A Report on the Modelling of the Dispersion and Deposition of Ammonia from the Existing and Proposed Broiler Rearing Houses and the Impact of Proposed Mitigation Measures at Neuadd Isaf, Penybont, near Llandrindod Wells in Powys

AS Modelling & Data Ltd.

01952 462500

www.asmodata.co.uk

Prepared by Phil Edgington

philedgington@asmodata.co.uk
07483 340262
20th May 2021

Reviewed by Steve Smith

stevesmith@asmodata.co.uk
01952 462500
21st May 2021

1. Introduction

AS Modelling & Data Ltd. has been instructed by Mr. Steve Raasch, on behalf of Mr. William Bedell, to use computer modelling to assess the impact of ammonia emissions from the existing and proposed broiler rearing houses and proposed mitigation measures at Neuadd Isaf, Penybont, Llandrindod Wells, Powys. LD1 5SW.

Ammonia emission rates from the existing and proposed poultry houses have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors and also upon an emissions model that estimates emissions from the Inno+ ammonia scrubbing equipment that would be used as the primary ventilation for the proposed poultry houses. 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

Neuadd Isaf is in an isolated rural area approximately 2.5 km to the south-west of the village of Penybont and approximately 3.0 km to the east of the town of Llandrindod Wells in Powys. The land surrounding the farm is used primarily for pasture and fodder production and there are areas of semi-natural woodlands nearby. The farm has an elevation of around 250 m in a hilly area and is sited within a loop of the River Ithon.

Currently, there are four side fan ventilated poultry rearing houses at Neuadd Isaf. These poultry houses provide accommodation for up to 152,000 broiler chickens. The chickens are raised from day old chicks to up to around 38 days old and there are approximately 7.5 flocks per year.

Under the proposals, two additional poultry houses would be constructed to the south-east of the existing poultry houses at Neuadd Isaf; these new houses would provide accommodation for an additional 106,000 broiler chickens. The primary ventilation for these new poultry houses would be provided by Inno+ scrubber units, which would provide the majority of the ventilation for the majority of the time. Backup ventilation, in the case of scrubber failure and for supplementary ventilation which would only be required at the end of the crops in warm weather, would be provided by high speed ridge fans, each with a short chimney. The chickens would be reared from day old chicks for 38 days and there would be approximately 7.5 flocks per annum. Additionally, under the proposals, the existing poultry houses would have an indirect heating system installed.

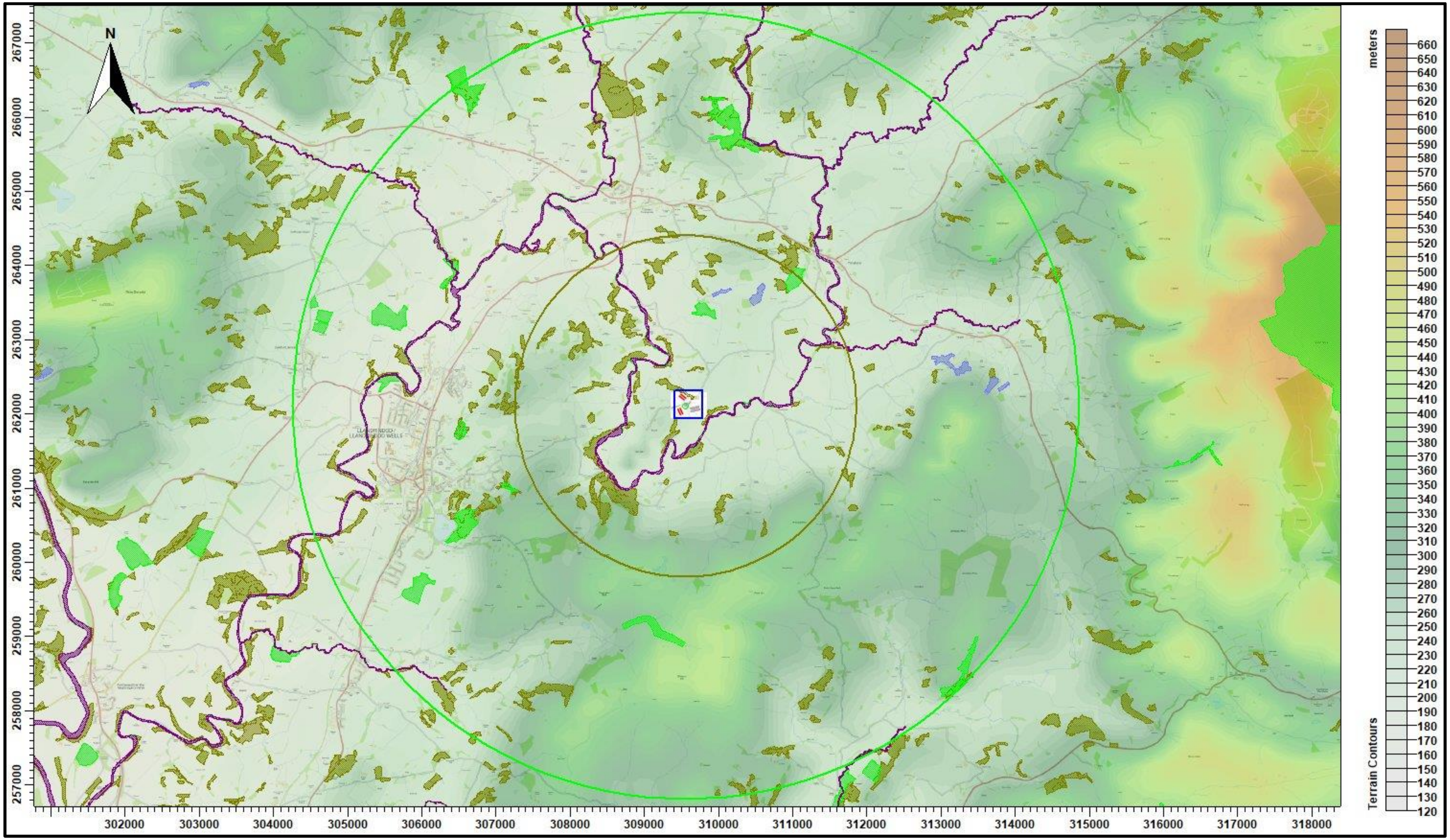
There are a number of areas that are designated as Ancient Woodlands (AWs) within 2 km of Neuadd Isaf, two of which are defined as sensitive to ammonia concentrations and nitrogen deposition (ammonia sensitive AWs) by Natural Resources Wales (NRW). There are two more areas designated by NRW as ammonia sensitive AWs and there are also thirteen areas that are designated as Sites of Special Scientific Interest (SSSIs) within 5 km of the farm, two of which, namely River Ithon SSSI and River Wye (Tributaries) SSSI that are also designated as part of River Wye Special Area of Conservation (SAC). Further details, including excerpts from the citations, of the closest SSSIs that are sensitive to ammonia concentrations and nitrogen deposition are provided below:

- Cae Llwyn SSSI - approximately 1.0 km to the north-north-east. A single, gently sloping field with a southerly aspect. It is an excellent example of a traditionally managed herb-rich meadow supporting both "wet" and "dry" plant communities.
- Cae Cwm-Rhocas SSSI - approximately 2.0 km to the north-east. A single large hay meadow on gently sloping ground in the valley of the River Ithon at Penybont. It supports an unusual plant community that has strong affinities with those found in certain flood-meadows in central and southern England. On the western side there is an alder carr and there are ancient oak trees.
- Llanfawr Quarries, Llandrindod Wells SSSI - approximately 3.0 km to the west-south-west. The vegetation of the slopes of the quarry and cliff areas is very variable in composition, dependent upon base-status. The site is species poor areas of the quarry and cliffs and species rich in areas of grassland.
- Lake Wood, Llandrindod Wells SSSI - approximately 2.8 km to the west. A species-rich mature sessile oakwood that illustrates the variation in vegetation developed on free-draining and waterlogged soils.
- Pentrosfa Mire SSSI - approximately 4.0 km to the south-west. The mire supports a range of characteristic fen types, including plant communities which are nationally and locally uncommon. Within a small area there is a complete transition from dry grassland through to open water. The diversity of plant species present reflects this habitat diversity. The mire has several plants which are uncommon in Radnor.

- Crabtree Green Meadows SSSI - approximately 3.8 km to the west. Of special interest due to its neutral grassland vegetation, in particular, a scarce form of grassland associated with river flood-plains. The site is part of a highly disjunct chain of flood-plain meadows which extend from Clwyd to Gwent down the Marcher fringes of Wales.
- Gweunydd Coch-Y-Dwst SSSI - approximately 3.8 km to the west-north-west. A series of agriculturally unimproved fields lying in the valley of the River Ithon near Llanyre. Variations in drainage and base status have produced a range of different vegetation types which in turn support a great variety of plant species. Of particular interest are the extensive areas of grassland which appear to be intermediate in species composition between acidic and more neutral swards.
- Coed Aberdulas SSSI - approximately 3.5 km to the north-west. A small but unusually diverse area of broadleaved woodland supporting a variety of plant communities, two of which are rare in Wales and of restricted distribution in Britain. Transitions between woodland and other important wildlife habitats such as unimproved pasture, wetland and scrub provide added interest.
- Moorlands Pastures SSSI - approximately 4.8 km to the west-north-west. Three separate fields on a gently sloping south-facing hillside. It is a good example of herb-rich acid grassland and it also contains some mesotrophic grassland with uncommon species. The nationally uncommon species, whorled caraway *Carum verticillatum*, is well represented throughout the site. This umbelliferous plant occurs mainly in the unimproved grasslands of the Carmarthen Coalfield, but also in out-lying sites like this one, which is at the northern limit of that part of the plant's range centred on the Coalfield.
- Ithon Valley Woodlands SSSI - approximately 3.4 km to the north-north-east. An important example of semi-natural mixed deciduous ancient woodland. It is relatively species-rich for woodland development on acid/neutral soils and contains uncommon plant species. The area is largely a plateau of level or gently east-facing slopes above the flood plain of the River Ithon. However, steeper ground occurs in the vicinity of the river and of east-flowing streams whose dingles dissect the plateau. The woodland is mainly open to grazing stock from the adjacent improved grassland, but in recent years the central area has been fenced out from stock.
- Twenty-Five Acre Wood SSSI - approximately 4.8 km to the north-north-west. A gently sloping south-facing oakwood developed on acidic, poorly draining clay overlying Ordovician strata. It has close affinities with the lowland hazel-sessile oak facies of the acid birch/oak woodland grouping. The wood is largely composed of mature maiden trees of oak with occasional alder and birch. Grazing in the southern portion is light and in the northern part is largely confined to winter and early spring. In winter cattle are fed in the northern part, but poaching of the soil is only localised.
- Graig Fawr SSSI - approximately 4.9 km to the south-east. Of special interest for its good examples of both acidic and calcareous grassland, supporting a wide variety of plant species; for its woodland, developed on cliffs and scree; and for its lichen community developed on volcanic rocks.
- River Ithon SSSI/River Wye SAC - approximately 150 m to the south-east at it's closest. Of special interest for its mesotrophic river types, which include communities containing water crowfoot *Ranunculus spp*. It supports important populations of otter *Lutra lutra*, Atlantic salmon *Salmo salar*, bullhead *Cottus gobio*, brook lamprey *Lampetra planeri* and river lamprey *Lampetra fluviatilis*. The headwaters support more oligotrophic aquatic communities and extensive areas of seminatural riparian habitats can still be found next to the Ithon and its tributaries. These include semi-natural woodland, dry and marshy grassland, stands of tall fen and marsh vegetation and gravel banks. The site also includes back channels and oxbows that support otters and waterfowl and provide valuable refuges for small fish and invertebrates in times of flood.
- River Wye (Tributaries)/River Wye SAC - approximately 5.0 km to the south-south-east. The tributaries are of special interest for two main aquatic plant community types - rivers on sandstone, mudstone and hard limestone and mesotrophic rivers downstream from oligotrophic catchments. The fish fauna is of special interest and the tributaries also support internationally important populations of Atlantic stream crayfish *Austropotamobius pallipes* and common otter *Lutra lutra*. Rivers and woodlands make up marginal vegetation.

A map of the surrounding area showing the position of the poultry houses at Neuadd Isaf, the AWs, the SSSIs and the SAC is provided in Figure 1. In the figure, the AWs are shaded in olive, the ammonia sensitive AWs are shaded in blue, the SSSIs are shaded in green, the SAC is shaded in purple and the location of Neuadd Isaf is outlined in blue.

Figure 1. The area surrounding Neuadd Isaf - with concentric circle radii at 2.0 km (olive) and 5.0 km (green)



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 ($\mu g\text{-}NH_3/m^3$) 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 background ammonia concentration (annual mean) in the area around Neuadd Isaf is 1.34 $\mu g\text{-}NH_3/m^3$. The background nitrogen deposition rate to woodland is 26.88 kg-N/ha/y and to short vegetation is 16.94 kg-N/ha/y. The background acid deposition rate to woodland is 2.01 keq/ha/y and to short vegetation is 1.26 keq/ha/y. The source of these background figures is the Air Pollution Information System (APIS, May 2021).

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 $\mu g\text{-}NH_3/m^3$ 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 $\mu g\text{-}NH_3/m^3$ 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. Note, the SSSI citations for Bach-Y-Graig Stream Section SSSI, Howey Brook Stream Section SSSI and Meeting House Quarry SSSI indicate that these sites have been designated because of their geology; therefore, they have not been considered further. 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)
AWs	1.0 [1]	10.0	-
Cae Cwm-Rhocas SSSI, Lake Wood, Llandrindod Wells SSSI, Coed Aberdulas SSSI, Ithon Valley Woodlands SSSI, Twenty-Five Acre Wood SSSI, Graig Fawr SSSI, River Ithon SSSI/River Wye SAC, River Wye (Tributaries) SSSI/River Wye SAC	1.0 [1 & 2]	10.0 [3]	-
Llanfawr Quarries, Llandrindod Wells SSSI, Pentrosfa Mire SSSI, Gweunydd Coch-Y-Dwst SSSI, Moorlands Pastures SSSI	3.0 [2]	8.0 [3]	-
Crabtree Green Meadows SSSI	3.0 [2]	10.0 [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 and information from Natural Resources Wales (Website).
3. The lower bound of the range of Critical Loads for broad-leaved woodlands obtained from APIS.

3.4 Guidance on the significance of ammonia emissions

In May 2021, Natural Resources Wales published guidance for ammonia assessments. Which contains the following:

- We are using Critical Level as a standard to ensure the sensitive site is protected and to enable sustainable development. The following statements should help you decide on the next course of action.
- If the process contribution and background levels do not exceed the Critical Level and there are no other sources to consider then normally the application can proceed.
- There will be occasions where the Critical Level is close to being reached. It is important to note that the Critical Level is not a target but a level that we want to avoid. Where the background is close to the critical level we may advise against the development even if the Critical Level is not exceeded.
- If the process contribution plus the background level reaches or exceeds the Critical Level then abatement must be used to reduce the process contribution to below 1% of the critical level in order for the application to proceed.
- If your process contribution is below 1% of the Critical Level and there are no other sources of ammonia to consider, the application can proceed regardless of the background level.

For new developments at existing farms, it is assumed that the process contribution means the change in process contribution, rather than the entire process contribution and that the existing process contribution is included in background figures. However, AS Modelling & Data Ltd. would note that although the process contribution from most farming installations is already included in the background ammonia concentrations and nitrogen and acid deposition rates, for established farms that are in close proximity to a wildlife site then, because the background concentrations and deposition rates are derived as an average for a 5 km by 5 km grid, there may be large underestimation of the existing process contributions to the local background level.

The Natural Resources Wales guidance appears to apply to statutory sites and some Ancient Woodlands. For Local Nature Reserves (LNRs), Local Wildlife Sites (LWSs) and other Ancient Woodlands (AWs), it is assumed that the Environment Agency's horizontal guidance, H1 Environmental Risks Assessment, H1 Annex B - Intensive Farming is still applicable as there is other official guidance that AS Modelling & Data Ltd. are aware of. The following are taken from this document.

"An emission is insignificant where Process Contribution (PC) is <50% for local and national nature reserves (LNRs & NNRs), ancient woodland and local wildlife sites." And "Where modelling predicts a process contribution >100% at a NNR, LNR, ancient woodland or local wildlife site, your proposal may not be considered acceptable. In such cases, your assessment should include proposals to reduce ammonia emissions."

This document was withdrawn February 1st 2016 and replaced with a web-page titled "Intensive farming risk assessment for your environmental permit", which contains essentially the same criteria. It is assumed that the upper threshold and lower threshold on the web-page refers to the levels that were previously referred to as levels of insignificance and acceptability in Annex B - Intensive Farming.

Within the range between the lower and upper thresholds, whether or not the impact is deemed acceptable is at the discretion of the Environment Agency. N.B. 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%).

3.5 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 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.

3.5.1 Modelling of existing poultry housing emissions

For poultry housing, the Environment Agency provides an Intensive farming guidance note which lists standard ammonia emission factors for a variety of livestock, including broiler chickens. The emission factor for broiler chickens is 0.034 kg-NH_3/bird place/y; this figure is used to calculate the emissions from the existing poultry houses. Under the proposals, the existing poultry houses would be fitted with an indirect heating system. The use of an indirect heating system has been shown to reduce ammonia emissions and regulators have previously accepted a reduction of 35% from the standard emission factor for broiler chickens; however, this is usually accompanied by monitoring conditions. The following points should be noted:

- It is thought that indirect heating systems are effective where they lead to a reduction in moisture in the housing by replacing direct heating, leading to a reduction in the moisture content of litter and consequently a reduction in microbial activity and ammonia production.
- The monitoring trials from which the 35% reduction was obtained were conducted on older style broiler housing with direct heating and involved heat exchanger units rather than full indirect heating systems. It is assumed that in this case, the existing poultry houses are such older style houses and that there is scope for such a reduction in moisture levels.

For the existing poultry housing, the calculated emissions total 0.163764 g-NH_3/s. Under the proposals, with an indirect heating system installed in the existing poultry houses, the calculated emissions total 0.106447 g-NH_3/s.

3.5.2 Modelling of the proposed poultry housing air scrubber emissions and bypass system

For the calculation of the emission rates from the air scrubber, the outlet ammonia concentration is assumed to be a constant 2 ppm (1,408.8 $\mu g/m^3$). This figure is based upon the guaranteed maximum outlet concentration from the manufacturers of the ammonia scrubbing equipment. It should be noted that, typically, an agricultural wet chemical scrubber can achieve 1 to 1.5 ppm outlet ammonia concentration, therefore the 2 ppm assumed is precautionary.

The ventilation rates used in the calculations are based on industry practices and standard bird growth factors. Minimum ventilation rates are as those of an operational poultry house and maximum ventilation rates are based on Defra guidelines. Target internal temperature is 33 Celsius at the beginning of the crop and is decreased to 22 Celsius by day 34 of the crop. If the external temperature is 7 Celsius, or more, lower than the target temperature, minimum ventilation only is assumed for the calculation. Above this, ventilation rates are increased in proportion to the difference between ambient temperature and target internal temperature. A maximum transitional ventilation rate (35% of the maximum possible ventilation rate) is reached when the ambient temperature is equal to the target temperature. A high ventilation rate (70% maximum possible ventilation rate) is reached when the temperature is 4 degrees above target and if external temperature is above 33 Celsius the maximum ventilation rate is assumed.

Based upon these principles, an ammonia emission rate for each hour of the period modelled is calculated by multiplying the outlet concentration by the ventilation rate.

The capacities of the air scrubbers would be 333,900 m^3/h (92.75 m^3/s); if the modelled ventilation rate exceeds the scrubber capacity, additional ventilation would be provided by the ridge mounted fans. The concentration is based upon long term, high temporal resolution monitoring of broiler rearing houses elsewhere and is dependent upon the crop stage. The internal ammonia concentrations assumed are then set so as to give approximately the same overall emission factor as the regulatory standard emission factor. Similarly, to the scrubber emissions, an emission rate from the bypass ventilation system is calculated by multiplying the internal concentration by the ventilation rate.

Since emissions are variable, to avoid some of the uncertainty introduced because of timing of higher emission rates, wind directions and atmospheric stability and provide robust statistics, three sets of calculations were performed; the first with the first day of the meteorological record coinciding with day 1 of the crop cycle, the second coinciding with day 16 of the crop and the third coinciding with day 32 of the crop.

The annual emission rates are variable, as they depend on ambient temperature and for example, how often bypass ventilation is used. However, in this case, the average emission rate of all three crop cycles over the four year meteorological record is equivalent to an emission factor of 0.0078 kg-NH_3/bird place/y, which is approximately 23% of the standard emission factor of 0.034 kg-NH_3/bird place/y i.e. assuming an outlet concentration of 2 ppm, the use of scrubbers would reduce housing emissions by approximately 77% from regulatory emission figures.

4. The Atmospheric Dispersion Modelling System (ADMS) and model parameters

The Atmospheric Dispersion Modelling System (ADMS) ADMS 5 is a new generation Gaussian plume air dispersion model, which means that the atmospheric boundary layer properties are characterised by two parameters; the boundary layer depth, and the Monin-Obukhov length rather than in terms of the single parameter Pasquill-Gifford class.

Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetrical Gaussian expression).

ADMS has a number of model options that include: dry and wet deposition; NO_x chemistry; impacts of hills, variable roughness, buildings and coastlines; puffs; fluctuations; odours; radioactivity decay (and γ-ray dose); condensed plume visibility; time varying sources and inclusion of background concentrations.

ADMS has an in-built meteorological pre-processor that allows flexible input of meteorological data both standard and more specialist. Hourly sequential and statistical data can be processed and all input and output meteorological variables are written to a file after processing.

The user defines the pollutant, the averaging time (which may be an annual average or a shorter period), which percentiles and exceedance values to calculate, whether a rolling average is required or not and the output units. The output options are designed to be flexible to cater for the variety of air quality limits, which can vary from country to country and are subject to revision.

4.1 Meteorological data

Computer modelling of dispersion requires hourly sequential meteorological data and to provide robust statistics, the record should be of a suitable length; preferably four years or longer.

The meteorological data used in this study is obtained from assimilation and short term forecast fields of the Numerical Weather Prediction (NWP) system known as the Global Forecast System (GFS).

The GFS is a spectral model: the physics/dynamics model has an equivalent resolution of approximately 9 km (latterly 6 km); terrain is understood to be resolved at a resolution of approximately 2 km, with sub-9/6 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[1]). The use of NWP data has advantages over traditional meteorological records because:

- Calm periods in traditional observational records may be over represented, this is because the instrumentation used may not record wind speeds below approximately 0.5 m/s and start up wind speeds may be greater than 1.0 m/s. In NWP data, the wind speed is continuous down to 0.0 m/s, allowing the calms module of ADMS to function correctly.

- Traditional records may include very local deviations from the broad-scale wind flow that would not necessarily be representative of the site being modelled; these deviations are difficult to identify and remove from a meteorological record. Conversely, local effects at the site being modelled are relatively easy to impose on the broad-scale flow and provided horizontal resolution is not too great, the meteorological records from NWP data may be expected to represent well the broad-scale flow.

- Information on the state of the atmosphere above ground level which would otherwise be estimated by the meteorological pre-processor may be included explicitly.

The raw GFS wind speeds are modified by the treatment of roughness lengths (see Section 4.7) and where terrain data is included in the modelling, wind speeds and directions will be further modified. The raw GFS wind rose is shown in Figure 2a and the terrain and roughness length modified wind rose for the location of the poultry houses at Neuadd Isaf is shown in Figure 2b. Note that elsewhere in the modelling domain, the modified wind roses may differ more markedly and that the resolution of the wind field in preliminary modelling terrain runs and the detailed modelling at a 300 m horizontal resolution is approximately 300 m and the resolution of the wind field in the detailed modelling at a 100 m horizontal resolution is approximately 150 m. Please also note that FLOWSTAR is used to obtain a local flow field, not to explicitly model dispersion in complex terrain as defined in the ADMS User Guide; therefore, the ADMS default value for minimum turbulence length has been amended[2].

1. 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).

2. 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 cause over prediction of ground level concentrations in stable weather conditions and light winds (Steven R. Hanna & Biswanath Chowdhury, 2014); for non-elevated sources marked underprediction of ground level concentrations is possible. 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 52.250 N, 3.326 W, 2017-2020

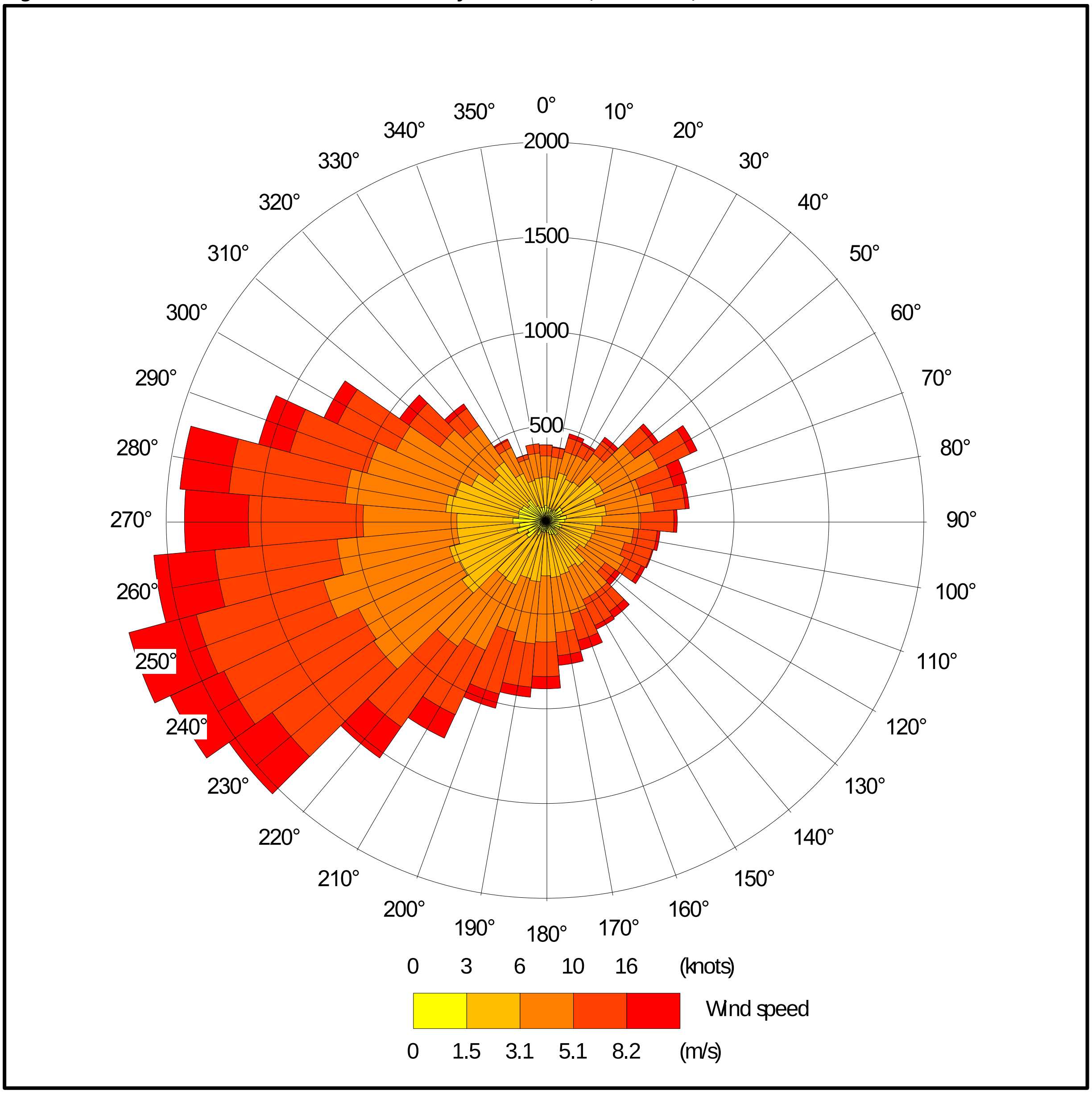
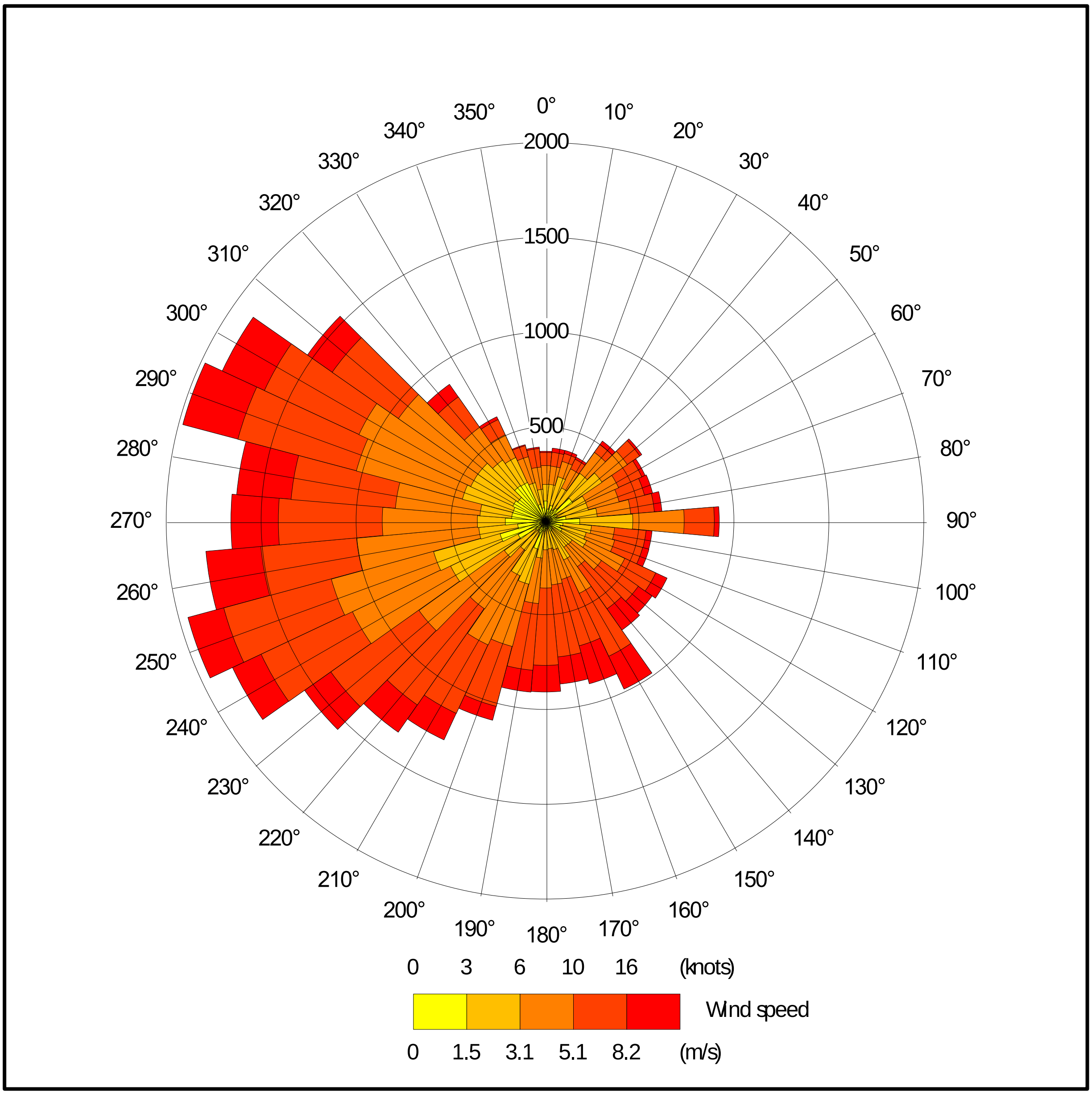


Figure 2b. The wind rose. FLOWSTAR derived data for NGR 309560, 262110, 2017-2020



4.2 Emission sources

Emissions from the side fans that are used to ventilate the existing poultry houses are represented by one volume source per house within ADMS (EX1_vol to EX4_vol).

Emissions from the air scrubbers and the chimneys of the high speed ridge fans that would be used as bypass or backup ventilation on the proposed houses are represented by six point sources per house within ADMS (PR5_BYP 1, 2 & 3 and PR6_BYP 1, 2 & 3 and PR5_SCR 1, 2 & 3 and PR6_SCR 1, 2 & 3).

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

Table 2a. Point source parameters

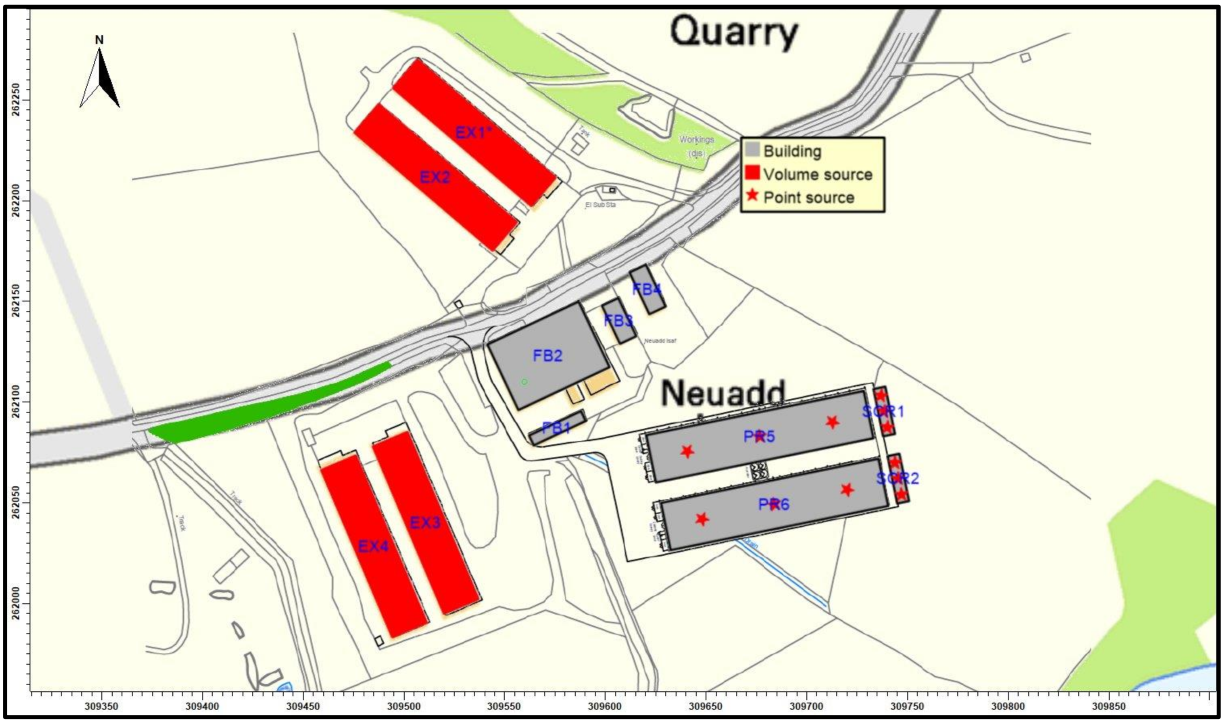
Source ID (Scenario)	Height (m)	Diameter (m)	Efflux velocity (m/s)	Emission temperature (˚C)	Emission rate per source ($g\text{-}NH_3/s$)
PR5_BYP and PR6 _BYP 1, 2 & 3	6.5	0.8	11.0	Variable [1]	Variable [1]
PR1_SCR and PR2_SCR 1, 2 & 3	5.5	Variable [1]	7.0	Variable [1]	Variable [1]

Table 2b. Volume source parameters

Source ID	Length (m)	Width (m)	Depth (m)	Base height (m)	Emission temperature (°C)	Emission rate per source ($g\text{-}NH_3/s$)
EX1_vol and EX4_vol	5.0	25.0	3.0	2.0	Ambient	0.040941 [2]

1. Dependent on crop stage and/or ambient temperature. Inno+ velocity control equipment is assumed.
2. Emission rate for the existing houses, based on the EA standard emission factor. The process contribution from the existing houses in the proposed scenario have been reduced by 35% as the proposals included the use of indirect heating systems in the existing houses.

Figure 3. The positions of modelled sources and buildings



4.3 Modelled buildings

The structure of the proposed poultry houses and other nearby farm buildings may affect the plumes from the point sources on the proposed poultry houses. Therefore, the buildings are modelled within ADMS. The positions of the modelled buildings may be seen in Figure 3, where they are marked by blue rectangles.

4.4 Discrete receptors

Sixty-six discrete receptors have been defined at the AWs, the SSSIs and the SSSIs/SACs. These receptors are defined at ground level within ADMS. The positions of the discrete receptors may be seen in Figure 4a and Figure 4b, where they are marked by enumerated pink rectangles.

4.5 Cartesian grid

To produce the contour plots presented in Section 5 of this report, two regular Cartesian grids, one at a horizontal resolution of 300 m and one at a horizontal resolution of 100 m 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 4a and Figure 4b, where they are 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 20.0 km by 20.0 km domain has been resampled at 100 m horizontal resolution for use within ADMS for the preliminary modelling terrain runs and for the detailed modelling at a 300 m horizontal resolution and a 10.0 km by 10.0 km domain has been resampled at 100 m horizontal resolution for use within ADMS for the detailed modelling at a 100 m horizontal resolution. N.B. The resolution of FLOWSTAR is 64 by 64 grid points; therefore, the effective resolution of the wind field for the terrain runs is approximately 300 m in the preliminary terrain modelling runs and the 300 m detailed modelling and is approximately 150 m in the 100 m detailed modelling.

4.7 Roughness Length

A fixed surface roughness length of 0.3 m has been applied over the entire modelling domain. As a precautionary measure, the GFS meteorological data is assumed to have a roughness length of 0.275 m. The effect of the difference in roughness length is precautionary as it increases the frequency of low wind speeds and the stability and therefore increases predicted ground level concentrations.

Figure 4a. The discrete receptors and Cartesian grids - a broad scale view

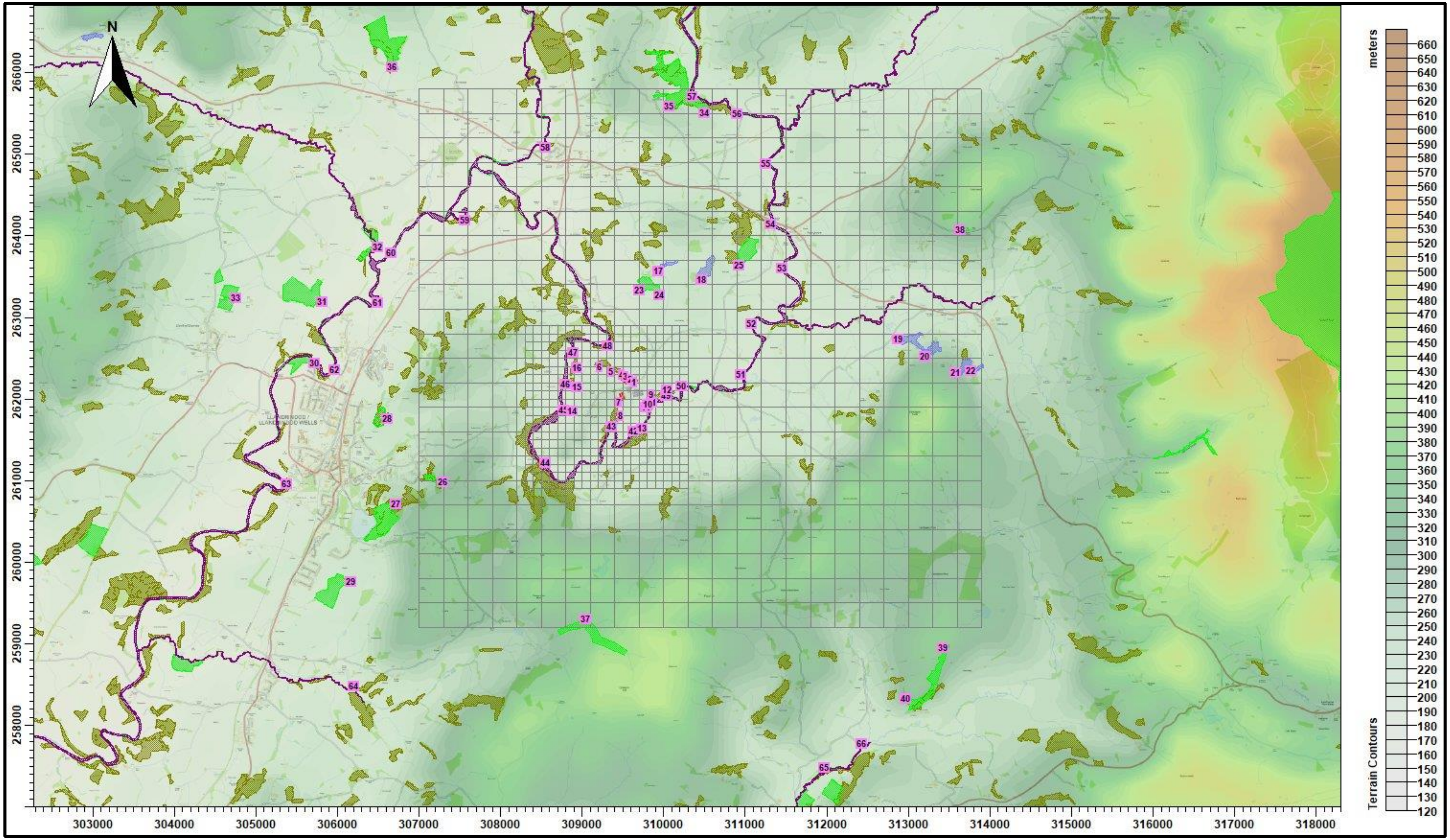
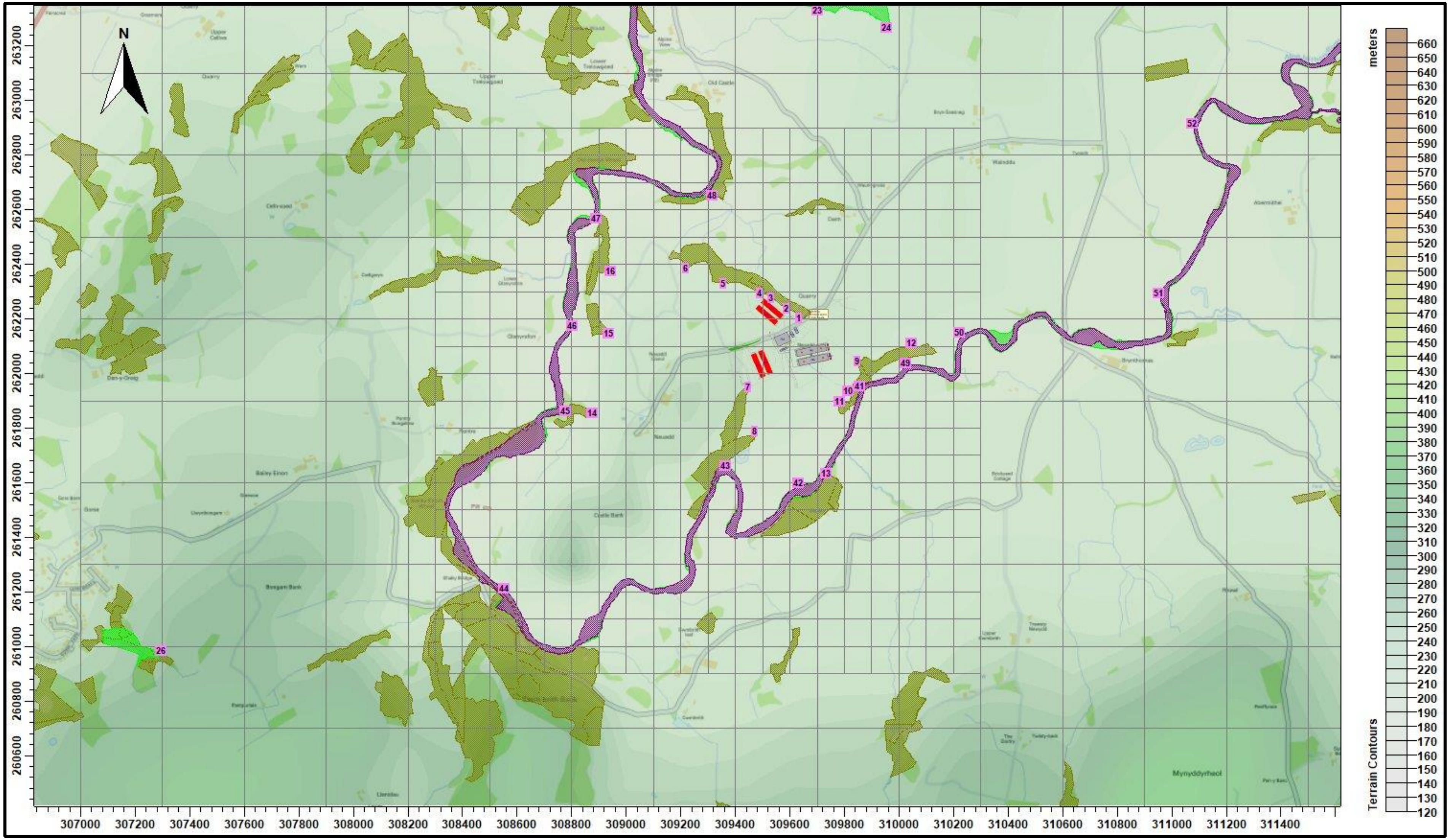


Figure 4b. The discrete receptors and Cartesian grids - a closer view



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.

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 3.

Table 3. 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 (0.01 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.

Contour plots of the spatially varying deposition fields are provided in Figure 5a and Figure 5b.

In this case, the model has also been run with a fixed deposition at 0.003 m/s and similarly to not modelling deposition at all, the predicted ammonia concentrations (and nitrogen and acid deposition rates) are always higher than if spatially varying deposition were modelled explicitly, particularly where there is some distance between the source and a receptor.

Figure 5a. The spatially varying deposition field - 300 m resolution domain

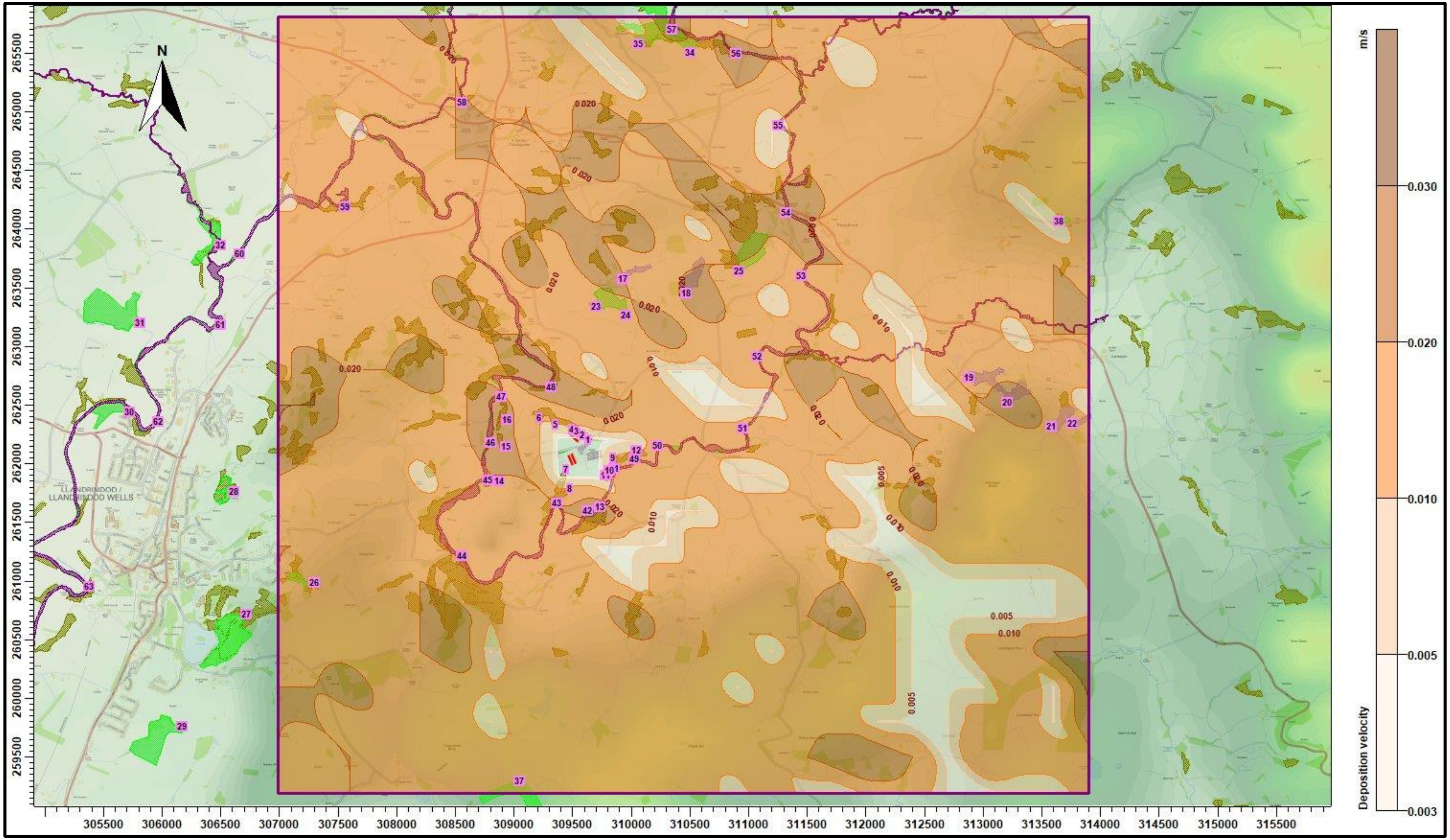
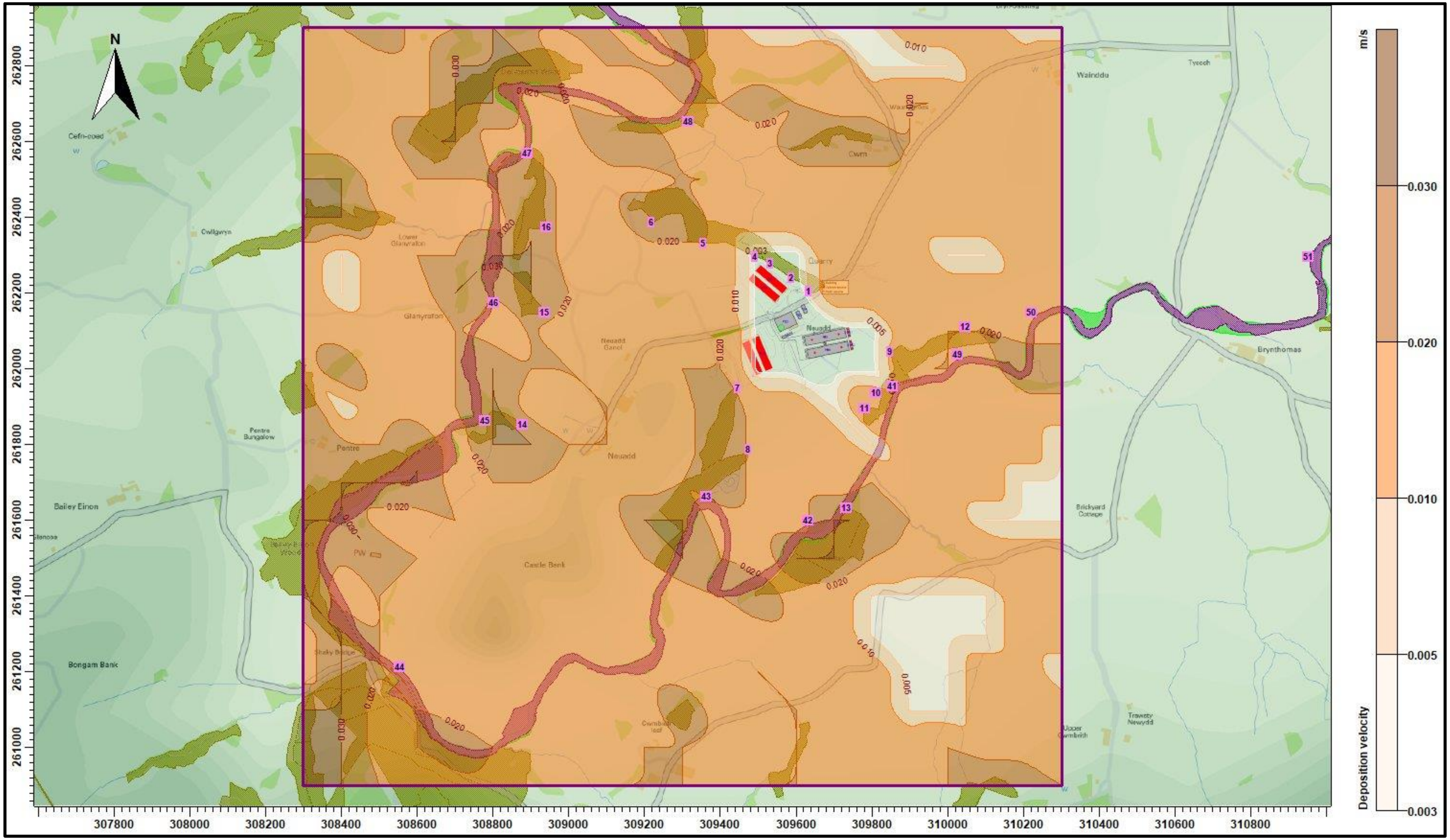


Figure 5b. The spatially varying deposition field - 100 m resolution domain



5. Details of the Model Runs and Results

5.1 Preliminary modelling

ADMS was run a total of thirty-two times; once for each year of the meteorological record, for the existing and proposed scenarios and in the following four modes:

- In basic mode without calms or terrain - GFS data.
- With calms and without terrain - GFS data.
- Without calms and with terrain - GFS data.
- Without calms, with terrain and fixed deposition at 0.003 m/s - GFS data.

For each mode, statistics for the maximum annual mean ammonia concentration at each receptor were compiled.

Details of the predicted process contribution from the existing scenario and the proposed scenario to annual mean ammonia concentrations at each receptor are provided in Table 4. In the Table, predicted ammonia concentrations (or those equivalent to nitrogen deposition rates) that are in excess of the Natural Resources Wales threshold of the relevant Critical Level or Critical Load (1% for an ammonia sensitive AW, SSSI or SAC and 100% for a non-statutory site) are coloured red. For convenience, cells referring to the AWs are shaded olive, those referring to the ammonia sensitive AWs are shaded blue, those referring to the SSSIs are shaded green and those referring to the SACs sites are shaded lilac.

Table 4. Predicted maximum annual mean ammonia concentration at the discrete receptors

Receptor number	X(m)	Y(m)	Designation	Maximum annual mean ammonia concentration - (µg/m³)							
				Existing				Proposed			
				GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [1]	GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [2]
1	309634	262203	Unnamed AWs	17.189	19.614	16.052	15.111	11.302	12.838	10.589	9.870
2	309586	262238	Unnamed AWs	36.136	40.828	28.278	28.776	23.544	26.593	18.437	18.511
3	309533	262276	Unnamed AWs	30.791	36.857	25.527	27.170	20.077	24.019	16.660	17.493
4	309490	262294	Unnamed AWs	18.852	22.728	12.820	12.961	12.305	14.824	8.387	8.371
5	309355	262330	Unnamed AWs	4.311	5.361	3.105	2.680	2.836	3.518	2.054	1.759
6	309218	262385	Unnamed AWs	1.836	2.316	0.963	0.842	1.216	1.528	0.651	0.568
7	309446	261949	Unnamed AWs	9.680	12.662	9.321	8.675	6.358	8.294	6.117	5.643
8	309473	261787	Unnamed AWs	2.083	2.840	3.017	2.237	1.375	1.866	1.984	1.459
9	309848	262044	Unnamed AWs	3.424	3.921	2.989	2.343	2.674	2.948	2.433	2.218
10	309812	261936	Unnamed AWs	3.183	3.630	2.345	1.867	2.164	2.453	1.616	1.339
11	309782	261896	Unnamed AWs	2.973	3.478	1.834	1.695	1.997	2.311	1.259	1.165
12	310046	262111	Unnamed AWs	1.807	2.048	1.563	1.164	1.283	1.437	1.136	0.884
13	309733	261633	Unnamed AWs	1.069	1.344	0.609	0.449	0.714	0.893	0.416	0.310
14	308878	261853	Unnamed AWs	0.763	0.956	0.802	0.539	0.511	0.635	0.536	0.359
15	308935	262147	Unnamed AWs	1.025	1.299	1.156	0.763	0.680	0.858	0.765	0.502
16	308942	262375	Unnamed AWs	0.798	1.002	0.572	0.440	0.534	0.666	0.388	0.299
17	309932	263570	Unnamed AWs sensitive to NH3	0.152	0.204	0.330	0.189	0.106	0.140	0.221	0.128
18	310470	263455	Unnamed AWs sensitive to NH3	0.163	0.208	0.141	0.099	0.113	0.143	0.100	0.071
19	312877	262733	Unnamed AWs sensitive to NH3	0.082	0.093	0.048	0.030	0.058	0.065	0.040	0.025
20	313204	262519	Unnamed AWs sensitive to NH3	0.069	0.078	0.047	0.025	0.049	0.055	0.039	0.021
21	313586	262318	Unnamed AWs sensitive to NH3	0.057	0.066	0.042	0.021	0.041	0.046	0.035	0.018
22	313763	262341	Unnamed AWs sensitive to NH3	0.054	0.061	0.029	0.017	0.038	0.043	0.024	0.014
23	309701	263333	Cae Llwyn SSSI	0.221	0.295	0.277	0.182	0.153	0.201	0.187	0.124
24	309955	263266	Cae Llwyn SSSI	0.221	0.296	0.448	0.274	0.154	0.202	0.300	0.185
25	310921	263638	Cae Cwm-Rhocas SSSI	0.133	0.161	0.193	0.109	0.093	0.111	0.133	0.077
26	307297	260984	Bach-Y-Graig Stream Section SSSI	0.080	0.102	0.076	0.040	0.056	0.070	0.053	0.029

Receptor number	X(m)	Y(m)	Designation	Maximum annual mean ammonia concentration - (µg/m³)							
				Existing				Proposed			
				GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [1]	GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [2]
27	306716	260712	Llanfawr Quarries, Llandrindod Wells SSSI	**0.055**	**0.070**	**0.050**	**0.026**	**0.038**	**0.048**	**0.036**	**0.019**
28	306610	261759	Lake Wood, Llandrindod Wells SSSI	**0.073**	**0.090**	**0.070**	**0.031**	**0.051**	**0.062**	**0.048**	**0.022**
29	306170	259761	Pentrosfa Mire SSSI	**0.035**	**0.044**	**0.031**	**0.016**	**0.025**	**0.031**	**0.022**	0.012
30	305721	262437	Crabtree Green Meadows SSSI	**0.043**	**0.055**	**0.047**	**0.020**	**0.030**	**0.038**	**0.032**	0.014
31	305809	263194	Gweunydd Coch-Y-Dwst SSSI	**0.037**	**0.047**	**0.040**	**0.019**	**0.026**	**0.032**	**0.028**	0.014
32	306496	263863	Coed Aberdulas SSSI	**0.041**	**0.053**	**0.032**	**0.018**	**0.029**	**0.037**	**0.023**	**0.013**
33	304762	263238	Moorlands Pastures SSSI	**0.025**	**0.033**	**0.033**	0.014	**0.018**	**0.023**	**0.023**	0.010
34	310501	265500	Ithon Valley Woodlands SSSI	**0.035**	**0.048**	**0.043**	**0.023**	**0.025**	**0.034**	**0.031**	**0.017**
35	310061	265579	Ithon Valley Woodlands SSSI	**0.036**	**0.049**	**0.061**	**0.031**	**0.026**	**0.034**	**0.042**	**0.021**
36	306672	266072	Twenty-Five Acre Wood SSSI	**0.027**	**0.034**	**0.011**	0.007	**0.019**	**0.024**	0.008	0.005
37	309049	259294	Howey Brook Stream Section SSSI	0.045	0.063	0.040	0.017	0.032	0.043	0.027	0.011
38	313644	264065	Meeting House Quarry SSSI	0.051	0.057	0.019	0.013	0.036	0.041	0.019	0.012
39	313432	258951	Graig Fawr SSSI	**0.035**	**0.041**	**0.018**	0.009	**0.025**	**0.029**	**0.014**	0.007
40	312975	258326	Graig Fawr SSSI	**0.032**	**0.038**	**0.017**	0.007	**0.023**	**0.026**	**0.014**	0.006
41	309855	261954	River Ithon SSSI/River Wye SAC	**2.856**	**3.247**	**2.221**	**1.729**	**2.002**	**2.248**	**1.579**	**1.315**
42	309631	261598	River Ithon SSSI/River Wye SAC	**0.899**	**1.201**	**0.771**	**0.560**	**0.600**	**0.796**	**0.521**	**0.380**
43	309363	261662	River Ithon SSSI/River Wye SAC	**1.004**	**1.433**	**1.373**	**0.957**	**0.679**	**0.958**	**0.907**	**0.629**
44	308554	261213	River Ithon SSSI/River Wye SAC	**0.235**	**0.296**	**0.208**	**0.132**	**0.160**	**0.200**	**0.144**	**0.092**
45	308778	261861	River Ithon SSSI/River Wye SAC	**0.630**	**0.788**	**0.672**	**0.439**	**0.422**	**0.524**	**0.449**	**0.293**
46	308802	262173	River Ithon SSSI/River Wye SAC	**0.725**	**0.920**	**0.808**	**0.512**	**0.482**	**0.609**	**0.536**	**0.339**
47	308890	262568	River Ithon SSSI/River Wye SAC	**0.546**	**0.701**	**0.200**	**0.182**	**0.366**	**0.467**	**0.142**	**0.129**
48	309314	262651	River Ithon SSSI/River Wye SAC	**1.228**	**1.488**	**0.545**	**0.492**	**0.816**	**0.985**	**0.372**	**0.336**
49	310026	262037	River Ithon SSSI/River Wye SAC	**1.841**	**2.056**	**1.544**	**1.152**	**1.323**	**1.461**	**1.129**	**0.883**
50	310221	262149	River Ithon SSSI/River Wye SAC	**1.137**	**1.286**	**0.984**	**0.700**	**0.794**	**0.890**	**0.706**	**0.522**
51	310952	262295	River Ithon SSSI/River Wye SAC	**0.341**	**0.386**	**0.206**	**0.144**	**0.236**	**0.265**	**0.151**	**0.109**
52	311074	262914	River Ithon SSSI/River Wye SAC	**0.251**	**0.283**	**0.113**	**0.095**	**0.175**	**0.196**	**0.088**	**0.078**
53	311450	263596	River Ithon SSSI/River Wye SAC	**0.123**	**0.142**	**0.068**	**0.052**	**0.087**	**0.099**	**0.051**	**0.040**
54	311316	264140	River Ithon SSSI/River Wye SAC	**0.081**	**0.099**	**0.089**	**0.051**	**0.058**	**0.069**	**0.062**	**0.037**

Receptor number	X(m)	Y(m)	Designation	Maximum annual mean ammonia concentration - (µg/m³)							
				Existing				Proposed			
				GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [1]	GFS No Calms No Terrain	GFS Calms No Terrain	GFS No Calms Terrain	GFS No Calms Terrain Fixed depo 0.003 m/s [2]
55	311252	264882	River Ithon SSSI/River Wye SAC	**0.045**	**0.060**	**0.049**	**0.028**	**0.032**	**0.042**	**0.035**	**0.021**
56	310898	265490	River Ithon SSSI/River Wye SAC	**0.034**	**0.046**	**0.029**	**0.019**	**0.025**	**0.032**	**0.021**	**0.014**
57	310343	265698	River Ithon SSSI/River Wye SAC	**0.033**	**0.045**	**0.044**	**0.023**	**0.024**	**0.031**	**0.031**	**0.016**
58	308557	265074	River Ithon SSSI/River Wye SAC	**0.065**	**0.078**	**0.036**	**0.023**	**0.046**	**0.055**	**0.027**	**0.018**
59	307563	264189	River Ithon SSSI/River Wye SAC	**0.060**	**0.078**	**0.027**	**0.019**	**0.042**	**0.054**	**0.019**	**0.014**
60	306662	263788	River Ithon SSSI/River Wye SAC	**0.045**	**0.058**	**0.034**	**0.019**	**0.032**	**0.040**	**0.024**	**0.014**
61	306500	263180	River Ithon SSSI/River Wye SAC	**0.050**	**0.063**	**0.048**	**0.025**	**0.035**	**0.043**	**0.034**	**0.018**
62	305969	262356	River Ithon SSSI/River Wye SAC	**0.049**	**0.063**	**0.051**	**0.022**	**0.034**	**0.043**	**0.035**	**0.016**
63	305376	260954	River Ithon SSSI/River Wye SAC	**0.036**	**0.045**	**0.037**	**0.016**	**0.026**	**0.031**	**0.026**	**0.012**
64	306200	258482	River Ithon SSSI/River Wye SAC	**0.025**	**0.032**	**0.020**	0.010	**0.018**	**0.022**	**0.015**	0.008
65	311968	257481	River Wye Tributaries SSSI/River Wye SAC	**0.022**	**0.028**	**0.020**	0.007	**0.016**	**0.020**	**0.015**	0.006
66	312430	257766	River Wye Tributaries SSSI/River Wye SAC	**0.025**	**0.031**	**0.019**	0.007	**0.018**	**0.022**	**0.014**	0.006

1. Increased by a factor of 1.24, the average increase due to calms at the discrete receptors in the modelling for the existing poultry houses.
2. Increased by a factor of 1.23, the average increase due to calms at the discrete receptors in the modelling for the proposed poultry houses.

5.2 Detailed deposition modelling

The detailed modelling, which includes deposition and consequent plume depletion, was carried out at two horizontal resolutions using spatially varying resolutions at 300 m and 100 m. For the 300 m resolution detailed modelling, a 6.9 km by 6.6 km spatially varying deposition field, that includes the existing and proposed poultry houses, has been applied and a fixed deposition velocity of 0.003 m/s has been assumed for discrete receptors beyond this domain. For the 100 m resolution detailed modelling, a 2.0 km by 2.0 km spatially varying deposition field, that includes the existing and proposed poultry houses, has been applied and only the discrete receptors within this domain have been included.

Terrain effects may be significant at some receptors; therefore, the detailed deposition runs were made with terrain included. Calms cannot be used with terrain or spatially varying deposition and have not been included in the detailed modelling; the results of the preliminary modelling show that the effects of calms are significant and therefore the process contributions to ammonia concentrations and nitrogen deposition rates have been corrected by a factor that is the average of the increase of the calms modelling runs from the basic modelling runs in the preliminary modelling. For the existing poultry houses, this is a factor of 1.24 and for the proposed this is a factor of 1.23.

The results of the detailed deposition modelling of ammonia emissions from the existing and proposed poultry houses are shown in Table 5a, for the detailed modelling at a horizontal resolution of 300 m and in Table 5b, for the detailed modelling at a horizontal resolution of 100 m. In these Tables, In the Tables, predicted ammonia concentrations (or those equivalent to nitrogen deposition rates) that are in excess of the Natural Resources Wales threshold of the relevant Critical Level or Critical Load (1% for an ammonia sensitive AW, SSSI or SAC and 100% for a non-statutory site) are coloured red. Note, the abbreviations PC, CLe and CLo in Tables 5a and 5b refer to Process Contribution, Critical Level and Critical Load, respectively.

Contour plots for the domain where the spatially varying deposition rates have been applied, of the predicted process contribution of the existing and proposed poultry houses to ground level maximum annual mean ammonia concentration and the maximum nitrogen deposition rate are shown in Figure 6a, Figure 6b, Figure 6c and Figure 6d for the existing poultry houses and in Figure 7a, Figure 7b, Figure 7c and Figure 7d for the proposed poultry houses.

Table 5a. Predicted process contribution to annual mean ammonia concentrations and nitrogen deposition rates at the discrete receptors - detailed modelling at 300 m horizontal resolution

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration				Maximum annual nitrogen deposition rate			
							Existing		Proposed		Existing		Proposed	
				Deposition Velocity	CLe (µg/m³)	CLo (kg/ha)	PC (µg/m³)	%age of CLe	PC (µg/m³)	%age of CLe	PC (kg/ha)	%age of CLo	PC (kg/ha)	%age of CLo
17	309932	263570	AW (ammonia sensitive)	0.03	1.0	10.0	0.066	**6.6**	0.047	**4.7**	0.511	**5.1**	0.363	**3.6**
18	310470	263455	AW (ammonia sensitive)	0.03	1.0	10.0	0.045	**4.5**	0.034	**3.4**	0.348	**3.5**	0.263	**2.6**
19	312877	262733	AW (ammonia sensitive)	0.03	1.0	10.0	0.016	**1.6**	0.014	**1.4**	0.128	**1.3**	0.112	**1.1**
20	313204	262519	AW (ammonia sensitive)	0.03	1.0	10.0	0.012	**1.2**	0.011	**1.1**	0.094	0.9	0.083	0.8
21	313586	262318	AW (ammonia sensitive)	0.03	1.0	10.0	0.010	1.0	0.009	0.9	0.077	0.8	0.067	0.7
22	313763	262341	AW (ammonia sensitive)	0.03	1.0	10.0	0.009	0.9	0.008	0.8	0.072	0.7	0.060	0.6
23	309701	263333	Cae Llwyn SSSI	0.02	3.0	-	0.084	**2.8**	0.059	**2.0**	-	**-**	-	**-**
24	309955	263266	Cae Llwyn SSSI	0.02	3.0	-	0.106	**3.5**	0.075	**2.5**	-	**-**	-	**-**
25	310921	263638	Cae Cwm-Rhocas SSSI	0.03	1.0	10.0	0.046	**4.6**	0.035	**3.5**	0.361	**3.6**	0.269	**2.7**
27	306716	260712	Llanfawr Quarries, Llandrindod Wells SSSI	0.02	3.0	8.0	0.009	0.3	0.007	0.2	0.045	0.6	0.034	0.4
28	306610	261759	Lake Wood, Llandrindod Wells SSSI	0.03	1.0	10.0	0.009	0.9	0.007	0.7	0.068	0.7	0.053	0.5
29	306170	259761	Pentrosfa Mire SSSI	0.02	3.0	8.0	0.004	0.1	0.003	0.1	0.021	0.3	0.016	0.2
30	305721	262437	Crabtree Green Meadows SSSI	0.02	3.0	10.0	0.006	0.2	0.004	0.1	0.029	0.3	0.023	0.2
31	305809	263194	Gweunydd Coch-Y-Dwst SSSI	0.02	3.0	8.0	0.006	0.2	0.005	0.2	0.031	0.4	0.025	0.3
32	306496	263863	Coed Aberdulas SSSI	0.03	1.0	10.0	0.007	0.7	0.006	0.6	0.057	0.6	0.045	0.4
33	304762	263238	Moorlands Pastures SSSI	0.02	3.0	8.0	0.004	0.1	0.003	0.1	0.019	0.2	0.015	0.2
34	310501	265500	Ithon Valley Woodlands SSSI	0.03	1.0	10.0	0.008	0.8	0.006	0.6	0.063	0.6	0.049	0.5
35	310061	265579	Ithon Valley Woodlands SSSI	0.03	1.0	10.0	0.010	1.0	0.007	0.7	0.074	0.7	0.056	0.6
36	306672	266072	Twenty-Five Acre Wood SSSI	0.03	1.0	10.0	0.003	0.3	0.002	0.2	0.023	0.2	0.018	0.2
39	313432	258951	Graig Fawr SSSI	0.03	1.0	10.0	0.004	0.4	0.004	0.4	0.034	0.3	0.027	0.3
40	312975	258326	Graig Fawr SSSI	0.03	1.0	10.0	0.003	0.3	0.003	0.3	0.026	0.3	0.020	0.2
51	310952	262295	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.091	**9.1**	0.073	**7.3**	0.710	**7.1**	0.569	**5.7**
52	311074	262914	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.062	**6.2**	0.051	**5.1**	0.479	**4.8**	0.401	**4.0**

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration				Maximum annual nitrogen deposition rate			
							Existing		Proposed		Existing		Proposed	
				Deposition Velocity	CLe ($\mu g/m^3$)	CLo (kg/ha)	PC ($\mu g/m^3$)	%age of CLe	PC ($\mu g/m^3$)	%age of CLe	PC (kg/ha)	%age of CLo	PC (kg/ha)	%age of CLo
53	311450	263596	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.030	**3.0**	0.024	**2.4**	0.231	**2.3**	0.184	**1.8**
54	311316	264140	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.023	**2.3**	0.017	**1.7**	0.177	**1.8**	0.135	**1.4**
55	311252	264882	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.012	**1.2**	0.010	1.0	0.094	0.9	0.075	0.7
56	310898	265490	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.007	0.7	0.006	0.6	0.057	0.6	0.045	0.5
57	310343	265698	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.007	0.7	0.006	0.6	0.058	0.6	0.045	0.4
58	308557	265074	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.009	0.9	0.007	0.7	0.067	0.7	0.056	0.6
59	307563	264189	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.009	0.9	0.007	0.7	0.071	0.7	0.054	0.5
60	306662	263788	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.008	0.8	0.006	0.6	0.063	0.6	0.049	0.5
61	306500	263180	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.009	0.9	0.007	0.7	0.069	0.7	0.055	0.5
62	305969	262356	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.006	0.6	0.005	0.5	0.049	0.5	0.039	0.4
63	305376	260954	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.004	0.4	0.004	0.4	0.035	0.3	0.028	0.3
64	306200	258482	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.001	0.1	0.001	0.1	0.006	0.1	0.005	0.0
65	311968	257481	River Wye Tributaries SSSI/River Wye SAC	0.03	1.0	10.0	0.002	0.2	0.002	0.2	0.018	0.2	0.015	0.2
66	312430	257766	River Wye Tributaries SSSI/River Wye SAC	0.03	1.0	10.0	0.003	0.3	0.002	0.2	0.020	0.2	0.016	0.2

Table 5b. Predicted process contribution to annual mean ammonia concentrations and nitrogen deposition rates at the discrete receptors - detailed modelling at 100 m horizontal resolution

Receptor number	X(m)	Y(m)	Name	Site Parameters			Maximum annual ammonia concentration				Maximum annual nitrogen deposition rate			
							Existing		Proposed		Existing		Proposed	
				Deposition Velocity	CLe (µg/m³)	CLo (kg/ha)	PC (µg/m³)	%age of CLe	PC (µg/m³)	%age of CLe	PC (kg/ha)	%age of CLo	PC (kg/ha)	%age of CLo
1	309634	262203	Unnamed AWs	0.03	1.0	10.0	13.479	**1,347.9**	8.860	**886.0**	105.012	**1,050.1**	69.028	**690.3**
2	309586	262238	Unnamed AWs	0.03	1.0	10.0	27.094	**2,709.4**	17.668	**1,766.8**	211.088	**2,110.9**	137.653	**1,376.5**
3	309533	262276	Unnamed AWs	0.03	1.0	10.0	23.747	**2,374.7**	15.501	**1,550.1**	185.012	**1,850.1**	120.771	**1,207.7**
4	309490	262294	Unnamed AWs	0.03	1.0	10.0	13.611	**1,361.1**	8.901	**890.1**	106.039	**1,060.4**	69.344	**693.4**
5	309355	262330	Unnamed AWs	0.03	1.0	10.0	2.044	**204.4**	1.359	**135.9**	15.924	**159.2**	10.586	**105.9**
6	309218	262385	Unnamed AWs	0.03	1.0	10.0	0.652	65.2	0.443	44.3	5.079	50.8	3.450	34.5
7	309446	261949	Unnamed AWs	0.03	1.0	10.0	5.678	**567.8**	3.736	**373.6**	44.239	**442.4**	29.107	**291.1**
8	309473	261787	Unnamed AWs	0.03	1.0	10.0	0.888	88.8	0.618	61.8	6.921	69.2	4.813	48.1
9	309848	262044	Unnamed AWs	0.03	1.0	10.0	2.102	**210.2**	1.920	**192.0**	16.376	**163.8**	14.957	**149.6**
10	309812	261936	Unnamed AWs	0.03	1.0	10.0	1.746	**174.6**	1.231	**123.1**	13.600	**136.0**	9.593	95.9
11	309782	261896	Unnamed AWs	0.03	1.0	10.0	1.514	**151.4**	1.047	**104.7**	11.792	**117.9**	8.158	81.6
12	310046	262111	Unnamed AWs	0.03	1.0	10.0	0.839	83.9	0.649	64.9	6.538	65.4	5.057	50.6
13	309733	261633	Unnamed AWs	0.03	1.0	10.0	0.324	32.4	0.225	22.5	2.525	25.3	1.756	17.6
14	308878	261853	Unnamed AWs	0.03	1.0	10.0	0.205	20.5	0.147	14.7	1.595	16.0	1.145	11.5
15	308935	262147	Unnamed AWs	0.03	1.0	10.0	0.298	29.8	0.206	20.6	2.321	23.2	1.608	16.1
16	308942	262375	Unnamed AWs	0.03	1.0	10.0	0.235	23.5	0.165	16.5	1.832	18.3	1.287	12.9
41	309855	261954	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	1.548	**154.8**	1.143	**114.3**	12.062	**120.6**	8.904	**89.0**
42	309631	261598	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.294	**29.4**	0.204	**20.4**	2.288	**22.9**	1.593	**15.9**
43	309363	261662	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.371	**37.1**	0.264	**26.4**	2.892	**28.9**	2.058	**20.6**
44	308554	261213	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.076	**7.6**	0.059	**5.9**	0.591	**5.9**	0.459	**4.6**
45	308778	261861	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.165	**16.5**	0.120	**12.0**	1.282	**12.8**	0.933	**9.3**
46	308802	262173	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.200	**20.0**	0.142	**14.2**	1.557	**15.6**	1.106	**11.1**
47	308890	262568	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.133	**13.3**	0.095	**9.5**	1.034	**10.3**	0.739	**7.4**
48	309314	262651	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.386	**38.6**	0.266	**26.6**	3.009	**30.1**	2.071	**20.7**
49	310026	262037	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.886	**88.6**	0.698	**69.8**	6.904	**69.0**	5.435	**54.4**
50	310221	262149	River Ithon SSSI/River Wye SAC	0.03	1.0	10.0	0.447	**44.7**	0.357	**35.7**	3.483	**34.8**	2.778	**27.8**

Figure 6a. Process contribution to maximum annual mean ammonia concentrations - existing poultry houses, 300 m horizontal resolution

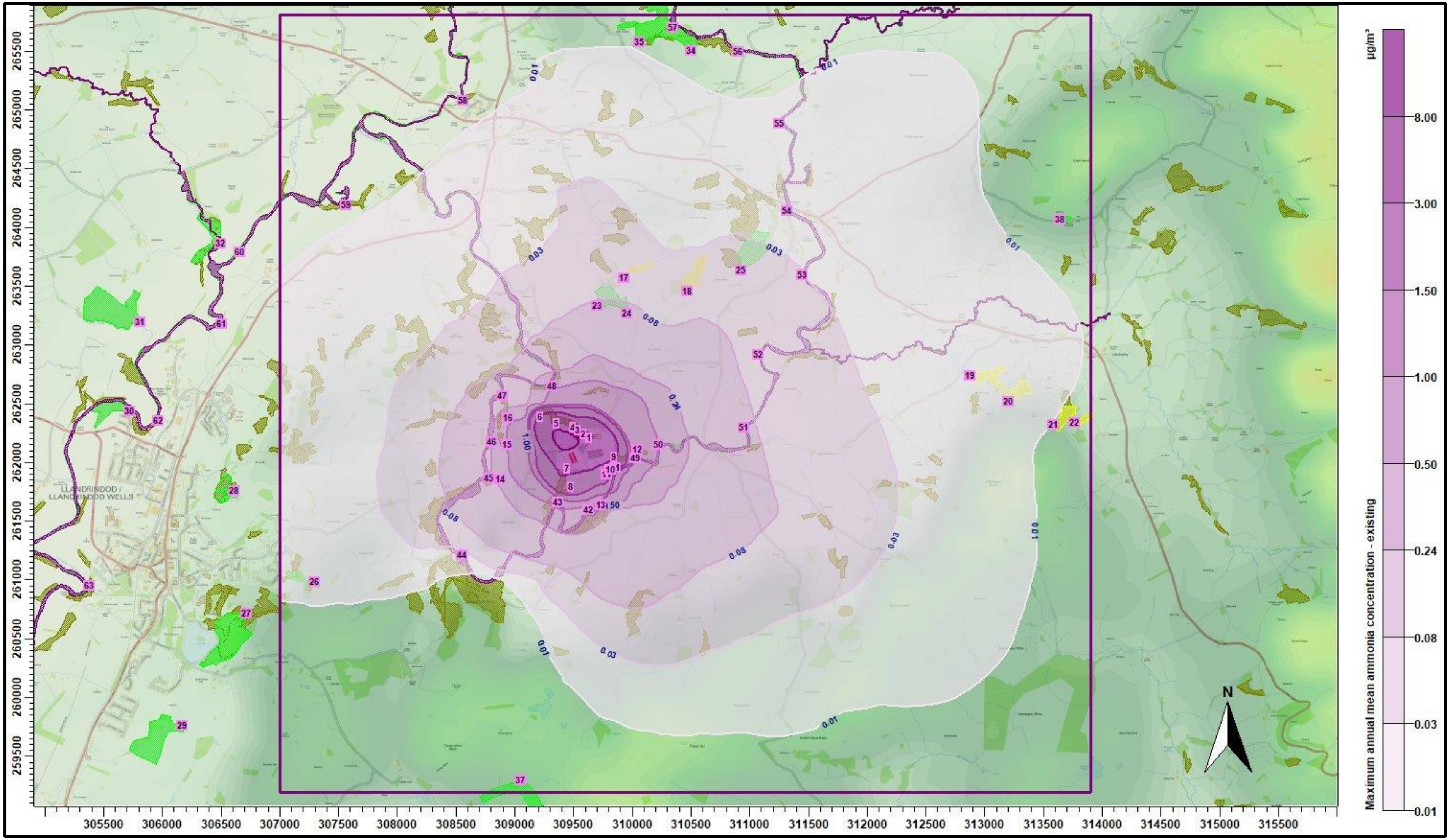


Figure 6b. Process contribution to maximum annual mean nitrogen deposition rate - existing poultry houses, 300 m horizontal resolution

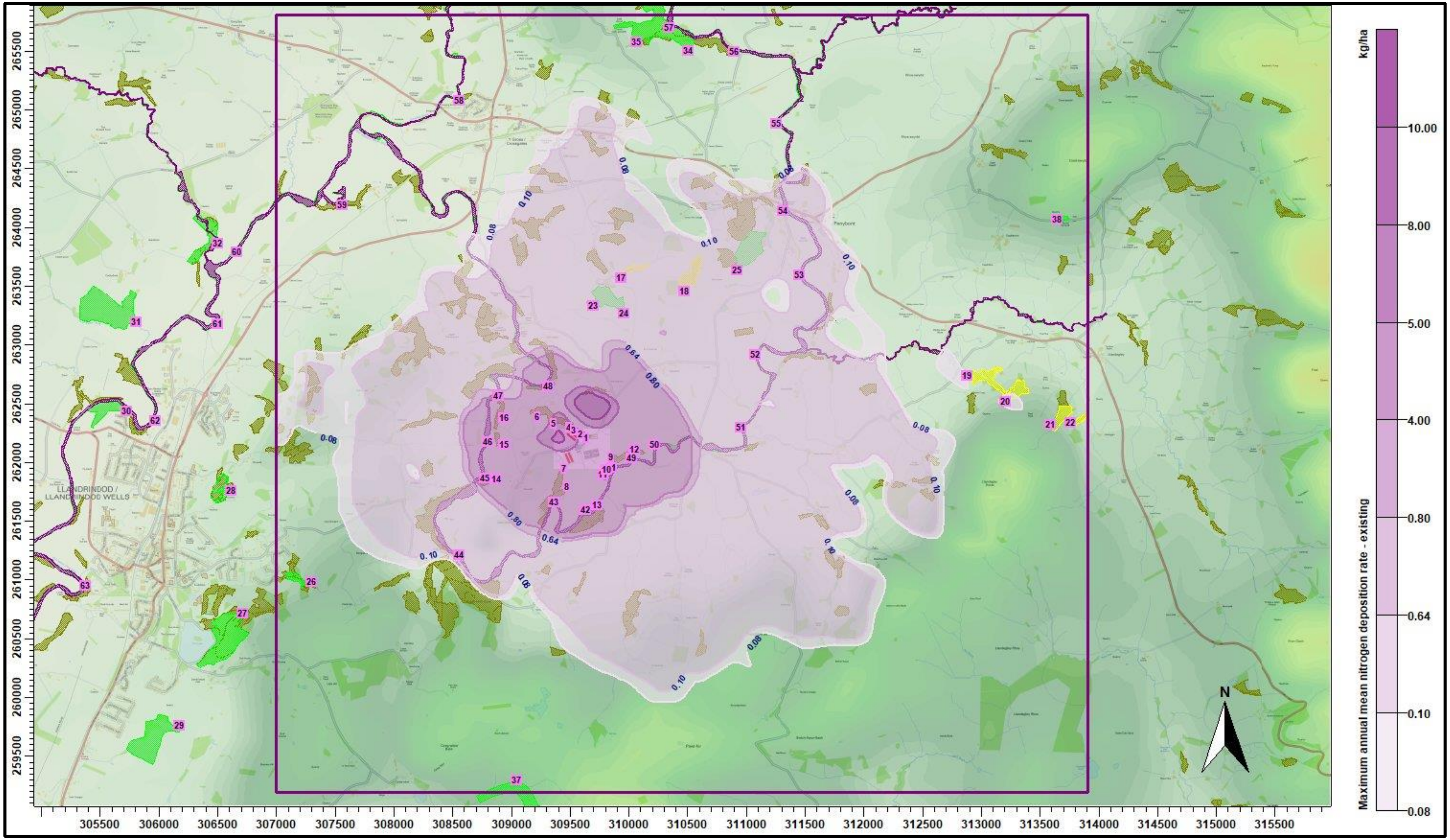


Figure 6c. Process contribution to maximum annual mean ammonia concentrations - existing poultry houses, 100 m horizontal resolution

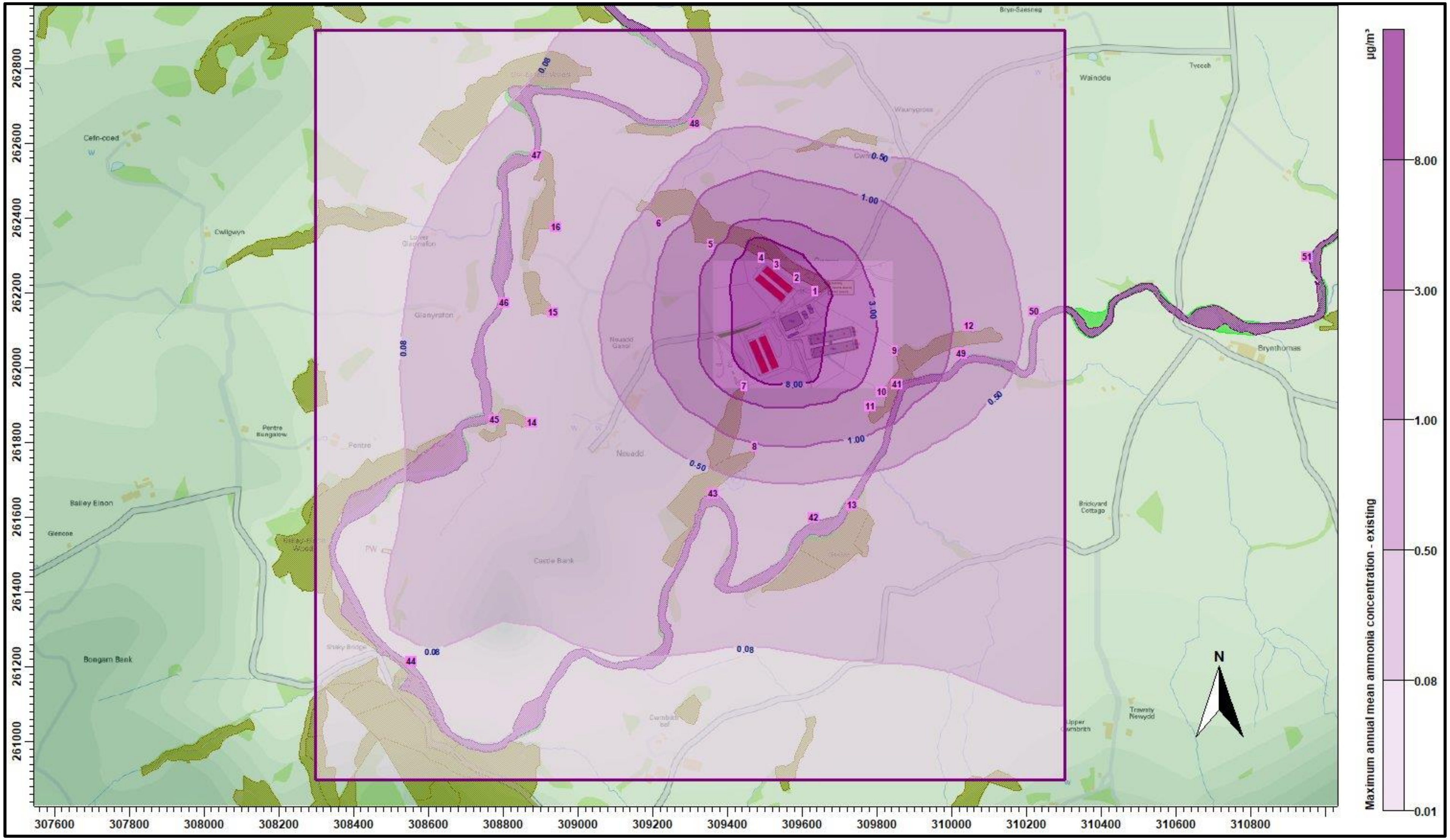
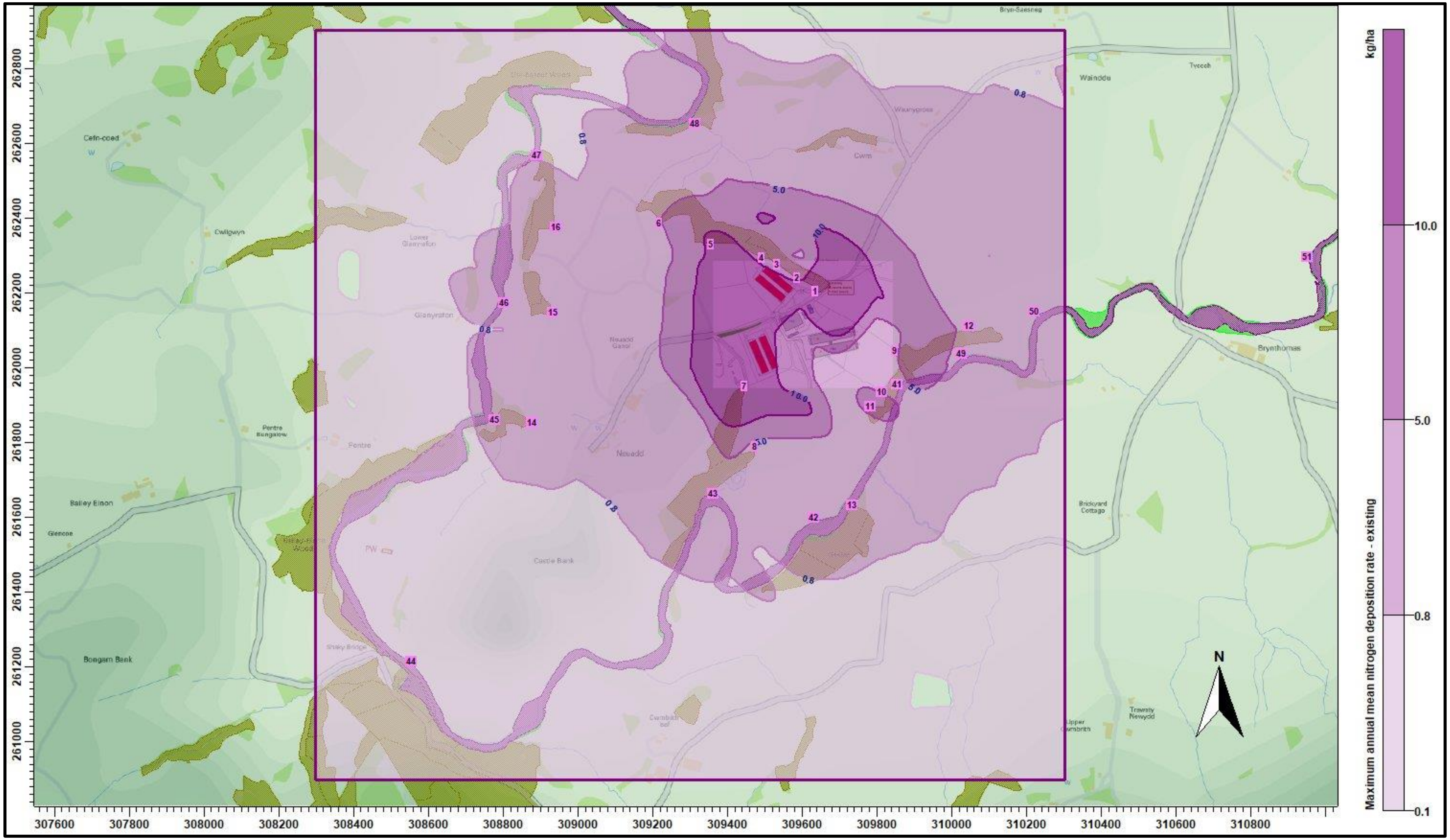


Figure 6d. Process contribution to maximum annual mean nitrogen deposition rate - existing poultry houses, 100 m horizontal resolution



© Crown copyright and database rights. 2021.

Figure 7a. Process contribution to maximum annual mean ammonia concentrations - proposed poultry houses, 300 m horizontal resolution

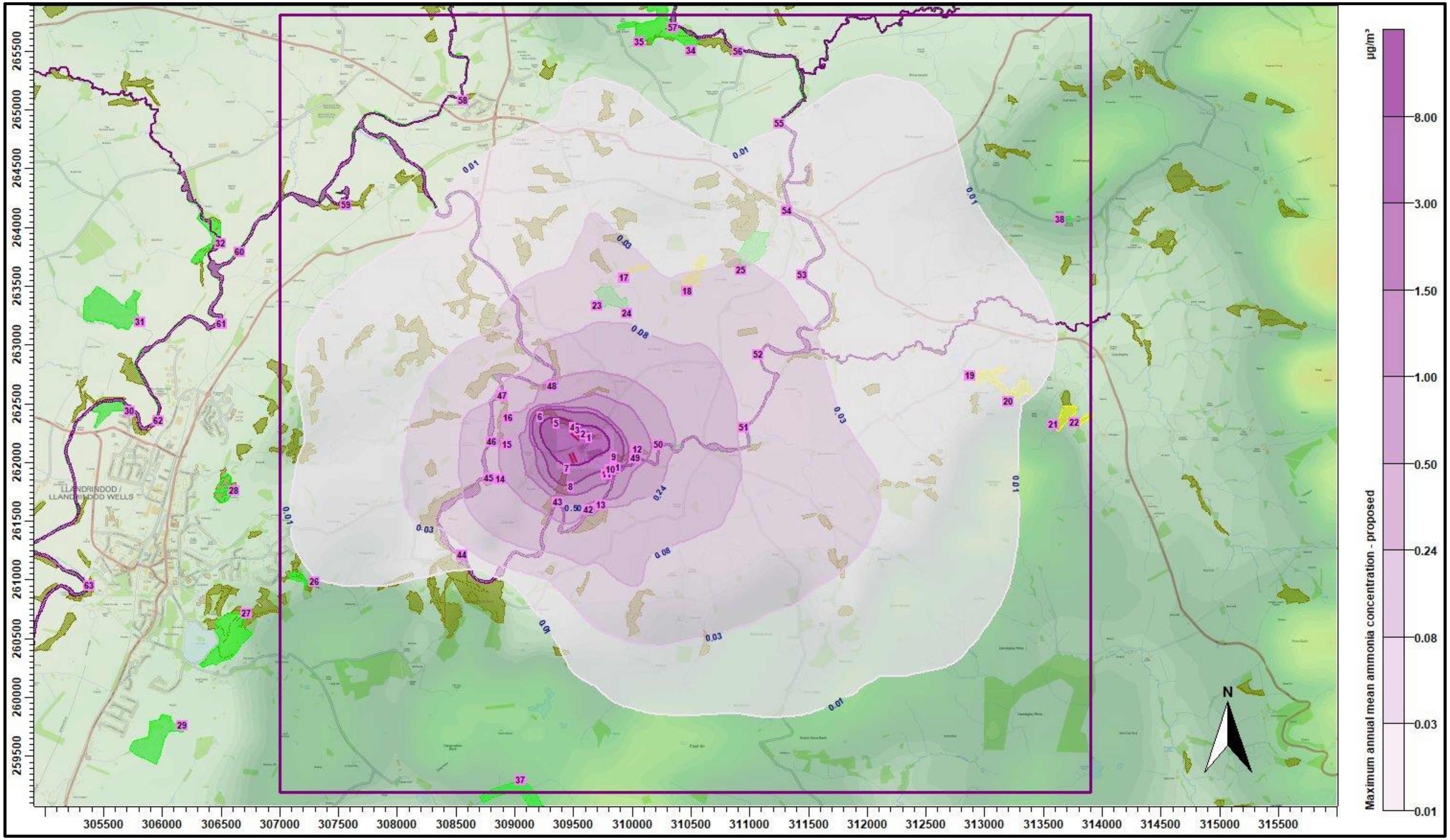


Figure 7b. Process contribution to maximum annual mean nitrogen deposition rate - proposed poultry houses, 300 m horizontal resolution

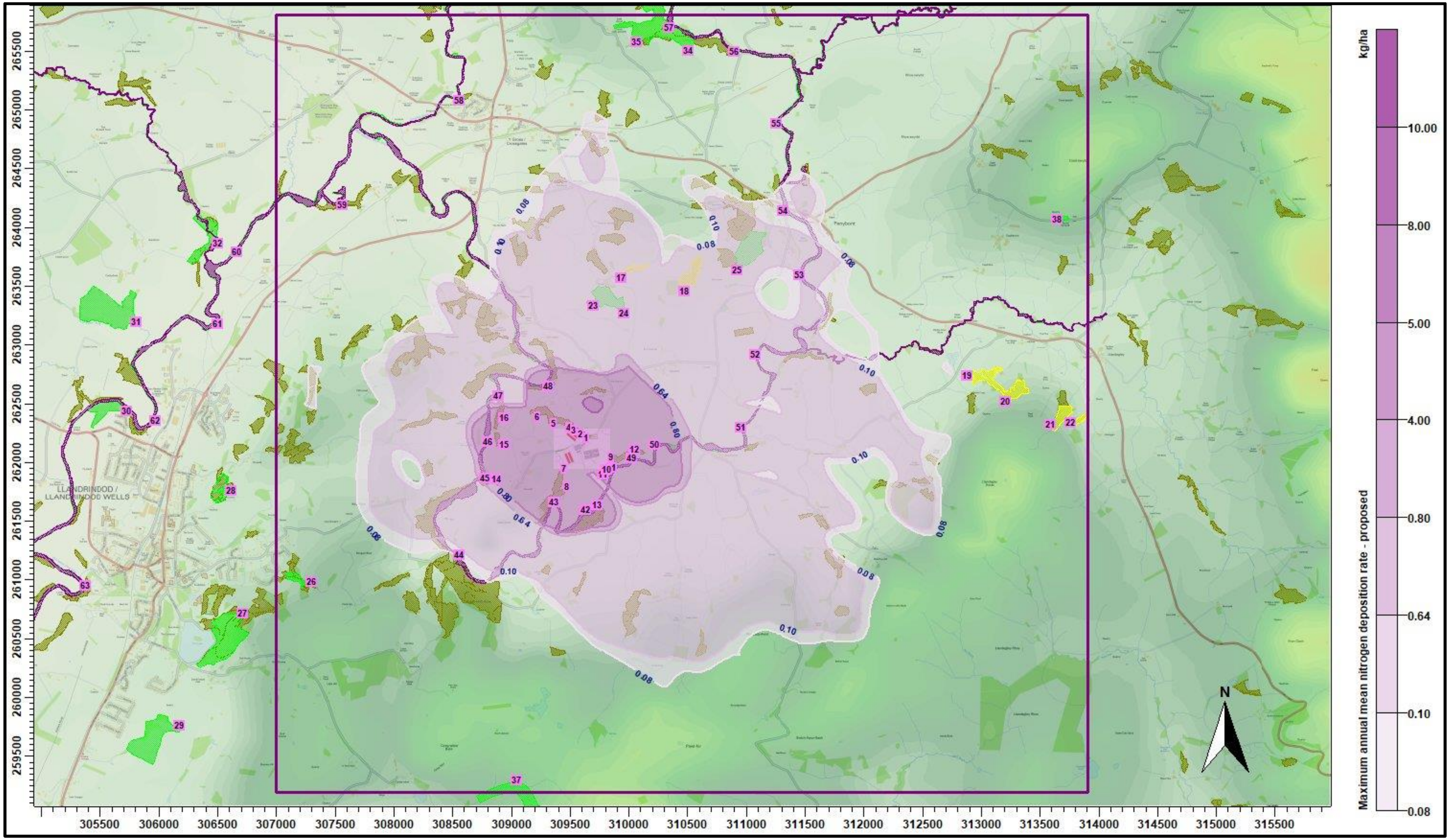


Figure 7c. Process contribution to maximum annual mean ammonia concentrations - proposed poultry houses, 100 m horizontal resolution

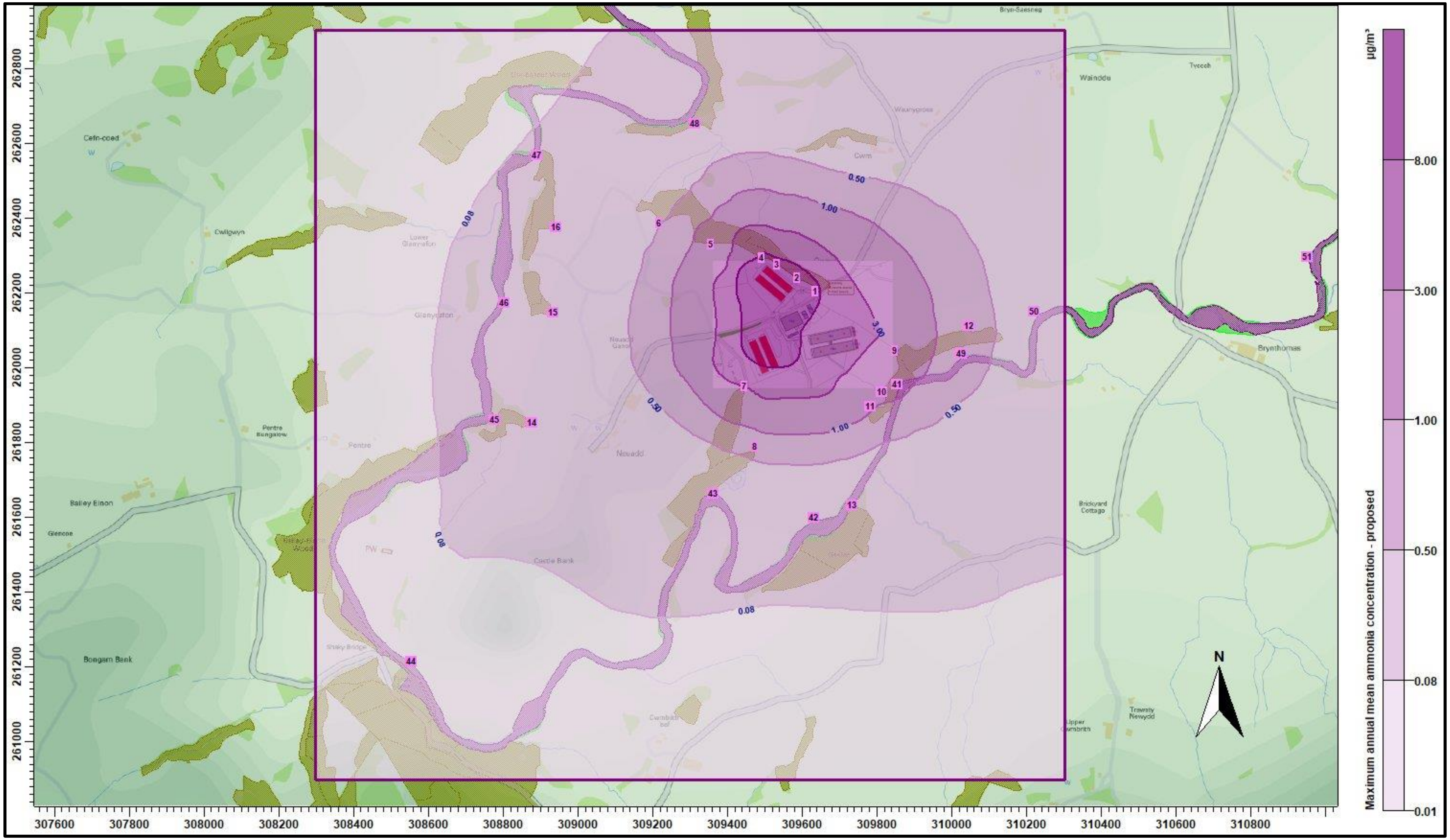
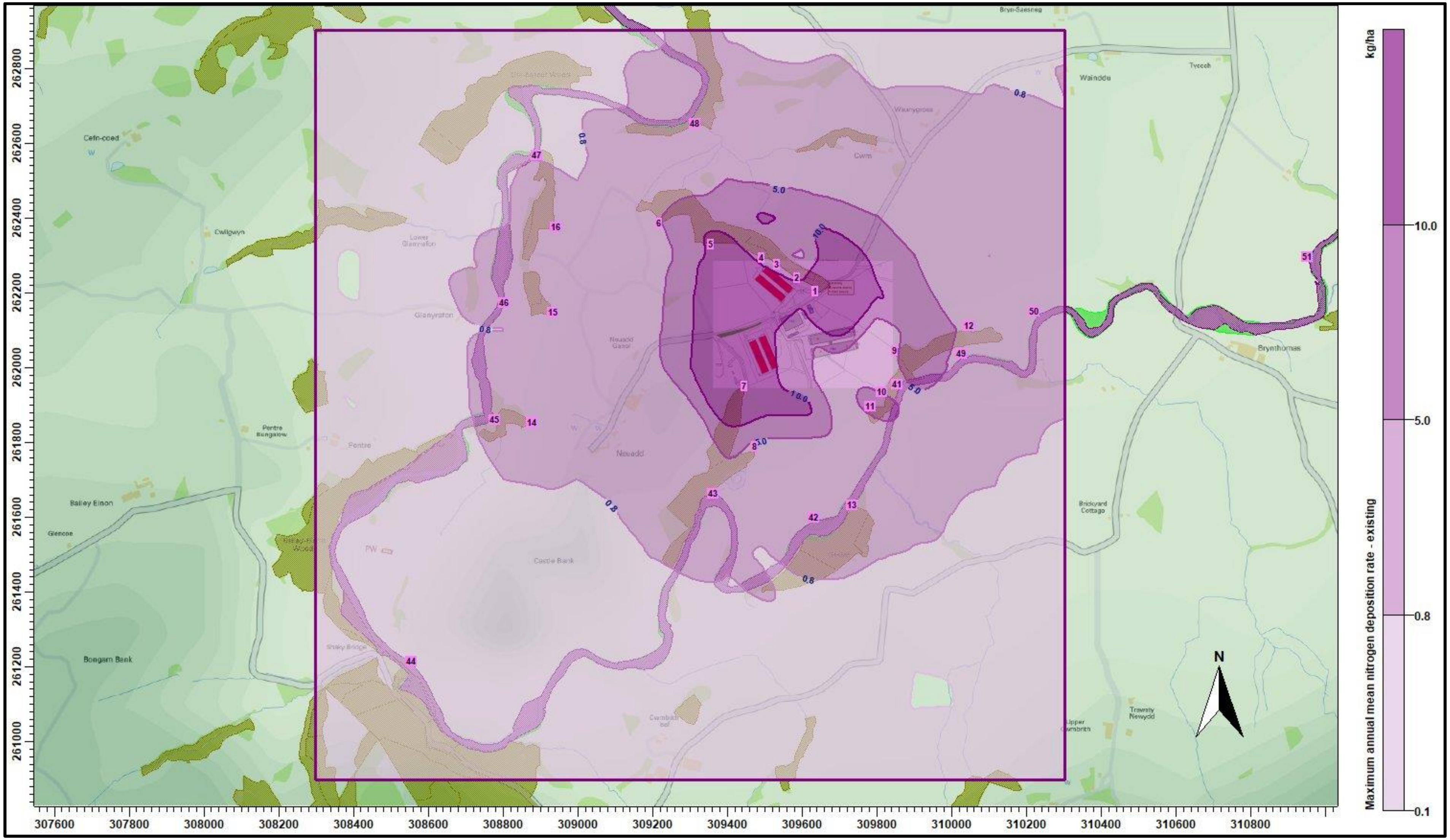


Figure 7d. Process contribution to maximum annual mean nitrogen deposition rate - proposed poultry houses, 100 m horizontal resolution



© Crown copyright and database rights. 2021.

6. Summary and Conclusions

AS Modelling & Data Ltd. has been instructed by Mr. Steve Raasch, on behalf of Mr. William Bedell, to use computer modelling to assess the impact of ammonia emissions from the existing and proposed broiler rearing houses and proposed mitigation measures at Neuadd Isaf, Penybont, Llandrindod Wells, Powys. LD1 5SW.

Ammonia emission rates from the existing and proposed poultry houses have been assessed and quantified based upon the Environment Agency's standard ammonia emission factors and also upon an emissions model that estimates emissions from the Inno+ ammonia scrubbing equipment that would be used as the primary ventilation for the proposed poultry houses. 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.

It should be noted that the modelling is for Inno+ ammonia scrubbing equipment of design and specification supplied to AS Modelling & Data Ltd. and is unlikely to be applicable to other designs and specifications. The modelling also assumes that the scrubbers are 100% operational.

Existing poultry houses

The modelling predicts that:

- At the River Ithon SSSI/River Wye SAC and at three of the ammonia sensitive AWs, Cae Llwyn SSSI and Cae Cwm-Rhocas SSSI, there are exceedances of 1% of the relevant Critical Level and Critical Load by process contributions to ammonia concentrations and nitrogen deposition rates.

- The process contribution of the existing poultry houses to ammonia concentration and nitrogen deposition rate exceeds the 100% relevant Critical Level and Critical Load at nine discrete receptors located at AWs.

Proposed poultry houses

The modelling predicts that:

- Exceedances of 1% of the relevant Critical Levels and Critical Loads at the ammonia sensitive AWs, Cae Llwyn SSSI, Cae Cwm-Rhocas SSSI and River Ithon SSSI/River Wye SAC would remain.

- The process contribution of the existing poultry houses to ammonia concentration and nitrogen deposition rate would continue to exceed 100% relevant Critical Level and Critical Load at nearby AWs.

- At all receptors considered there would be a reduction in the process contribution to both the annual mean ammonia concentrations and nitrogen/acid deposition rates.

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.

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

Natural Resources Wales. Find protected areas areas of land and sea (website).

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

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

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