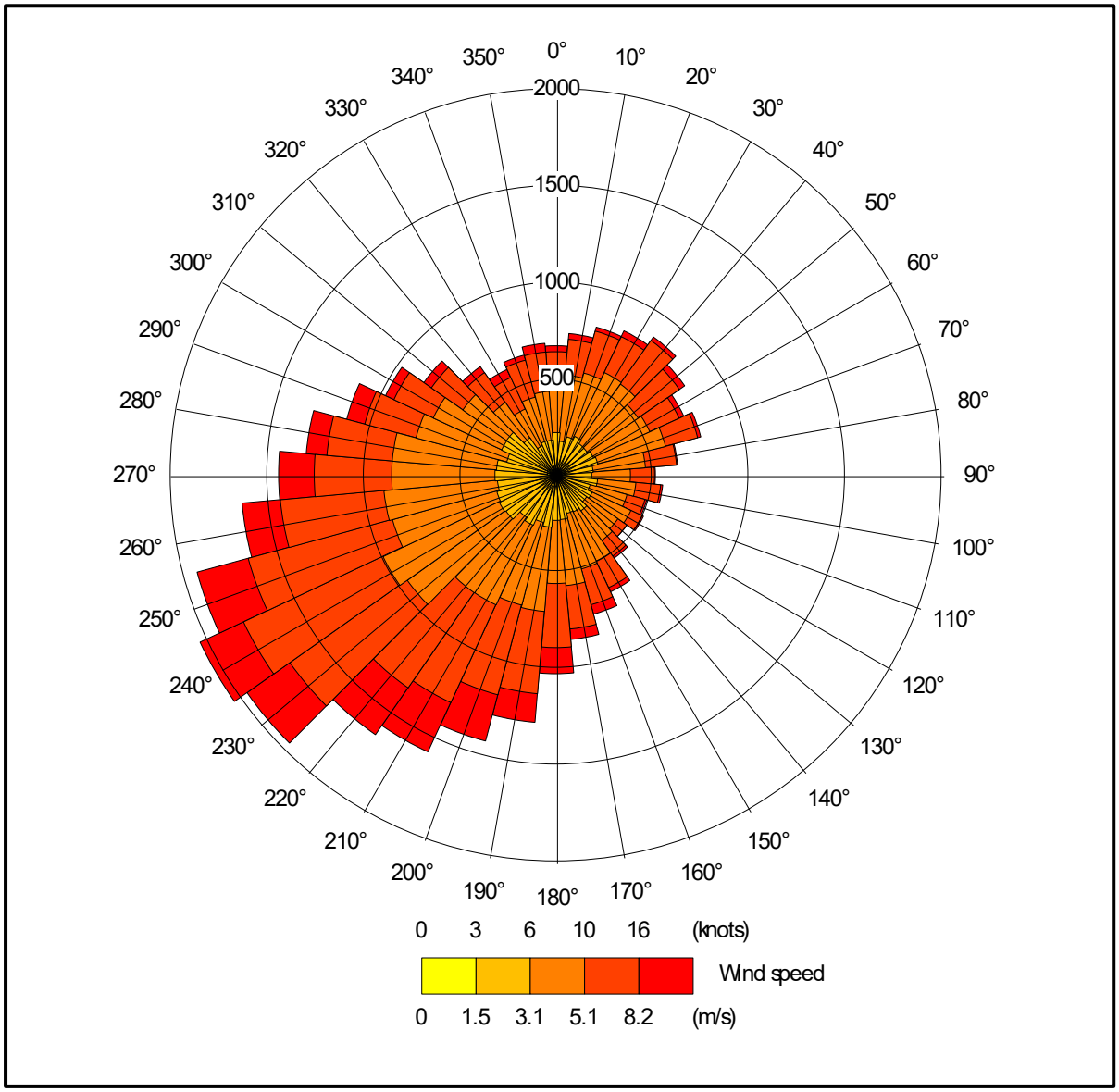
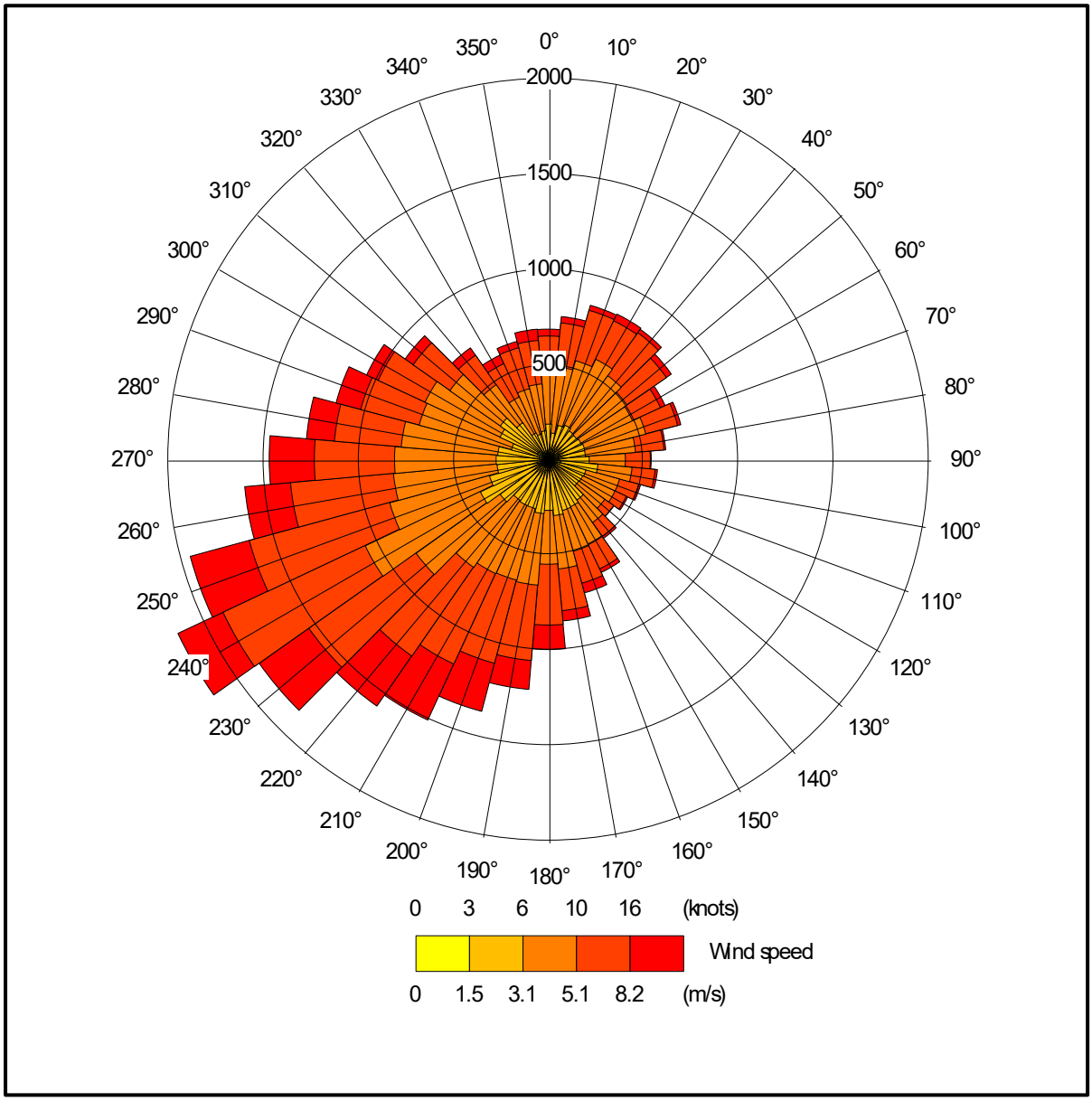


Figure 2b. The FLOWSTAR derived wind rose for NGR 613100, 284450, 2021 – 2024



4.2 Emission sources

The existing and proposed pig houses are/would be naturally ventilated and are represented by volume sources within ADMS. The lagoon and manure storage areas are also represented by volume sources.

Details of the volume and point source parameters are shown in Table 3a (Existing Scenario) and Table 3b (Proposed Scenario). The positions of the volume sources may be seen in Figures 3a and 3b (marked by red shaded rectangles).

Table 3a. Volume source parameters – Existing Scenario

Source ID	Length (m)	Width (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate (g-NH_3/s)
F1234	90.5	38.0	3.0	0.5	Ambient	0.152559
F5	28.7	11.3	3.0	0.5	Ambient	0.001417
G1	9.1	23.8	3.0	0.5	Ambient	0.001996
G2	9.7	19.6	3.0	0.5	Ambient	0.001803
G3	11.0	23.0	3.0	0.5	Ambient	0.003091
G45	13.8	22.8	3.0	0.5	Ambient	0.002833
W1	12.0	23.0	3.0	0.5	Ambient	0.001610
W2	10.0	23.0	3.0	0.5	Ambient	0.002447
W3	10.1	45.7	3.0	0.5	Ambient	0.004121
MAN2	10.6	7.3	1.0	1.5	Ambient	0.013467
MAN1	502.2 m^2		1.0	1.5	Ambient	0.053870
DWLAG	810.1 m^2		1.0	0.0	Ambient	0.013461

Table 3b. Volume source parameters – Proposed Scenario

Source ID	Length (m)	Width (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate (g-NH_3/s)
F1234	90.5	38.0	3.0	0.5	Ambient	0.138320
F5	28.7	11.3	3.0	0.5	Ambient	0.002060
F6	15.4	61.0	3.0	0.5	Ambient	0.081365
G2	9.7	19.6	3.0	0.5	Ambient	0.002704
G3	11.0	23.0	3.0	0.5	Ambient	0.005924
G45	13.8	22.8	3.0	0.5	Ambient	0.004507
G6	15.4	61.0	3.0	0.5	Ambient	0.101706
W1	12.0	23.0	3.0	0.5	Ambient	0.002704
W2	10.0	23.0	3.0	0.5	Ambient	0.003606
W3	10.1	45.7	3.0	0.5	Ambient	0.007469
MAN2	10.6	7.3	1.0	1.5	Ambient	0.013467
MAN1	502.2 m^2		1.0	1.5	Ambient	0.053870
DWLAG	810.1 m^2		1.0	0.0	Ambient	0.013461

4.3 Modelled buildings

Not modelled.

4.4 Discrete receptors

Twenty discrete receptors have been defined at the nearby wildlife sites. These receptors are defined at ground level within ADMS. The positions of the discrete receptors may be seen in Figures 4a and 4b (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, two 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 Figures 4a and 4b (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 km x 22 km domain has been resampled at 100 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 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 0.149 m (arithmetic average of the spatially varying roughness over the modelling domain). A sample of the central area of the spatially varying roughness length field is shown in Figure 5.

Figure 3a. The positions of modelled sources – Existing Scenario

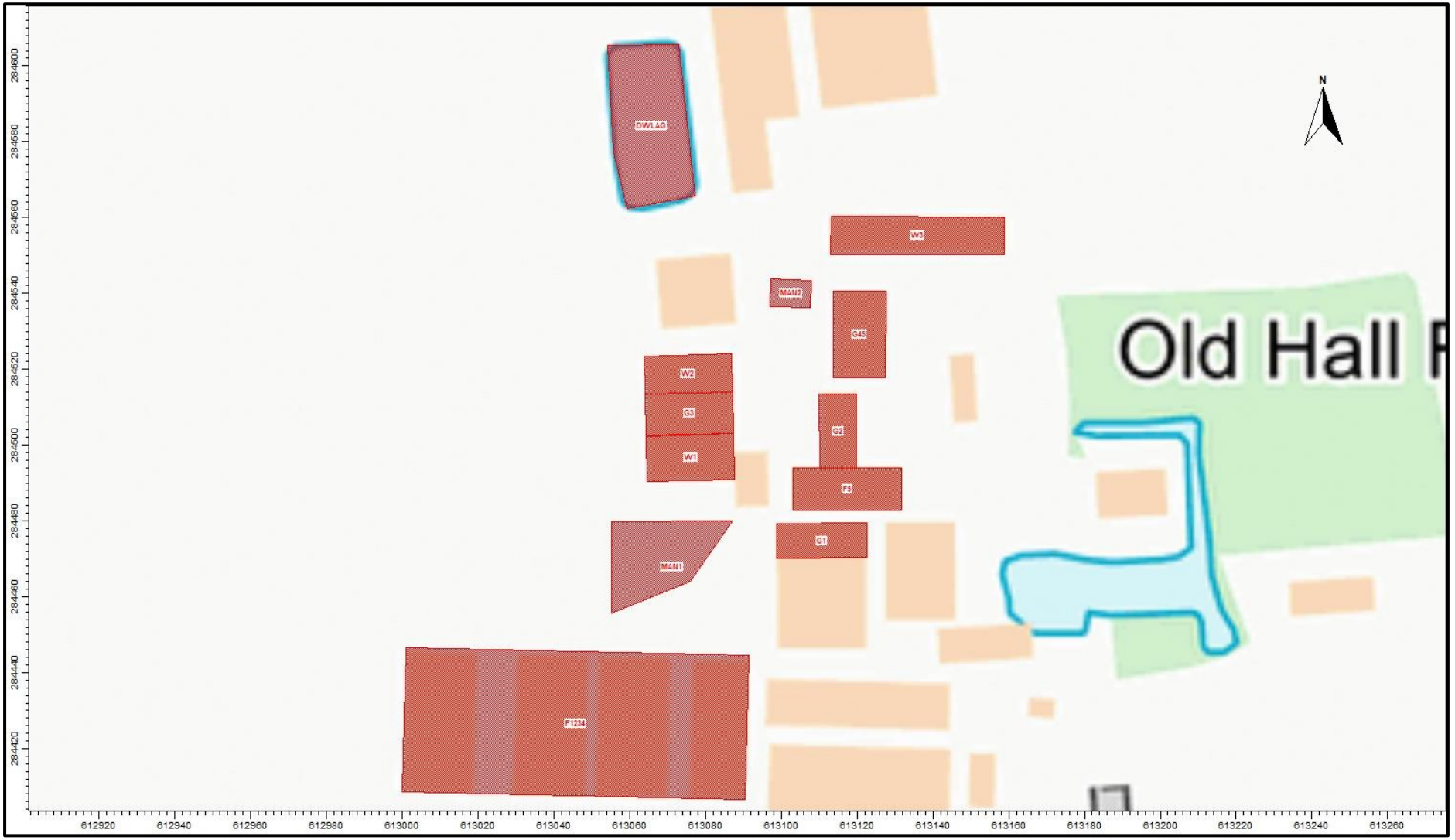


Figure 3b. The positions of modelled sources – Proposed Scenario

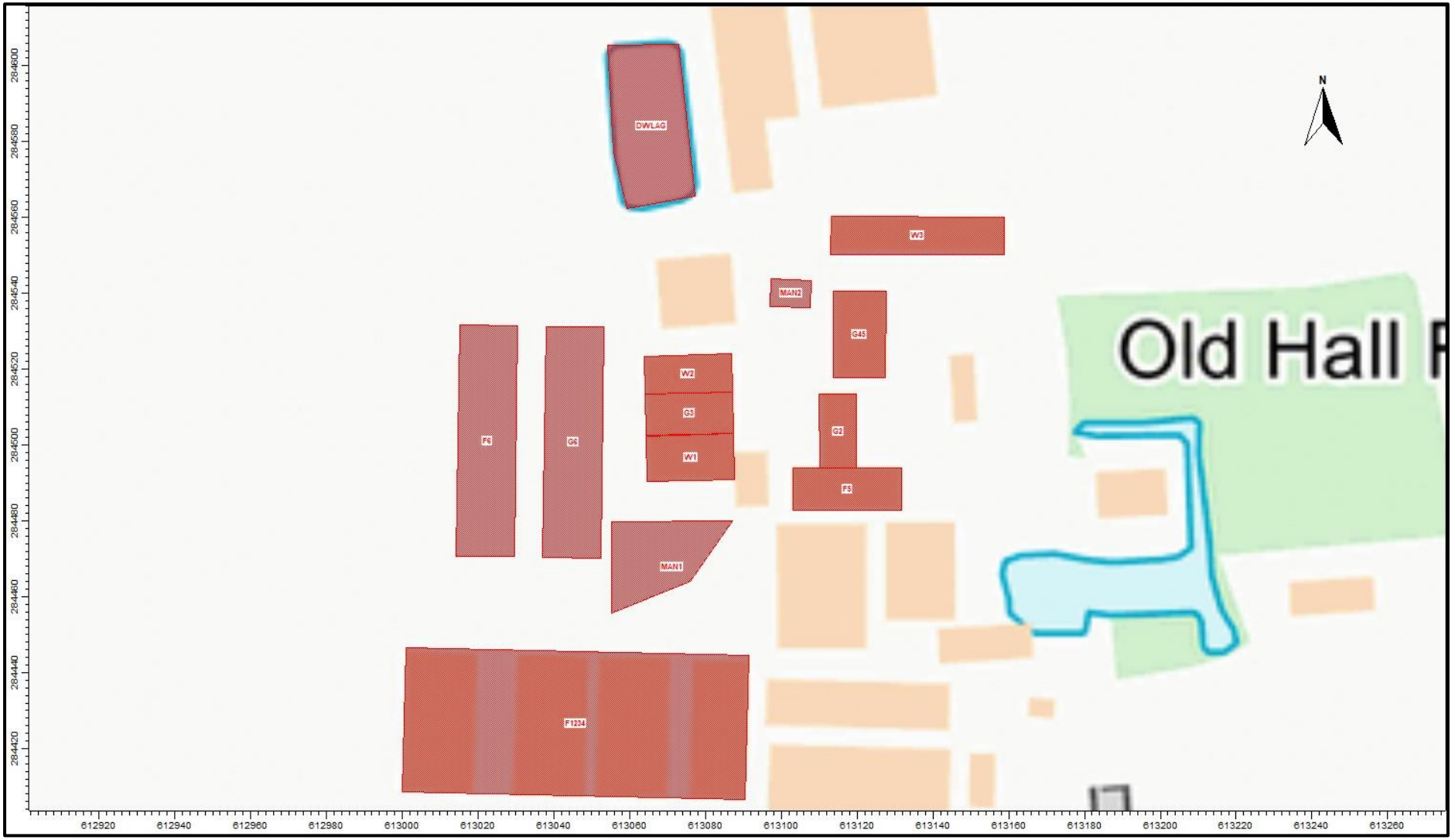


Figure 4a. The discrete receptors and regular Cartesian grids – a broadscale view

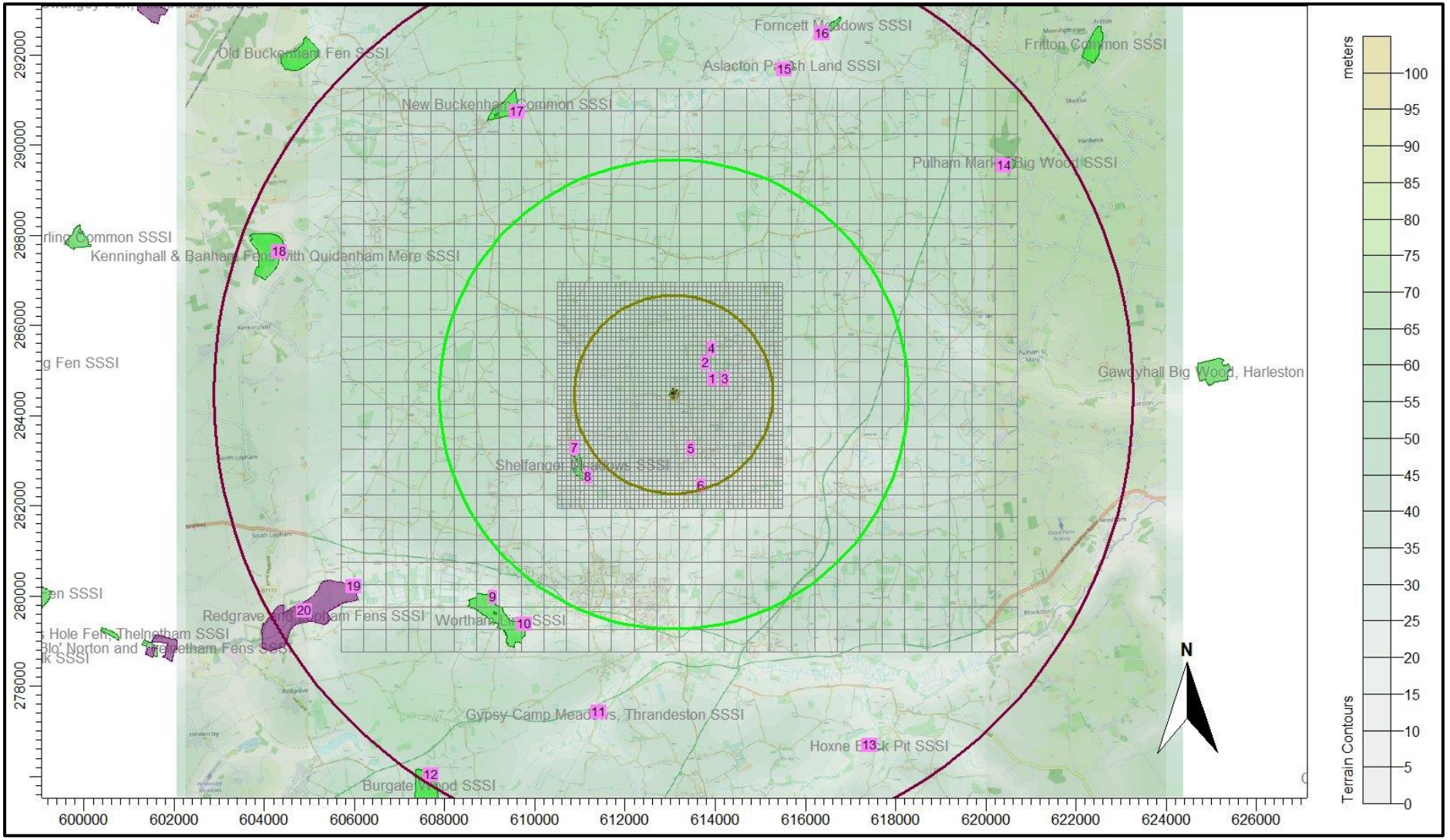


Figure 4b. The discrete receptors and regular Cartesian grids – a closer view

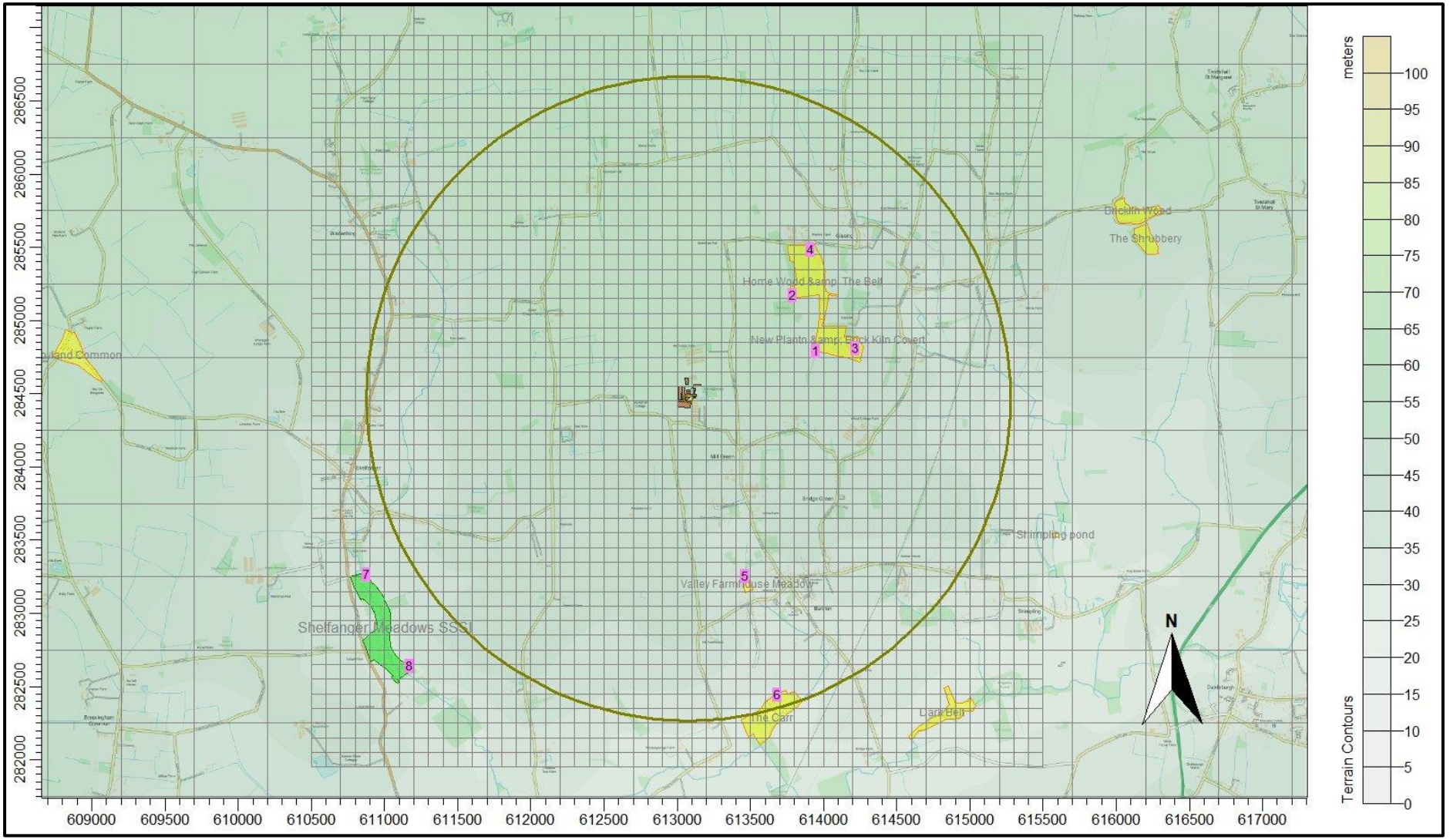
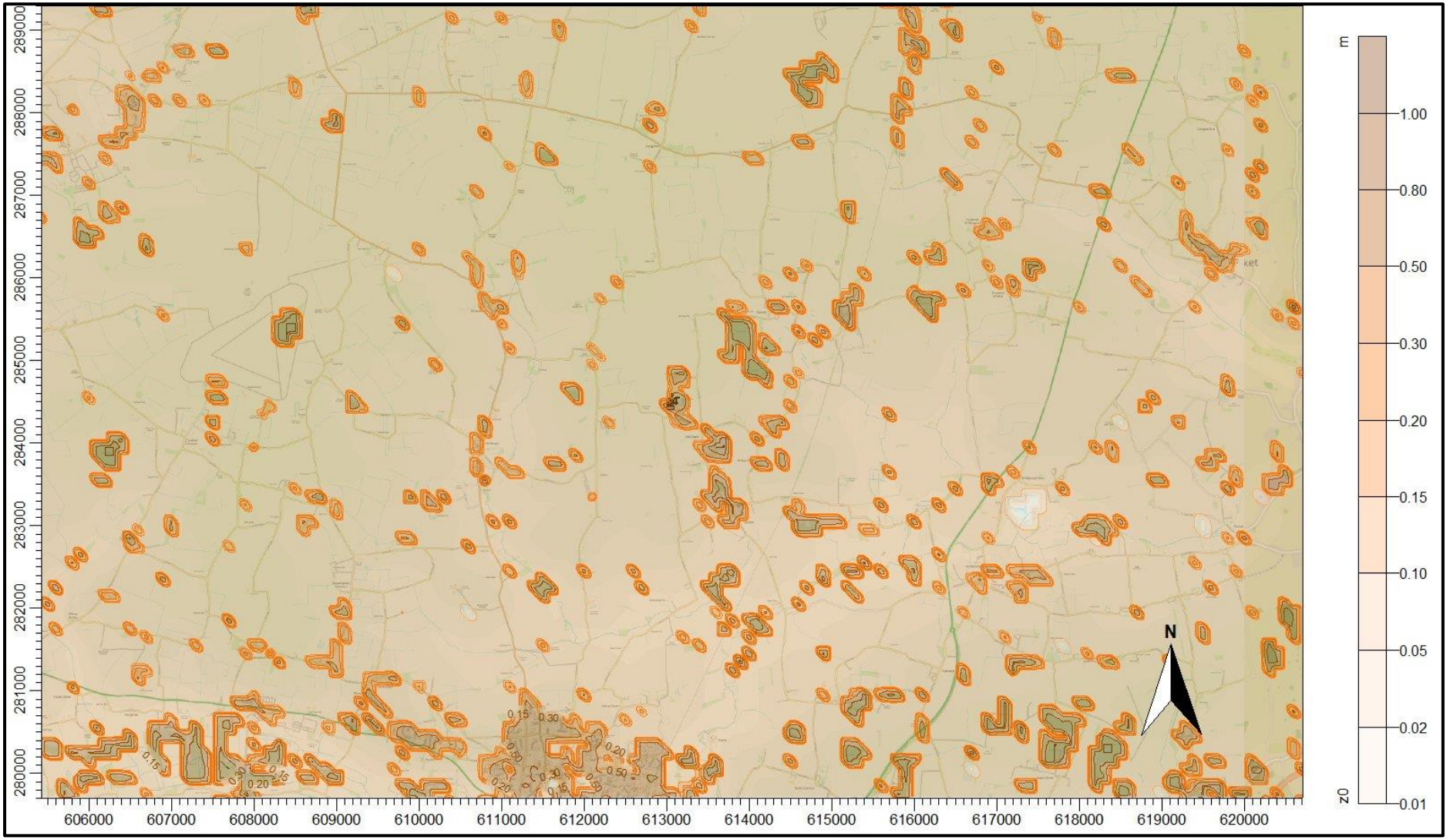


Figure 5. The spatially varying surface roughness field (central area)



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 livestock 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. In summary the method is as follows:

- A preliminary run of the model without deposition is used to provide an ammonia concentration field.
- The preliminary ammonia concentration field, along with land usage is used to define a deposition velocity field. The deposition velocities used are provided in Table 4.

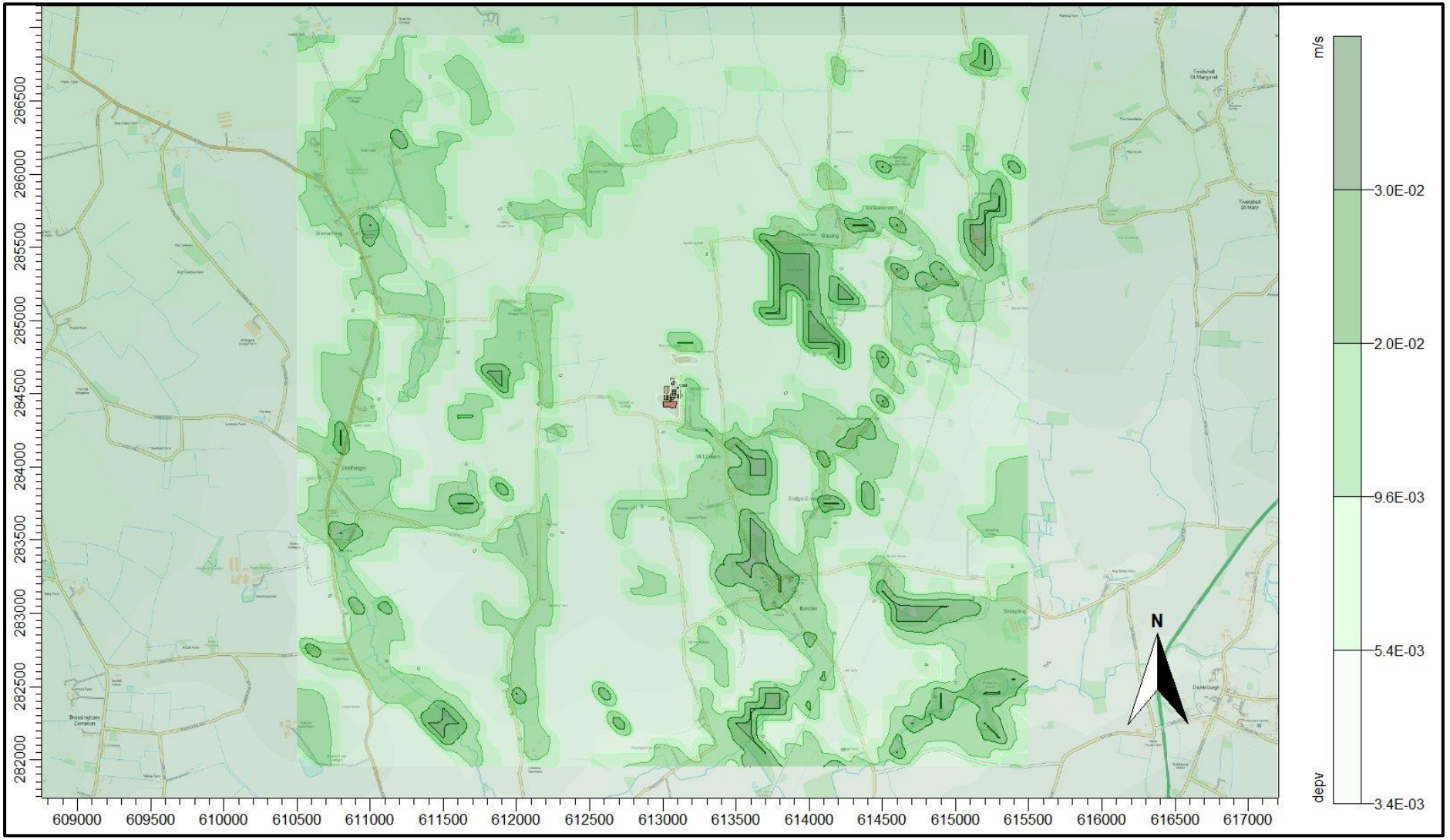
Table 4. Deposition velocities

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

- The model is then rerun with the spatially varying deposition module.

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

Figure 6. The spatially varying deposition field



5. Details of the Model Runs and Results

5.1 Preliminary modelling and model sensitivity tests

ADMS was effectively run a total of sixteen times, once for each year of the meteorological record for the existing and proposed scenarios in the following modes:

- In basic mode without calms, or terrain – GFS data.
- With calms and without terrain – GFS data.

For each mode, statistics for the maximum annual mean ammonia concentration at each receptor were compiled. Details of the predicted annual mean ammonia concentrations at each receptor are provided in Table 5. The primary purpose of the preliminary modelling is to assess the effect of calms on the results.

Table 5. Predicted maximum annual mean ammonia concentration at the discrete receptors – preliminary modelling

Receptor number	X(m)	Y(m)	Name/Designation	Maximum annual mean ammonia concentration - (µg/m³)			
				Existing Scenario		Proposed Scenario	
				GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms No Terrain	GFS Calms No Terrain
1	613945	284790	LWS	0.566	0.631	0.958	1.070
2	613788	285166	LWS	0.530	0.589	0.929	1.031
3	614219	284804	LWS	0.366	0.408	0.623	0.695
4	613911	285480	LWS	0.335	0.368	0.575	0.633
5	613460	283246	LWS	0.236	0.262	0.390	0.431
6	613686	282440	LWS	0.101	0.112	0.170	0.187
7	610878	283263	Shelfanger Meadows SSSI	0.113	0.125	0.191	0.211
8	611169	282635	Shelfanger Meadows SSSI	0.076	0.088	0.130	0.150
9	609063	279958	Wortham Ling SSSI	0.022	0.025	0.037	0.042
10	609768	279358	Wortham Ling SSSI	0.024	0.027	0.040	0.045
11	611417	277424	Gypsy Camp Meadows, Thrandeston SSSI	0.015	0.017	0.025	0.029
12	607684	276014	Burgate Wood SSSI	0.011	0.012	0.018	0.021
13	617415	276689	Hoxne Brick Pit SSSI	0.010	0.011	0.017	0.019
14	620410	289536	Pulham Market Big Wood SSSI	0.014	0.015	0.024	0.026
15	615534	291663	Aslacton Parish Land SSSI	0.014	0.017	0.024	0.028
16	616364	292467	Forncett Meadows SSSI	0.012	0.014	0.020	0.023
17	609597	290728	New Buckenham Common SSSI	0.013	0.015	0.023	0.026
18	604332	287617	Kenninghall & Banham Fens with Quidenham Mere SSSI	0.011	0.012	0.018	0.021
19	605976	280197	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.015	0.017	0.026	0.029
20	604892	279664	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.013	0.014	0.021	0.024

5.2 Detailed deposition modelling

In this case, detailed modelling has been carried out over a high resolution 5.0 km x 5.0 km domain. 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 the 5.0 km x 5.0 km domain a fixed deposition velocity of 0.005 m/s is assumed (with appropriate deposition velocities applied post-modelling at the discrete receptors).

Modelling was carried out for each of the four years in the meteorological record. The predicted process contributions to the maximum annual mean ground level ammonia concentrations and nitrogen deposition rates at the discrete receptors are shown in Tables 6a (Existing Scenario), 6b (Proposed Scenario) and 6c (Proposed Houses Only). Calms corrections (based upon the preliminary results) are applied to receptors within 2.5 km in these tables.

In the Tables, there are no predicted ammonia concentrations or nitrogen deposition rates as a percentage of the Critical Level or Critical Load that are in excess of the Environment Agency's upper threshold for the site (20% for a SAC/Ramsar Site, 50% for a SSSI and 100% for a non-statutory site) nor in the range between the Environment Agency's upper threshold and lower threshold (4% and 20% for a SAC/Ramsar Site, 20% and 50% for a SSSI and 100% and 100% for a non-statutory site). Process Contributions that exceed 1% of the relevant Critical Level or Critical Load at a statutory wildlife site are highlighted with bold text.

Contour plots of the predicted process contributions from the pig rearing houses to maximum annual mean ammonia concentrations and nitrogen deposition rates are shown in Figures 7a and 7b Existing Scenario), Figures 8a and 8b (Proposed Scenario) and Figures 9a and 9b (Proposed Houses Only).

Table 6a. Annual ammonia concentration and nitrogen deposition rate at the discrete receptors – Existing Scenario

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level (µg/m^3)	Critical Load (kg/ha)	Process Contribution (µg/m^3)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	613945	284790	LWS	0.03	1.0	10.0	0.413	41.30	3.22	32.18
2	613788	285166	LWS	0.03	1.0	10.0	0.264	26.40	2.06	20.57
3	614219	284804	LWS	0.03	1.0	10.0	0.228	22.75	1.77	17.73
4	613911	285480	LWS	0.03	1.0	10.0	0.141	14.07	1.10	10.96
5	613460	283246	LWS	0.02	1.0	10.0	0.095	9.52	0.49	4.94
6	613686	282440	LWS	0.03	1.0	10.0	0.036	3.58	0.28	2.79
7	610878	283263	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.036	**3.57**	0.19	**1.24**
8	611169	282635	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.032	**3.21**	0.17	**1.11**
9	609063	279958	Wortham Ling SSSI	0.02	1.0	5.0	0.007	0.68	0.04	0.71
10	609768	279358	Wortham Ling SSSI	0.02	1.0	5.0	0.008	0.81	0.04	0.84
11	611417	277424	Gypsy Camp Meadows, Thrandeston SSSI	0.03	3.0	10.0	0.005	0.17	0.04	0.41
12	607684	276014	Burgate Wood SSSI	0.03	1.0	15.0	0.003	0.28	0.02	0.15
13	617415	276689	Hoxne Brick Pit SSSI	-	n/a	n/a	0.002	-	-	-
14	620410	289536	Pulham Market Big Wood SSSI	0.03	1.0	10.0	0.005	0.48	0.04	0.37
15	615534	291663	Aslacton Parish Land SSSI	0.02	3.0	15.0	0.005	0.18	0.03	0.18
16	616364	292467	Forncett Meadows SSSI	0.02	3.0	10.0	0.004	0.15	0.02	0.23
17	609597	290728	New Buckenham Common SSSI	0.02	3.0	10.0	0.004	0.14	0.02	0.22
18	604332	287617	Kenninghall & Banham Fens with Quidenham Mere SSSI	0.03	1.0	15.0	0.002	0.23	0.02	0.12
19	605976	280197	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.004	0.37	0.02	0.38
20	604892	279664	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.003	0.30	0.02	0.31

Table 6b. Annual ammonia concentration and nitrogen deposition rate at the discrete receptors – Proposed Scenario

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level (µg/m^3)	Critical Load (kg/ha)	Process Contribution (µg/m^3)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	613945	284790	LWS	0.03	1.0	10.0	0.695	69.48	5.41	54.13
2	613788	285166	LWS	0.03	1.0	10.0	0.460	46.02	3.59	35.86
3	614219	284804	LWS	0.03	1.0	10.0	0.382	38.24	2.98	29.79
4	613911	285480	LWS	0.03	1.0	10.0	0.244	24.36	1.90	18.98
5	613460	283246	LWS	0.02	1.0	10.0	0.159	15.89	0.83	8.25
6	613686	282440	LWS	0.03	1.0	10.0	0.060	6.05	0.47	4.71
7	610878	283263	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.060	**6.03**	0.31	**2.09**
8	611169	282635	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.054	**5.43**	0.28	**1.88**
9	609063	279958	Wortham Ling SSSI	0.02	1.0	5.0	0.012	**1.16**	0.06	**1.21**
10	609768	279358	Wortham Ling SSSI	0.02	1.0	5.0	0.014	**1.38**	0.07	**1.44**
11	611417	277424	Gypsy Camp Meadows, Thrandeston SSSI	0.03	3.0	10.0	0.009	0.30	0.07	0.69
12	607684	276014	Burgate Wood SSSI	0.03	1.0	15.0	0.005	0.48	0.04	0.25
13	617415	276689	Hoxne Brick Pit SSSI	-	n/a	n/a	0.004	-	-	-
14	620410	289536	Pulham Market Big Wood SSSI	0.03	1.0	10.0	0.008	0.82	0.06	0.64
15	615534	291663	Aslacton Parish Land SSSI	0.02	3.0	15.0	0.009	0.30	0.05	0.32
16	616364	292467	Forncett Meadows SSSI	0.02	3.0	10.0	0.008	0.25	0.04	0.39
17	609597	290728	New Buckenham Common SSSI	0.02	3.0	10.0	0.007	0.24	0.04	0.37
18	604332	287617	Kenninghall & Banham Fens with Quidenham Mere SSSI	0.03	1.0	15.0	0.004	0.39	0.03	0.20
19	605976	280197	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.006	0.63	0.03	0.65
20	604892	279664	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.005	0.51	0.03	0.53

Table 6c. Annual ammonia concentration and nitrogen deposition rate at the discrete receptors – Proposed Houses Only

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration		Maximum annual nitrogen deposition rate	
				Deposition Velocity	Critical Level (µg/m^3)	Critical Load (kg/ha)	Process Contribution (µg/m^3)	%age of Critical Level	Process Contribution (kg/ha)	%age of Critical Load
1	613945	284790	LWS	0.03	1.0	10.0	0.288	28.77	2.24	22.42
2	613788	285166	LWS	0.03	1.0	10.0	0.203	20.30	1.58	15.82
3	614219	284804	LWS	0.03	1.0	10.0	0.159	15.87	1.24	12.36
4	613911	285480	LWS	0.03	1.0	10.0	0.105	10.46	0.81	8.15
5	613460	283246	LWS	0.02	1.0	10.0	0.066	6.62	0.34	3.44
6	613686	282440	LWS	0.03	1.0	10.0	0.026	2.55	0.20	1.99
7	610878	283263	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.025	**2.53**	0.13	0.88
8	611169	282635	Shelfanger Meadows SSSI	0.02	1.0	15.0	0.023	**2.29**	0.12	0.79
9	609063	279958	Wortham Ling SSSI	0.02	1.0	5.0	0.005	0.55	0.03	0.57
10	609768	279358	Wortham Ling SSSI	0.02	1.0	5.0	0.007	0.65	0.03	0.68
11	611417	277424	Gypsy Camp Meadows, Thrandeston SSSI	0.03	3.0	10.0	0.004	0.14	0.03	0.32
12	607684	276014	Burgate Wood SSSI	0.03	1.0	15.0	0.002	0.23	0.02	0.12
13	617415	276689	Hoxne Brick Pit SSSI	-	n/a	n/a	0.002	-	-	-
14	620410	289536	Pulham Market Big Wood SSSI	0.03	1.0	10.0	0.004	0.39	0.03	0.30
15	615534	291663	Aslacton Parish Land SSSI	0.02	3.0	15.0	0.004	0.14	0.02	0.15
16	616364	292467	Forncett Meadows SSSI	0.02	3.0	10.0	0.004	0.12	0.02	0.19
17	609597	290728	New Buckenham Common SSSI	0.02	3.0	10.0	0.003	0.11	0.02	0.18
18	604332	287617	Kenninghall & Banham Fens with Quidenham Mere SSSI	0.03	1.0	15.0	0.002	0.18	0.01	0.09
19	605976	280197	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.003	0.29	0.02	0.31
20	604892	279664	Redgrave and Lopham Fens SSSI/SAC/Ramsar site	0.02	1.0	5.0	0.002	0.24	0.01	0.25

Figure 7a. Maximum annual mean ammonia concentration – Existing Scenario

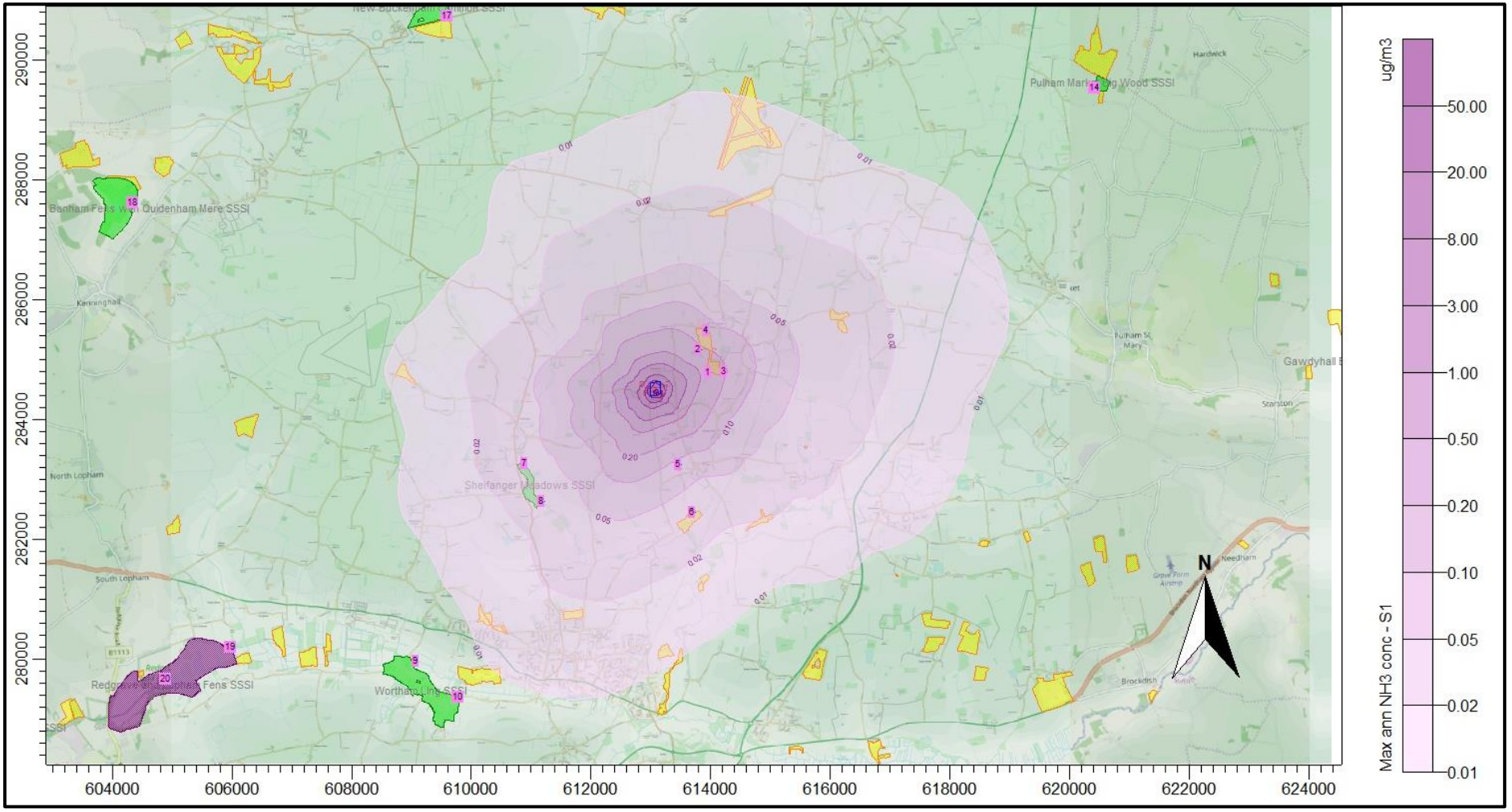


Figure 7b. Maximum annual nitrogen deposition rate – Existing Scenario

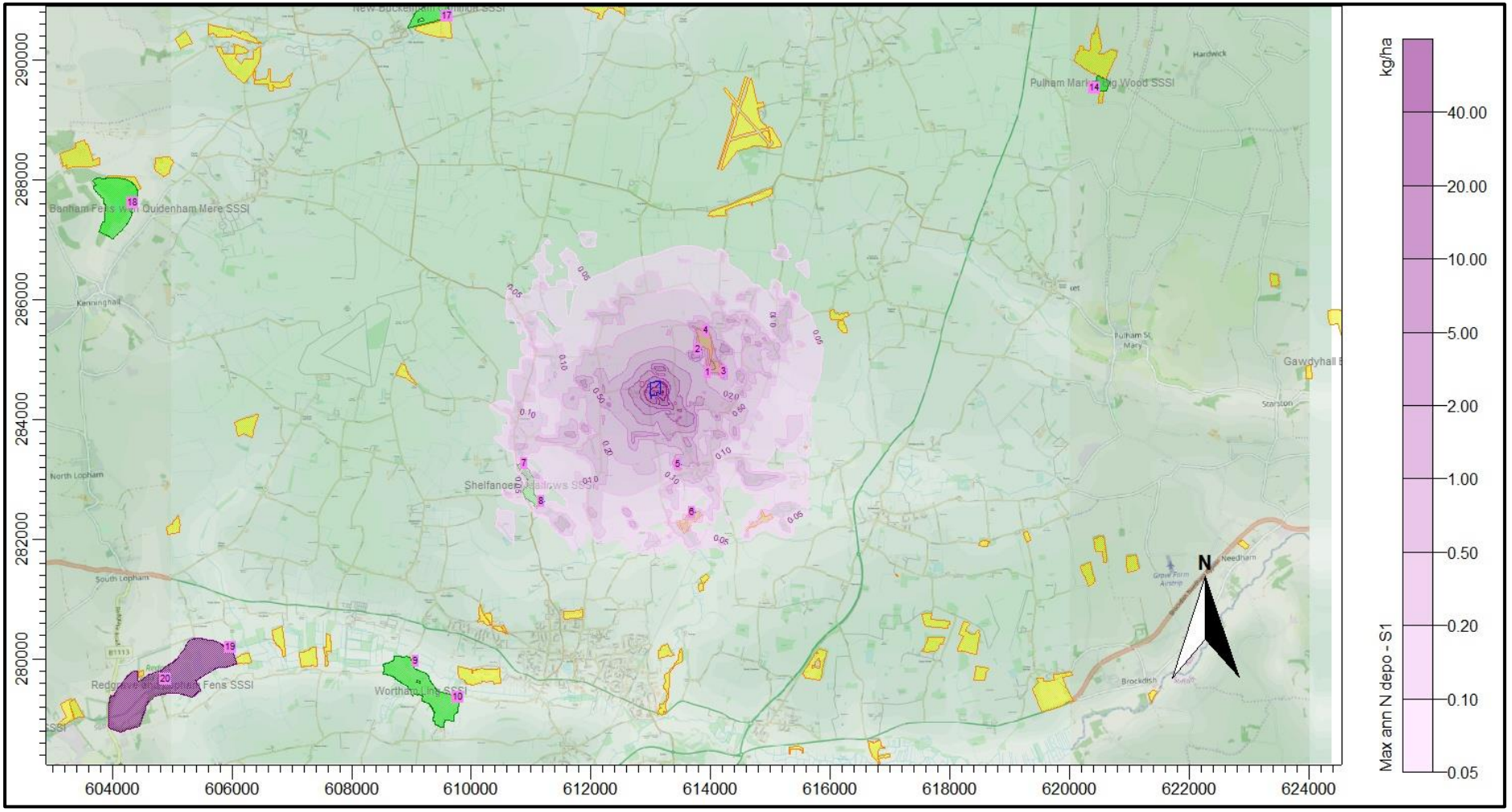


Figure 8a. Maximum annual mean ammonia concentration – Proposed Scenario

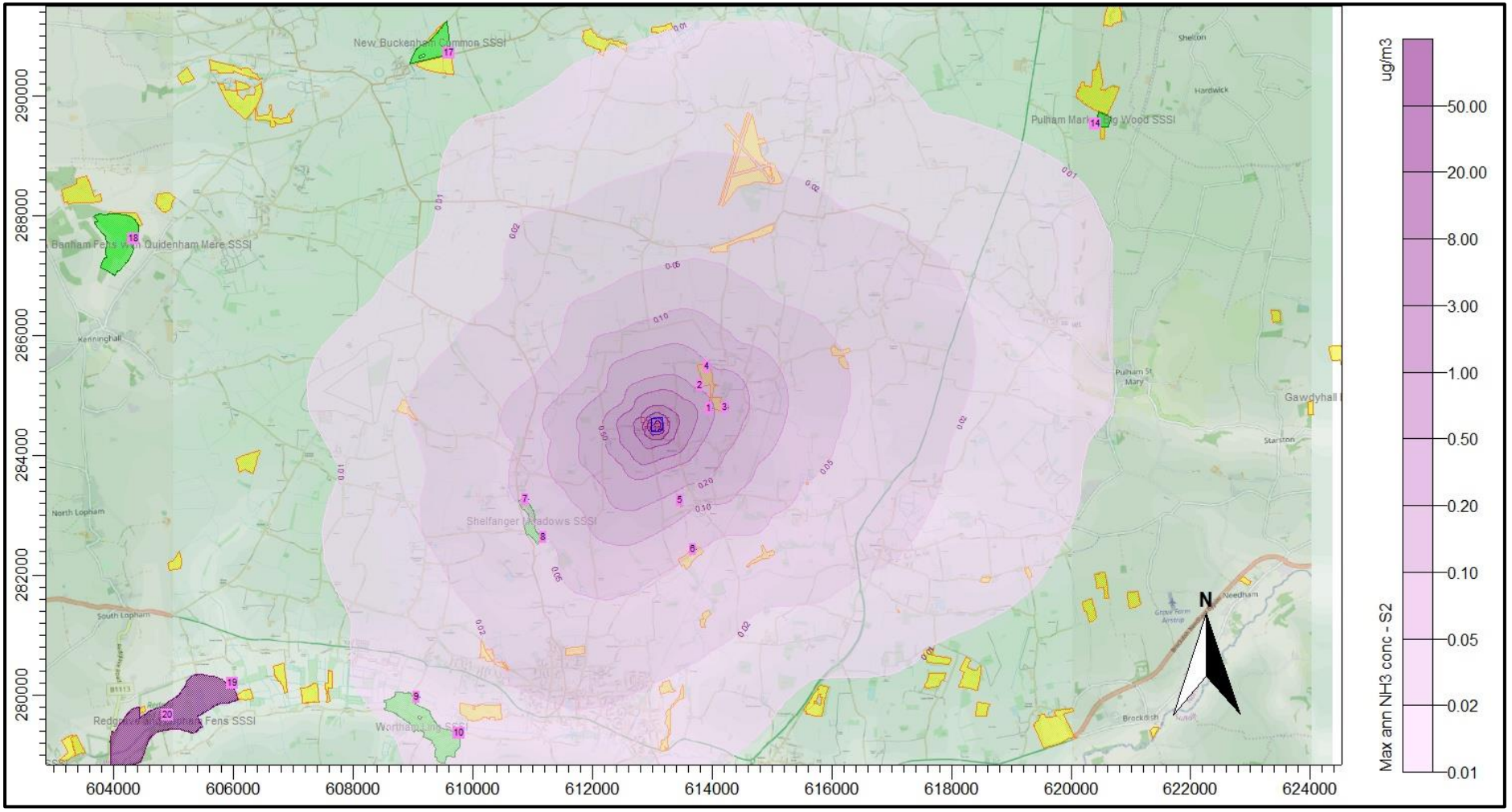


Figure 8b. Maximum annual nitrogen deposition rate – Proposed Scenario

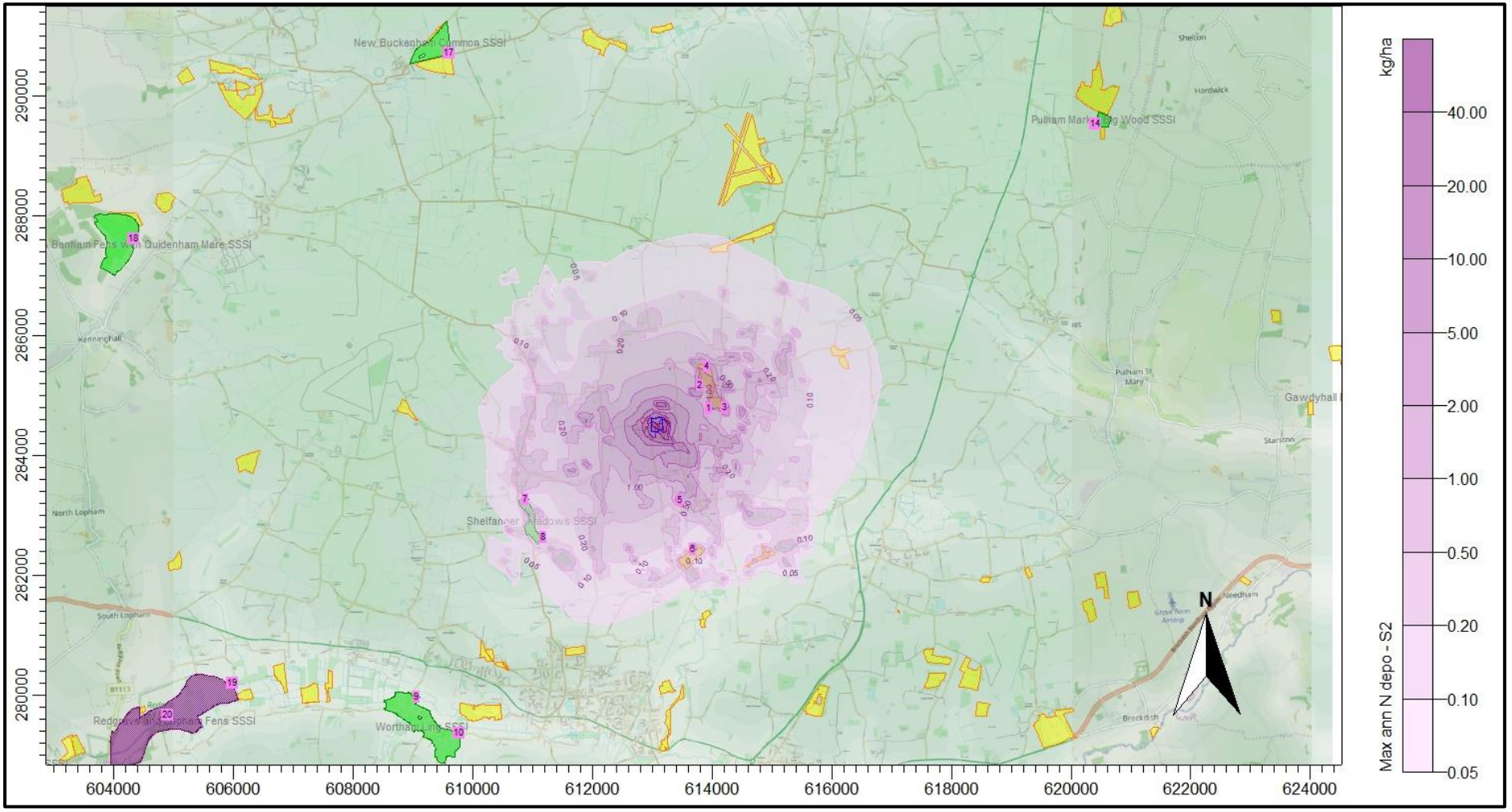


Figure 9a. Maximum annual mean ammonia concentration – Proposed Houses Only

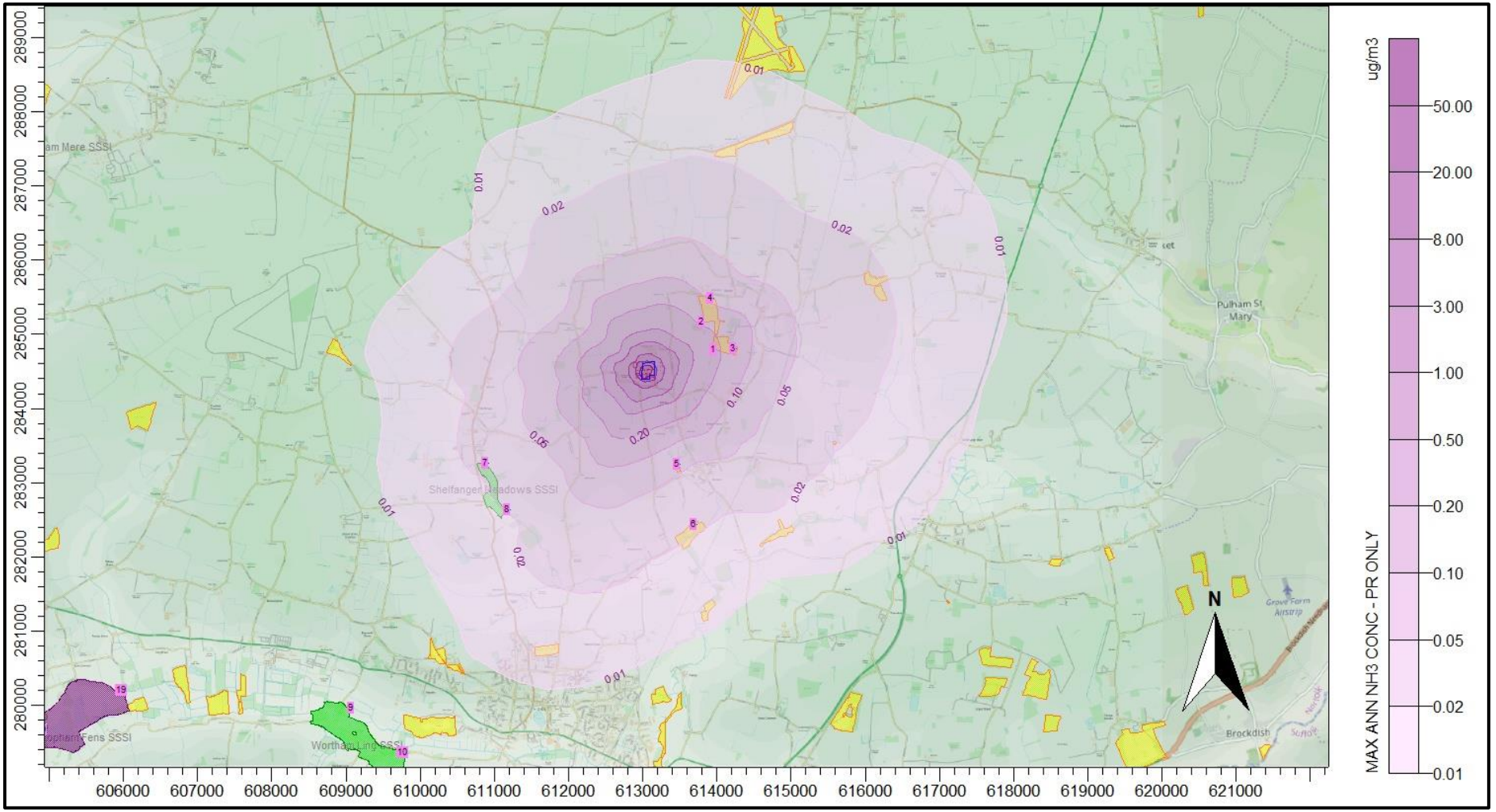
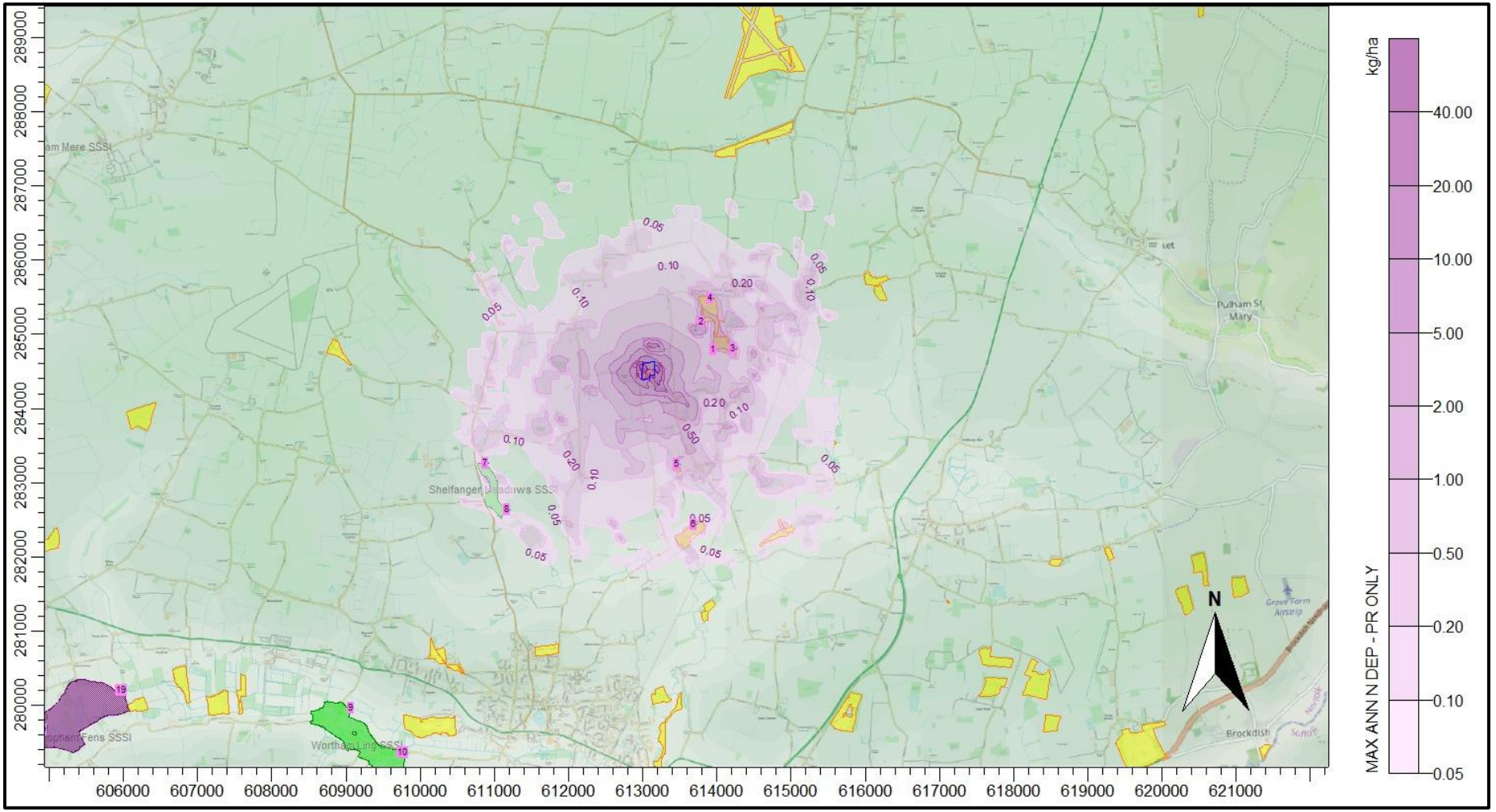


Figure 9b. Maximum annual nitrogen deposition rate – Proposed Houses Only



6. Summary and Conclusions

Ammonia emission rates from the existing and proposed pig rearing buildings at Old Hall Farm have been assessed and quantified based upon bespoke ammonia emission factors provided by 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.

Three scenarios are considered in this report:

- **Existing Scenario** – The existing farm, with up to 3,000 <30 kg pigs and 3,000 >30 kg pigs, housed in a variety of naturally ventilated buildings. Spent litter and manure are stored in two middens and a covered slurry lagoon.
- **Proposed Scenario** – The proposed farm, with up to 4,500 <30 kg pigs and 6,320 >30 kg pigs, housed in a variety of naturally ventilated buildings which includes some of the existing houses and two newly constructed houses. Spent litter and manure would continue to be stored in two middens and a covered slurry lagoon.
- **Proposed Houses Only** (for planning purposes) – The two newly constructed naturally ventilated buildings housing up to 3,600 >30 kg pigs.

Existing Scenario

The modelling predicts that:

- Process contributions to annual mean ammonia concentrations and annual nitrogen deposition rates as a percentage of the relevant Critical Levels and Critical Loads are currently well below the Environment Agency lower thresholds (4% for an internationally designated site, 20% for a SSSI and 100% for a non-statutory wildlife site) at all wildlife sites considered.
- Process contributions at receptors covering Shelfanger Meadows SSSI would exceed the 1% screening criteria by a maximum of 3.57% of the Critical Level and 1.24% of the Critical Load.
- At all other statutory sites the process contributions would be below 1% of the relevant Critical Levels and Loads for the site.

Proposed Scenario

The modelling predicts that should the proposed development at Old Hall Farm proceed:

- Although ammonia emissions and impacts would increase slightly, the process contributions would remain below the Environment Agency lower threshold of the relevant Critical Levels and Critical Loads at all wildlife sites considered.
- There would be increased exceedances of 1% of both the Critical Level and Critical Load at Shelfanger Meadows SSSI.
- Receptors at Wortham Ling SSSI would also exceed 1% by a small margin.

- At all other statutory sites the process contributions would be below 1% of the relevant Critical Levels and Loads for the sites.

Proposed Houses Only

For planning purposes the modelling predicts that should the process contributions from the proposed houses only:

- Would be well below the Environment Agency lower threshold of the relevant Critical Levels and Critical Loads at all wildlife sites considered.
- Would exceed 1% at Shelfanger Meadows SSSI by a maximum of 2.53% of the Critical Level but would be below 1% of the Critical Load.
- Would be below 1% of the relevant Critical Level and Critical Load at all other statutory sites considered.

7. References

Cambridge Environmental Research Consultants (CERC) (website).

Environment Agency H1 Risk Assessment (website).

Steven R Hanna, & Biswanath Chowdhury. Minimum turbulence assumptions and u* and L estimation for dispersion models during low-wind stable conditions.

Frederik Schrader and Christian Brümmer. Land Use Specific Ammonia Deposition Velocities: a Review of Recent Studies (2004–2013).

M. A. Sutton *et al*. Measurement and modelling of ammonia exchange over arable croplands.

United Nations Economic Commission for Europe (UNECE) (website).

UK Air Pollution Information System (APIS) (website).