# AROMA – Agri-Environment Reduction Options for Mitigating Ammonia: Assessment of the effects of RDPE environmental land management schemes on air quality

## Draft final report

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# Contents

# 1 Introduction

Atmospheric nitrogen (N) deposition represents a significant threat to habitats and species in the UK (Emmett et al., 2011; RoTAP, 2012; Natural England, 2015; Defra, 2018a; Defra, 2018b; Environment Agency, 2018). It leads to nutrient imbalances associated with eutrophication and acidification, resulting in declines in many of the key species of high conservation value at the expense of a smaller number of fast growing species that can exploit conditions of improved nitrogen supply (e.g., Dise *et al*. 2011). $NH_3$ also contributes to human health issues through its contribution to the formation of fine particulate matter (e.g. PM2.5). These threats result from emissions of ammonia ($NH_3$, mainly from agricultural sources) and nitrogen oxides ($NO_x$, mainly from transport, industry, power generation and other combustion sources). Substantial efforts in UK and European policies over the last decades have reduced $NO_x$ emissions considerably, whereas, so far, much less has been achieved in reducing $NH_3$ emissions (RoTAP, 2012; National Atmospheric Emission Inventory[1]). Furthermore, $NH_3$ emissions to the atmosphere from livestock manures and mineral fertilisers also represent a loss of nutrients that could otherwise benefit crop growth. The implication is that mitigation of $NH_3$ emissions provides potential cost savings to the agricultural sector in parallel with environmental benefits for human and ecosystem health.

The Rural Development Programme for England (RDPE) funding of environmental land management schemes and other grants (Environmental Stewardship, Countryside Stewardship, English Woodland Grant Scheme) includes options/measures (referred to as *measures* throughout this report) that are relevant for $NH_3$ and N, even if they are not directly targeted at reducing atmospheric $NH_3$ or N deposition to sensitive habitats. Other schemes, such as the Countryside Productivity Scheme and the Farming Ammonia Reduction Grant (FARG) have relevant $NH_3$ reduction measures, including low-emission slurry application systems, air scrubbers and heat exchangers for pig and poultry housing, poultry litter drying systems, slurry store covers and advice on reducing $NH_3$ emissions and N use efficiency (N.B. No data on one-on-one advice provided were made available for this study). A qualitative analysis of the 2007-2014 Environmental Stewardship Scheme under *Defra project AC0109* (*Ammonia Future Patterns*, Dragosits *et al*. 2014) found that related measures such as buffer zones, conversion to low N management or semi-natural vegetation could be spatially targeted near sensitive habitats/designated sites, to help reduce N input to these semi-natural systems. It was concluded that the most environmentally effective land management measures would be those that deliver multiple benefits, including more specific $NH_3$ measures as well as co-benefits on nutrient use efficiency, greenhouse gas emissions, water quality and biodiversity. Similarly, previous Defra funded work under *AC0201* (*Agroforestry for ammonia abatement*, Bealey *et al.* 2012) explored the potential of spatially targeted woodland grants as a measure to reduce N emissions through sheltering of sources and deposition to sensitive habitats by recapturing, diluting and dispersion of atmospheric $NH_3$. These schemes have not been fully evaluated in this study as to their effectiveness for air quality improvements and the protection of sensitive habitats, as the available scheme datasets do not record local $NH_3$ relevance and woodlands have not been designed with $NH_3$ mitigation in mind under previous and current schemes.

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http://naei.beis.gov.uk/[1]

**Objectives**

The objectives of the project, listed below, match with the six required tasks outlined in the project specification: this

1. To assess the scheme measures available in England for relevance for $NH_3$ mitigation and quantify the mitigation potential of the identified relevant measures (Countryside Stewardship 2016-2017, Countryside Productivity Scheme 2016-2017, Farming Ammonia Grant Scheme 2017, Environmental Stewardship ELS/HLS from 2006-2015, Woodland Grant Scheme 2011-2016)
2. To assess the uptake of the identified measures relevant for $NH_3$, including identification of any obvious trends by farm type, size or spatial location, across England
3. To assess the spatial patterns of uptake of the identified measures, in relation to sensitive habitats, designated sites and priority areas for action to reduce $NH_3$
4. To estimate the benefits of the measures on $NH_3$ emissions and concentrations, locally and nationally
5. To carry out farm case studies, demonstrating how $NH_3$ emissions can be reduced alongside other benefits of the schemes, record farmer experience and highlight wider benefits of $NH_3$ measures
6. To consider options for future scheme designs, for optimising $NH_3$ mitigation, including costs, benefits for the environment and farmers, and interactions with other environmental objectives, at different levels of uptake.

Measures available under agri-environment and grant schemes were assessed for their $NH_3$ mitigation potential. The agri-environment and grant schemes investigated in this study are as follows:

1. **Countryside Stewardship** (including high tier, mid-tier and capital grants including woodland grants): 2016-2017, administered by Natural England and the Forestry Commission and the Rural Payments Agency.
https://www.gov.uk/government/collections/countryside-stewardship-get-paid-for-environmental-land-management
2. **Countryside Productivity Scheme** (including the large and small grants): 2016-2017 administered by the Rural Payments Agency.
3. **Farming Ammonia Grant Scheme**: 1 December 2016 to 30th September 2017, administered by Natural England and the Rural Payments Agency
https://www.gov.uk/government/publications/farming-ammonia-reduction-grant-scheme-claim-form-and-offer-terms
4. **Environmental Stewardship** (including ELS/HLS from 2012, but using data on individual measures implemented 2006-2015 as provided by NE):
http://webarchive.nationalarchives.gov.uk/20140605104008/http://www.naturalengland.org.uk/ourwork/farming/funding/es/default.aspx
5. **English Woodland Grant Scheme**: 2005 to 2015, administered by the Forestry Commission (data provided by FC covered the years 2011-2016).
https://www.forestry.gov.uk/ewgs

# 2 Methodology

## 2.1 Task 1 - Identification of ammonia-relevant scheme measures

Using the schemes' guidance notes and description of measures, all listed measures were screened to identify those that can help to reduce $NH_3$ emissions at source or re-capture emissions (as a secondary measure for reducing atmospheric concentration or deposition, such as tree belts planted under the Woodland Grant Scheme). The resulting list of measures has been tabulated, with short descriptions of the expected benefits of reductions in $NH_3$ emissions, the scheme(s) they are included in, and other relevant information such as grouping the measures to enable filtering and sub-setting for a wide range of purposes, as well as summary statements by groups of measures (e.g. type of option: land use conversion, wildlife, crop management, buffers & margins, tree/hedge planting etc.). The detailed table is supplied electronically as Annex 1 to the project report.

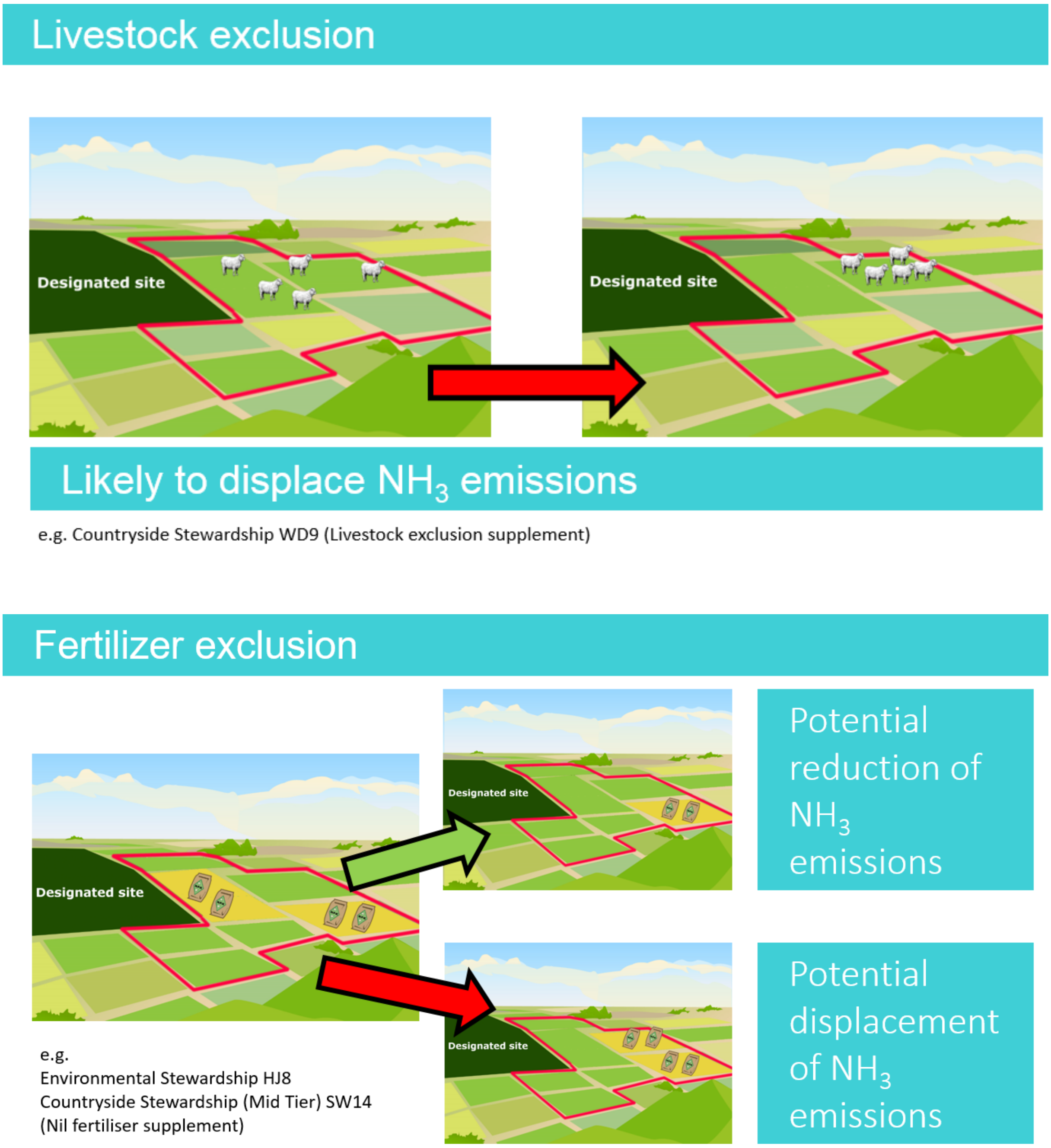
### *2.1.1. Task 1a – Assessment of scheme measures for ammonia relevance*

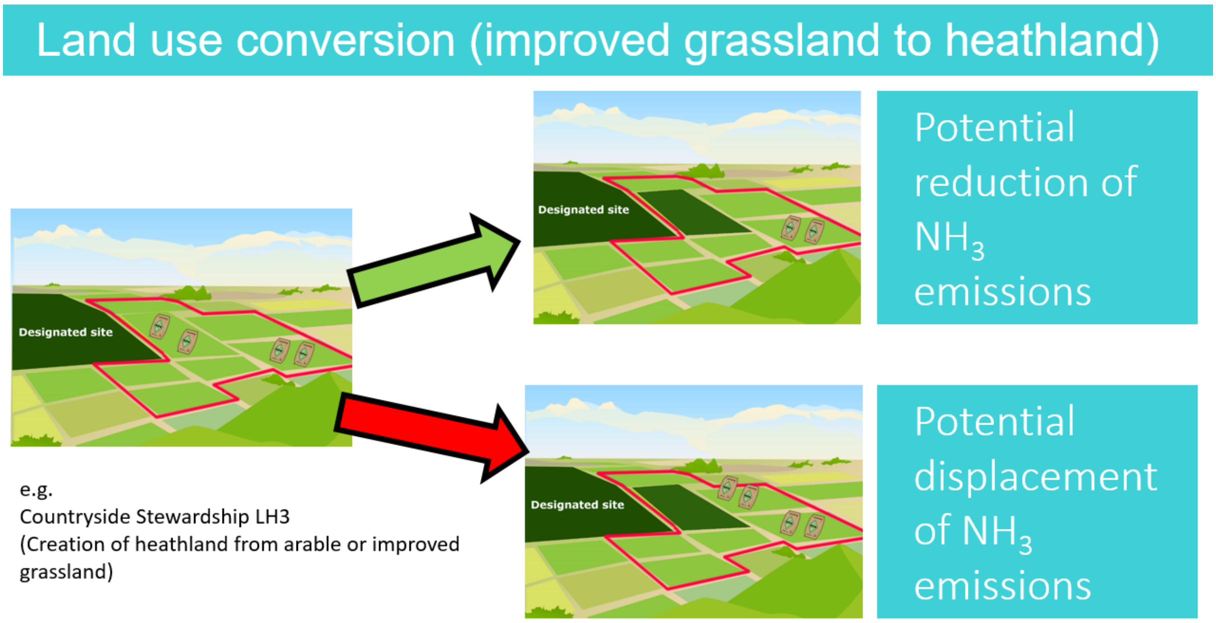
All measures were assessed and categorised in terms of their $NH_3$ relevance. Measures were considered to be $NH_3$ relevant if they achieved any of the following N reductions:

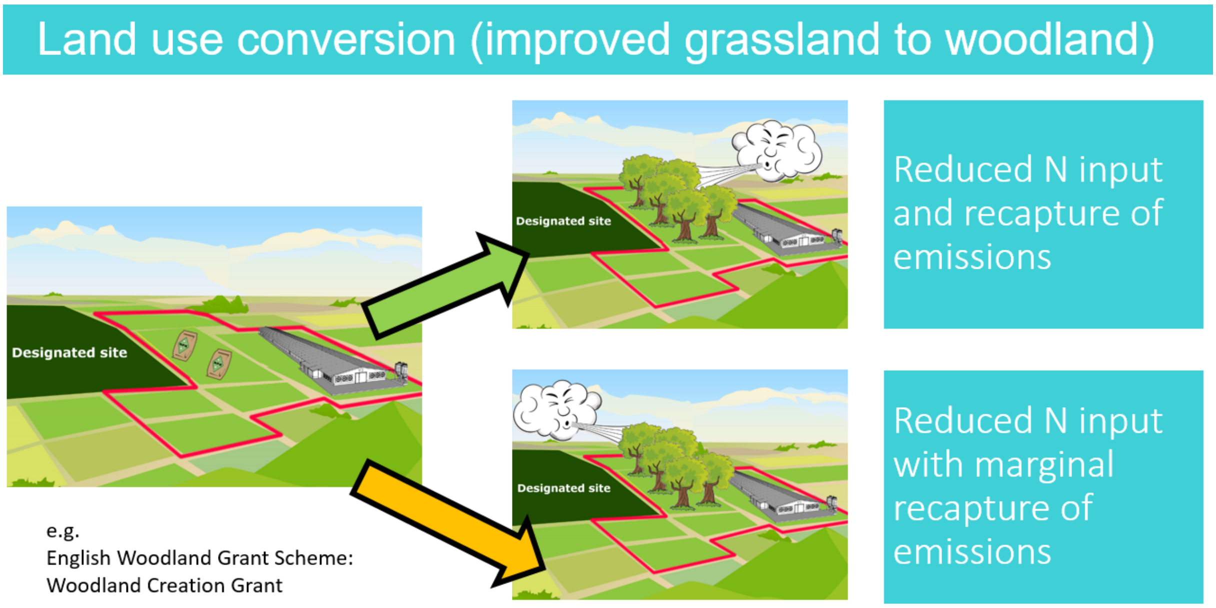
- Reduced N inputs from mineral fertiliser application
- Reduced N inputs from manure/slurry application
- Reduced emissions at source (i.e. slurry store covers)
- Reduced emissions associated with livestock (e.g. livestock exclusion)
- Recaptured atmospheric $NH_3$ (as a secondary measure for reducing atmospheric concentration or deposition, such as tree belts planted under the Woodland Grant Scheme)

Some measures are difficult to quantify in terms of their $NH_3$ relevance, as they may result in emission reductions at a field level but are compensated for elsewhere on the farm, rather than resulting in net reductions at a farm level. However, such measures may still be useful if they reduce emissions next to designated sites and displace them to a location further away. Some examples are illustrated in Figure 1 below. Local environmental conditions (such as prevailing wind directions) may also influence whether a measure has a substantial impact on reducing atmospheric N input to designated sites.

**Figure 1**: Examples of net and gross reductions of $NH_3$ emissions at a field/farm level and their potential impact on nearby designated sites. Red arrows indicate displacement, green arrows indicate reduction, and yellow arrows indicate recapture. The farm extent is indicated by the red boundary line.






**Ammonia relevance** was grouped into the following six categories of ammonia relevance:

- **Direct benefit:** These measures are likely to reduce $NH_3$ emissions in the local area to where they have been installed (e.g. slurry tank cover, reduction in mineral or organic N application). However, such reductions may be offset, for some measures, by intensification elsewhere on a farm, and therefore gross and net reductions may not be equal. Ammonia benefits may be achieved through any of the mechanisms of reduction outlined above (this section).
- **Negligible:** These measures are unlikely to produce any significant benefits in terms of reductions in $NH_3$. Examples include badger gates, educational access, fencing, restoration of historic buildings etc. Some of these measures may have very minor

$NH_3$ relevance depending on circumstances, e.g. skylark plots will be temporarily excluded from agricultural management, cattle drinking bays may be influencing the preference of cattle for a particular part of a field, etc. However, at a national level this would be very marginal and therefore these measures will not be considered in detail in Tasks 2-6.

- **Potential reduction:** These measures have the potential to reduce $NH_3$ through any of the ammonia reduction mechanisms outlined above. These measures may include temporary livestock exclusion or taking small areas of land out of production and are therefore likely less effective at a local level than the measures considered to be 'Direct' in terms of $NH_3$ relevance. With regard to national-scale effects, these measures are assessed in terms of uptake under Task 2, to check whether there is sufficient area managed under these measures to make a difference.
- **Potential recapture**: These measures are associated with the planting of trees or woodland which may provide some recapture of atmospheric $NH_3$ that has been emitted from local or regional sources. The recapture effectiveness depends on the design of the woodland (shape, height, tree species, density, backstop (dense vegetation buffer), etc.) and its relative location respective to a local source and/or sensitive site, prevailing wind direction, etc. As the guidelines for such measures are not set out to provide $NH_3$ benefits, any benefits from woodland creation under the schemes are difficult to assess and quantify except for any detailed case studies where recapture potential has been assessed with local information, and regional upscaling of benefits for quantifying benefits in terms of the reduction of $NH_3$ concentrations or N deposition is not possible.
- **Potential increase in ammonia impacts:** These measures have the potential to increase atmospheric $NH_3$ impacts. These are typically measures associated with the removal of trees or woodland which may have provided some recapture of atmospheric $NH_3$ that has been emitted from local or regional sources.
- **Unquantifiable:** The $NH_3$ increase/reduction achieved by measures is highly dependent on local circumstances and therefore it is not possible to quantify and summarise their $NH_3$ relevance nationally (see Figure 1 above). Such measures may include managing land organically, which may be associated with higher or lower $NH_3$ emissions compared with the previous management practice (which is not recorded in terms of mineral and/or organic fertilisers applied).

Additionally, all listed measures were grouped, in terms of measure type/original purpose (e.g. buffer zones, land use conversion, invasive species control) and land use type (e.g. arable, grass, coastal, woodland).

### 2.1.2. Task 1b – Quantification of mitigation factors for ammonia-relevant scheme measures

The measures identified under Task 1a were assessed for the likely % reduction in emissions (or deposition) that is estimated to be achievable, using the Defra Mitigation Methods User Guide (Newell-Price et al. 2011; Defra project WQ0106) and the UNECE ammonia guidance document (Bittman et al. 2014). These figures are typically representative for the measure, however in practice will vary depending on local circumstances and the management practice in use before a measure was implemented in a particular land parcel or at a facility/site/feature. The % reduction estimates were added to the table of measures prepared under Task 1a and form Annex 1 to the project report (in electronic form).

This assessment was carried out for all measures considered to be $NH_3$ relevant under Task 1a, i.e. those which were not considered to be “negligible”, “unquantifiable” or may cause a “potential increase”. As detailed above, the latter refer to the removal of trees and their recapture potential for $NH_3$ emitted locally. Many of the measures identified as having a direct or potential reduction in emissions are associated with taking land out of production (e.g. buffer strips) or changing the management of land continuing to be used for agriculture (e.g. limiting nitrogen inputs). Emission reductions associated with these measures were related to the reduction in agricultural N inputs. Where land was taken out of production for an alternative use, this was assumed to be 100% reduction in agricultural inputs and therefore in emissions from that specific land area. Where management changes in terms of N inputs were stipulated, some assumptions had to be made regarding prior management (and N input level) of that land to provide an estimate of reduction in N input and emission. Where more specific $NH_3$ emission reduction measures are included (e.g. slurry store covers) then the direct mitigation effect associated with the specific measure was applied.

## 2.2. Task 2 – Assessment of uptake of ammonia relevant scheme measures

For all measures identified under the schemes investigated under Task 1, information was collated on their current uptake, using data that were made available by Natural England (NE), the Forestry Commission and the Rural Payments Agency (adhering to the data licensing conditions). The data were imported into a GIS and analysed for the total area managed under the different measures/number of grants (or other quantitative units, depending on the measures).

Quality checks were carried out on the data, to ensure that they were fit for purpose and compatible with other datasets. This included checking for data-gaps and ensuring every record had an area/length associated with it. The point locations of the FARG scheme were checked to ensure that the location corresponded to the measure location (i.e. a slurry store or lagoons). A large proportion of the FARG locations needed to be corrected, this was achieved with input from the FARG data custodian at Natural England. The FARG dataset was also modified so that records containing information about multiple stores was separated to enable calculations to be made for individual slurry stores.

Uptake was assessed for all measures identified in Task 1. The data table for assessing all measures (Annex 1) was based on the annual scheme guidance handbooks (as outlined under Task 1 and in the tender documentation), however there were some additional measures in the GIS data that had not been captured in the initial Annex 1 table. Most of these measures were variations on earlier/later versions that had either been changed slightly or discontinued. These measures were added into the table and also assessed for their ammonia relevance. The GIS data supplied could not be linked to information on farm type, as originally envisaged in the tender, as it did not use the same farm identifier as that used in the holding level agricultural census data Therefore it was not possible to summarise the uptake of measures by farm type as planned, due to data licensing issues, and the uptake of measures could not be associated with different agricultural sectors.

The database on the uptake of measures includes a number of multiple applications for the same measure over multiple years in some instances, These data points were retained as it was not possible to distinguish between fields that contained the same measure in multiple locations (e.g. taking field corners out of management) and measures that apply to the same part of the land parcel over multiple years/applications. The implications of this are likely to be very minor and are discussed further in Section 3.2.

## 2.3. Task 3 - Assess uptake of ammonia relevant scheme measures relative to sensitive receptors

Following on from Task 2, the available spatial data on measures relevant for $NH_3$ were overlaid in GIS with spatial datasets on the location of sensitive habitats in England and the location of designated sites (in particular SACs, SSSIs, SPAs and RAMSAR sites). The location of each measure was represented by a single point for all schemes except for FARG where the location of each slurry store cover was represented by a polygon. For FARG, the centroids of the small polygons were used to determine the distance to the closest part of the designated site. The spatial relationships between uptake of measures and proximity to sensitive receptors have been quantified for distances of 2, 5 and 10 km, as illustrated in Figure 2 for Walton Moss SAC. Trends in the uptake of $NH_3$ relevant measures in relation to areas with sensitive receptors will be summarised in tabulated and/or graphic format.

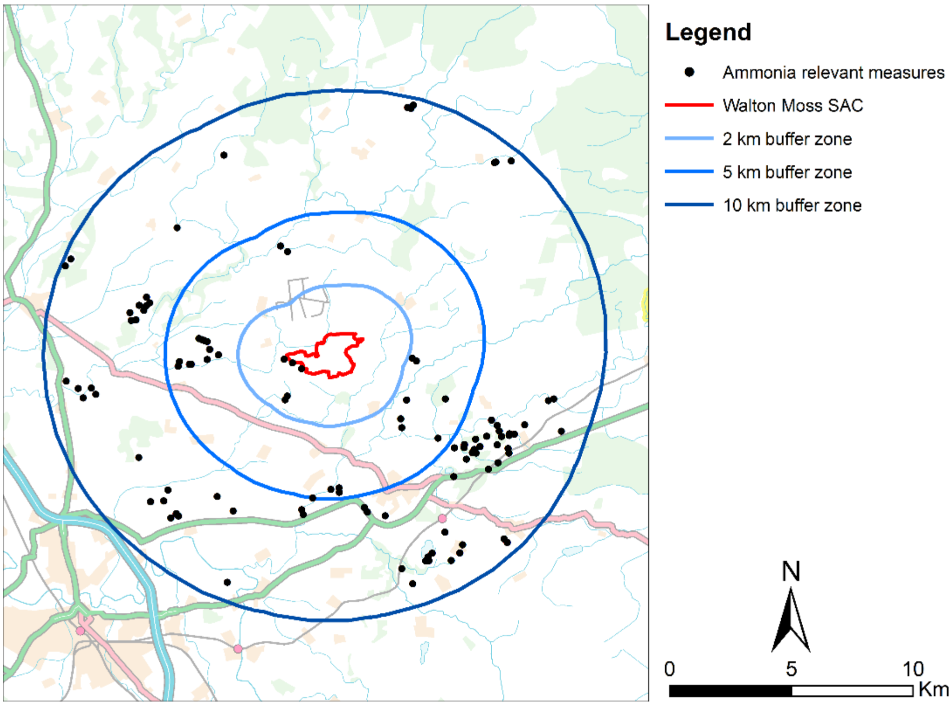



**Figure 2** – Measures surrounding Walton Moss SAC within buffer zones of 2, 5 and 10 km. N.B. several measures may share the same location.

## 2.4. Task 4 – Estimation of air quality benefits from ammonia relevant measures at the local/national scale

Air quality benefits were assessed for measures identified as achieving a quantifiable $NH_3$ reductions in Task 1. These measures are those that deliver a direct or potential reduction, which could be quantified at a national scale. This therefore excludes measures which were identified as 'unquantifiable', i.e. the lack of agricultural management information prior to uptake means that it is impossible to quantify the $NH_3$ benefits for the measure locally or nationally. Similarly, measures that provide potential recapture of $NH_3$ emissions were excluded from this assessment, as their effectiveness depends on the design of the tree plantings (size/area, shape, height, tree species, density etc.), their relative location respective to local sources and receptors, and local wind patterns, among other constraints. Woodlands designed specifically to reduce $NH_3$ emissions from a nearby source can be very effective (Bealey et al. 2016), however $NH_3$ relevance has not been a criterion in current and recent woodland schemes.

The majority of measures identified as delivering a quantifiable reduction in $NH_3$ were associated with taking areas out of production, reducing mineral fertiliser inputs by a specified amount and covering slurry stores.

Measures associated with taking areas out of production include the creation of buffer strips and reverting arable land to less intensive or different production. By taking these areas out of production, $NH_3$ emissions associated with mineral fertiliser application are reduced. This reduction was quantified by calculating the typical emissions associated with the land prior to implementation, using average mineral fertiliser application rates for England from the British Survey of Fertiliser Practice (BSFP, 2016) and average $NH_3$ volatilisation rates from Misselbrook et al. (2016). For example, N fertiliser input reduction due to the creation of buffer strips in a maize field was calculated using the average N fertiliser N input for England of 61 kg N $ha^{-1}$ $yr^{-1}$. Where a measure is applicable to "arable" fields, with no crop type specified, the fertiliser reduction was calculated for an average arable crop (i.e. weighted by crop type & respective average N input across all crops grown in England). For land use conversion measures, such as measures associated with arable reversion, N application reductions were applied as specific to the prior land use as possible. For a large number of measures, the handbooks did not specify what land use they could be applied to however, for these measures a weighted average N application rate from all arable and grassland present in England was applied.

For measures associated with covering slurry stores and lagoons, emission reductions were estimated following work by Misselbrook et al. (2005) and Bittman et al. (2014). Uncovered slurry stores are estimated to release 3.42 g $NH_3$-N $m^{-2}$ $day^{-1}$, with a 50 % emission reduction for stores with a natural crust (Misselbrook *et al.* 2005). The UK agricultural emissions inventory (Misselbrook *et al.* 2016) estimates that 80 % of slurry stores have a natural crust; therefore on average a slurry store produces 2.05 g $NH_3$-N $m^{-2}$ $day^{-1}$. Fitting a tight lid, roof or tent structure to a slurry store, such as those fitted under the FARG scheme, is estimated to provide an 80 % reduction in $NH_3$ emissions released from stores, and floating covers for slurry lagoons offer a 60 % reduction in emissions (Bittman et al. 2014).

A quantitative assessment of $NH_3$ emission reductions due to relevant agri-environment scheme measures was carried out by comparing UK $NH_3$ emissions with and without $NH_3$ relevant measures present, and their impacts on atmospheric $NH_3$ concentrations, N deposition and effects assessment for sensitive vegetation. The assessment methodology described here uses the expression "scenario" to mean a consistent picture based on assumptions rather than potential futures.

The baseline scenario (S0) estimates agricultural emissions without reductions achieved by $NH_3$ relevant measures, and S1 estimates agricultural emissions with the current uptake of $NH_3$ relevant measures for the schemes considered in this study. S1 therefore includes emission reductions from FARG slurry store covers, land taken out of production (land use conversion) and reductions in fertiliser applications from all $NH_3$ relevant measures identified under Task 1, with uptake quantified under Task 2. S0 discounts any $NH_3$ emission reductions from those measures. In practice, the current best estimate of agricultural $NH_3$ emissions that these calculations are based on (year 2015), as reported by Misselbrook et al. 2016 and mapped for the National Atmospheric Emission Inventory (naei.beis.gov.uk, see Carnell et al. (2017) for details) lies somewhere in between S0 and S1, as land taken out of agricultural use (e.g. arable reversion to unfertilised semi-natural land) would have already not been counted as part of productive and fertilised crop area in the relevant agricultural statistics. Conversely, the emission inventory methodology did not take account of slurry store covers, as FARG and Countryside Stewardship-funded measures post-date the 2015 inventory calculations. Agricultural $NH_3$ emissions were calculated with the 2015 NARSES model (Webb and Misselbrook 2004, Misselbrook et al. 2004), using the UK national $NH_3$ emission inventory as a basis. The official agricultural $NH_3$ emission inventory is based on data from the June Agricultural Survey (JAS) and average agricultural management practice for each of the countries of the UK (i.e. England, Wales, Scotland and Northern Ireland). The JAS includes information on livestock populations and areas of crops and grassland.

Spatial emission patterns were estimated for England using methods described in Carnell et al. (2017) and using the Atmospheric Emissions for National Environmental Impacts Determination (AENEID) model (Dragosits et al. 1998, Hellsten et al. 2008), aggregated to a 5 km grid to avoid disclosivity. The resulting agricultural emission maps for England were combined with data for the rest of the UK from the official 2015 emission inventory. Together with the non-agricultural $NH_3$ emission maps, $NO_x$ and $SO_2$ maps from the UK National Atmospheric Emission Inventory these data were used as input to the UK FRAME (Fine Resolution Atmospheric Multi-pollutant Exchange) model (Fournier et al. 2005, Dore et al. 2007, Matejko et al. 2009, Vieno et al. 2010, Hallsworth et al. 2010, Dore et al., 2012). The FRAME model is an atmospheric chemistry transport model, which simulates the emissions of N and S compounds, their vertical diffusion and horizontal transport, atmospheric chemical transformation and deposition to the surface by wet and dry processes. The model calculates annual average gas and aerosol concentrations and deposition for compounds of nitrogen and sulphur as well as base cations and heavy metals. For this project, the analysis focused on $NH_3$ concentrations and total N deposition.

The FRAME model was run for S0 and S1, at a 1 km grid resolution for $NH_3$ concentration estimates and a 5 km grid resolution for deposition estimates, using the calibrated version, i.e. scaled to the UK national monitoring network.

To assess the risk of environmental impacts on sensitive habitats and species by atmospheric $NH_3$ concentrations and N deposition, the critical thresholds of pollutant concentrations and deposition fluxes (CLE, CL) developed by United Nations Economic Commission for Europe (UNECE) were used. A Critical Level is the pollutant concentration in the atmosphere above which plants or ecosystems may be directly negatively affected, according to current knowledge (Nilsson and Grennfelt 1988, UBA 2004). The most recent long term critical levels for $NH_3$ (Cape et al. 2009, Sutton et al. 2009; UNECE 2007) are 1 µg $NH_3$ $m^{-3}$ for the most sensitive ecosystems, i.e. where lichens and bryophytes are part of the ecosystem integrity, and 3 ± 1 µg $NH_3$ $m^{-3}$ for higher plants in other semi-natural ecosystems. A Critical Load is a pollutant deposition below which no significant harmful effects on the environment are expected to occur according to current knowledge (Nilsson and Grennfelt 1988, UBA 2004). Nitrogen (N) CLs have been defined for specific ecosystem types (see Bobbink and Hettelingh (2011) for most up-to-date values). In contrast to the CLE approach, which is specifically defined for gases such as $NH_3$, the CL approach integrates all forms of reactive N and therefore requires estimates of total N deposition.

Ammonia concentration maps were compared with the Critical Levels that have been defined from ammonia. Exceedance of both of the 1 and 3 µg $NH_3$ $m^{-3}$ limits were calculated for every 1 $km^2$ grid cell containing at least one ammonia-sensitive habitat, and also for designated sites. A full description of the methods used to define habitats sensitive $NH_3$, and to calculate exceedances, is given in Hall et al. (2015).

Maps of nitrogen and deposition rates were compared with Critical Loads for acidity and nutrient-nitrogen. Critical Load exceedances were estimated on an area basis (1 x 1 grid-cells that contain at least one nutrient-nitrogen sensitive habitat) and a site basis, separately for Special Areas for Conservation (SACs), Special Protection Areas (SPAs), and Sites of Special Scientific Interest (SSSIs). A full description of the methods used to define habitats sensitive to ammonia and atmospheric nitrogen deposition, to assign critical loads to sites and habitats, and to calculate critical load and level exceedances, is given in Hall et al. (2015).

## 2.5. Task 5 – Farm case studies

Together with the Steering Group, it was agreed that at least one case study would be carried out for each of the schemes, for farms that have taken up one or more $NH_3$ relevant measures. Potential study farms were chosen in collaboration with the Steering Group, who facilitated **contact with farmers and local stakeholders** such as NE/CSF staff. Where more than one case study was offered for a scheme, the most relevant farms were selected from a short list, balancing the need for at least one case study per scheme and a total of no more that 6-7 studies overall, given the project resources and time frame.

The **survey template/questionnaire** was developed for a two-stage process to capture key information as effectively and efficiently as possible. Existing examples from similar case studies were investigated to inform the process (e.g. Catchment Sensitive Farming, CS, ES studies http://publications.naturalengland.org.uk/category/3556843). Questions were aimed to supplement the information already available from the datasets provided under Tasks 1-3, thereby avoiding repetition of information the farmer may have already provided as much as possible. Due to the short project time frame and resource implications, interviews were carried out by telephone rather than in-person visits. The questionnaire template (Annex 8) was agreed with the Steering Group and questions sent to local CSF contacts or other local stakeholders, to initiate communication with individuals for carrying out the interviews and collect basic information. The initial responses were valuable for preparing the detailed interviews, depending on the local circumstances and any measures taken up from across the relevant schemes.

Each case study was documented carefully to meet the stated objectives (subject to farmer/land manager consent):

- To **demonstrate $NH_3$ emission reductions** achieved with the implementation of measures. The implementation of the measures on-farm is described and quantified where possible, together with relevant general information about the farm (e.g. location, farm type, emission sources and management practices).
- To **record and share farmer experience of employing the measures**. A structured interview with the farmer, with questions relevant for the particular measure (or measures) adopted, was used to answer this question. The interviews provided more in-depth understanding of any issues, barriers or pitfalls encountered, as well as revealing expected or unexpected co-benefits, and appreciating specific local issues and whether/how these might be more widely relevant. This objective is highly relevant to assist with making any future measures more relevant or easy to implement, and/or increase co-benefits through changes to the measure.
- To **highlight and, where possible, quantify the wider benefits of $NH_3$ measure uptake**. The case studies also focused on the potential additional benefits provided by $NH_3$ relevant measures for other scheme priorities, e.g. on water quality, greenhouse gases etc., and quantify these for each study. In some cases (e.g. FARG slurry tank covers), considerable additional direct benefits to the farmer are expected, including increased nutrient value/mineral fertiliser saving due to reduced slurry storage emissions and reduced dilution by precipitation/saving in quantity of liquid to be spread and related transport costs/emissions (especially in high rainfall areas), as well as odour reduction. Benefits to both the farmer and the wider environment, were documented and quantified where possible. Any dis-benefits were also recorded and quantified where possible.

## 2.6. Task 6 – measures for optimisation of schemes for ammonia relevance

Following the identification and quantification of $NH_3$ benefits of measures under the scheme, for England as a whole as well as specific case studies under Tasks 1-5, the resulting data and statistics were reviewed, with a view to identifying any gaps in measures in the current schemes and possible options for targeting measures spatially, by sector, etc., to achieve more impact/benefits for similar costs. For example, spatial targeting of $NH_3$ measures near sensitive habitats or designated sites has been shown to provide a better cost-benefit ratio than random application of measures across the country (Dragosits et al. 2014 – Defra AC0109 project; NE IPENS-049 project; Carnell et al. 2017). In summary, current and potential future $NH_3$ measures were reviewed with the aim to optimise for the UK meeting NECD ceilings (analysing schemes relevant for England rather than UK wide). This included the identification of further measures (filling gaps in measures and targeting measures) while also maximising reduction in $NH_3$ concentrations and N deposition for sensitive habitats and designated sites, and identifying co-benefits with other environmental objectives, e.g. water protection, greenhouse gases), providing quantitative estimates where possible.

For example, the costs and benefits of converting current slurry storage facilities in England to covered slurry tanks can be up-scaled, using available data on current proportions of systems in use (slurry tanks, lagoons, etc.) from the agricultural $NH_3$ inventory database. A similar investigation could be carried out for low emission land-spreading techniques. Given the very large number of options for optimisation, specific avenues for prioritisation had to be followed up/quantified after an initial review of current measures and gaps, with a small number of quantitative analyses being carried out, given the limited project time frame and resources. The measures investigated were assessed in terms of effectiveness for reducing $NH_3$ emissions from agriculture. Another question to be explored for a limited number of measures was the level and type of financial support needed to make measures, such as capital grants for applying low emission land-spreading techniques viable, i.e. balance take-up vs. costs, to maximise benefits. It is important to consider both the initial capital costs and additional ongoing costs and/or savings for implementing such measures.

# 3. Results & discussion

## 3.1 Task 1 - Identification of ammonia-relevant scheme measures

### *3.1.1. Task 1a - Assessment of scheme measures for ammonia relevance*

Of the 794 measures available under the agri-environment schemes considered in this project, 128 measures were considered to be $NH_3$ relevant, as defined above (Methods Section, Task 1a). Of these, 110 measures (highlighted in blue in Table 1) were applicable for use for national scale modelling under Task 4 (as potential recapture measures could not be quantified nationally (outlined in Section 2.1.1 above). Table 1 and Figure 3 summarise the $NH_3$ relevance of the measures available under each of the schemes considered (for details on individual measures, please see Annex 1). Measures considered in Task 4 are highlighted below.

**Table 1** - Classification of measures from all schemes for ammonia relevance

| | Number of measures included | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Scheme | Direct benefit | Potential reduction | Potential recapture & Potential reduction | All measures with quantifiable ammonia relevance | Potential recapture | Potential increase | Unquantifiable | Negligible | **Total** |
| Countryside Stewardship | ***18*** | ***7*** | ***1*** | ***26*** | 4 | 2 | 43 | 179 | **254** |
| English Woodland Grant Scheme | ***0*** | ***0*** | ***0*** | ***0*** | 9 | 0 | 0 | 4 | **13** |
| Environmental Stewardship | ***74*** | ***8*** | ***0*** | ***82*** | 5 | 2 | 101 | 322 | **512** |
| Farming Ammonia Reduction Grant Scheme | ***2*** | ***0*** | ***0*** | ***2*** | 0 | 0 | 0 | 0 | **2** |
| Countryside Productivity Scheme [#] | ***0*** | ***0*** | ***0*** | ***0*** | 0 | 0 | 2 | 11 | **13** |
| **Total** | ***94*** | ***15*** | ***1*** | ***110*** | **18** | **4** | **146** | **516** | **794** |

[#] CPS measures as assessed under Task 1 such as "robotic equipment, digestate management, slurry management etc." are potentially very relevant but not quantifiable at this generic level, neither at the national level, nor per grant from the data table provided, and the scheme documentation is very inexplicit about details, with each application tailored individually. N.B. CPS case studies provide very useful insight at the individual grant level (see Section 3.5)

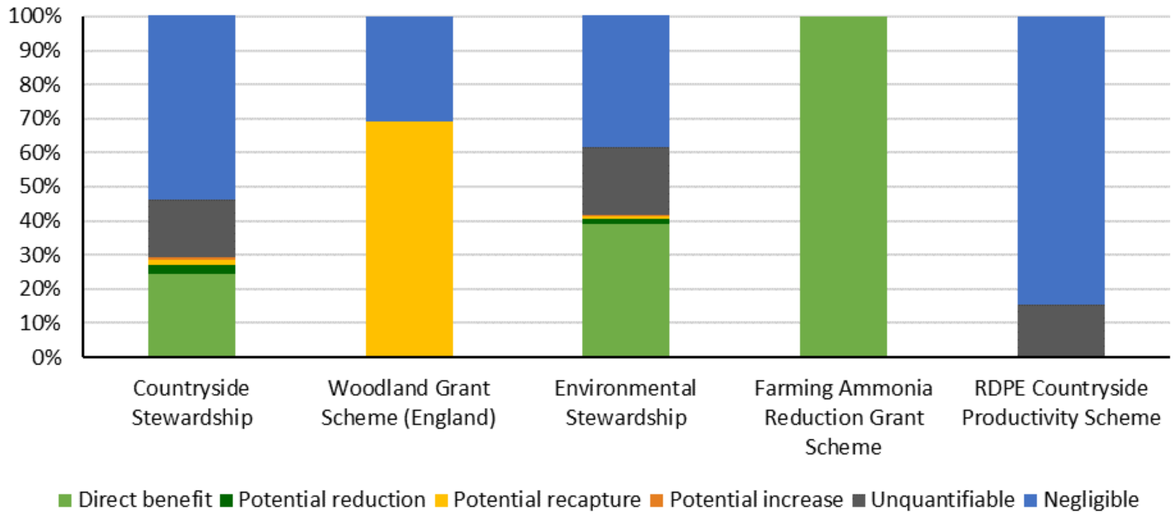



**Figure 3** – Ammonia relevance of measures under the agri-environment schemes analysed - relative proportions

By far the largest schemes in terms of the number of measures available are the Environmental Stewardship Scheme (ES) and its successor, the Countryside Stewardship scheme (CS), with 512 and 254 measures analysed, respectively. By comparison, the Farming Ammonia Reduction Grant Scheme (FARG) only consists of two measures in total (self-supporting covers for slurry stores and floating covers for slurry stores and lagoons). The Woodland Grant Scheme (WGS) and Countryside Productivity Scheme (CPS) having 13 assessed measures each (Table 1, full details see Annex 1).

All measures were assigned to one of the categories outlined in Section 2.1.1, as follows (one measure qualified for both potential reduction and recapture simultaneously).

- Direct $NH_3$ reduction
- Potential $NH_3$ reduction
- Potential $NH_3$ recapture
- Potential increase in N impacts (due to removal of trees, i.e. reversing potential recapture)
- Unquantifiable (potential for $NH_3$ benefits, but assessment not possible due to lack of information on management pre-implementation)
- Negligible (unlikely to produce any significant $NH_3$ benefits)

Given the stated aims of many of the measures, especially ES and CS, which include biodiversity, public access, soil and water protection, historic buildings/archaeology etc., it is not surprising that a large proportion (65%) of measures have no discernible $NH_3$ benefit ("negligible"). Only the FARG Scheme has been explicitly designed to provide $NH_3$ benefits. However across all schemes, a total of 94 measures (12%) were identified as providing direct and quantifiable $NH_3$ benefits. A further 15 measures (2%) are considered to have the potential for $NH_3$ emission reduction, and 18 (2%) of measures may provide recapture benefits in terms of $NH_3$ emitted elsewhere (i.e. secondary benefit rather than emission reduction). However, in addition there are large numbers of measures (146, 18%) that may provide $NH_3$ benefits, but due to a lack of agricultural management data (pre/post measure), it is not possible to quantify what benefit they may provide.

### 3.1.2. Task 1b – Quantification of mitigation factors for ammonia-relevant scheme measures

Emission reduction values were assigned to each measure identified as having either a direct or potential $NH_3$ emission reduction (Annex 1), a total of 110 measures. Of these, the simplest were where land was taken out of production for use as either buffers, margins or specified as wildlife areas or converted to non-agricultural land use (e.g. creation of heathland, woodland, hedge planting, fen or reed bed); a total of 84 measures. An emission reduction of 100% was assumed, compared with that from prior land use. There were four manure management measures concerned with covering slurry stores and these were associated with emission reductions of 80% for a self-supporting cover and 60% for a floating cover as estimated by Bittman *et al.* (2014). The remainder of quantifiable $NH_3$-relevant measures identified in Task 1 were associated with changing management of agricultural land. Where this implied removing all N inputs (as fertiliser or manure), then 100% emission reduction was assumed. However, many of these measures specified maximum amounts for N inputs, and the actual reduction in N input (and thereby emission) depends on the actual N inputs to that land prior and post- measure uptake. Assumptions were therefore made regarding N input reductions for these measures, as detailed individually in Annex 1, giving emission reductions varying from 50 to 100%. For other

## 3.2. Task 2 – Assessment of uptake of ammonia relevant scheme measures

The uptake of measures under each scheme was assessed in terms of area covered, and $NH_3$ relevance of measures was estimated proportional to the area covered by relevant measures, using the % emission reduction estimates from Task 1b and shown in detail in Annex 1. As agreed with the Steering Group, the analysis excluded the CPS measures, as these are individually designed for each application and upscaling is not possible. Table 2 shows the total area of all measures under each scheme and the total area of measures for schemes which are considered to be $NH_3$ relevant (excluding the CPS measures, as these are individually designed for each application and upscaling is not possible; agreed with the Steering group). Measures were considered to be $NH_3$ relevant when the reduction in $NH_3$ could be quantified nationally, i.e. classified as 'Direct' emission reductions or 'Potential reductions'. Multiple measures may be applied to the same parcel of land in ES and CS. If there is more than one $NH_3$ relevant measure applied in a field, each measure has been credited separately. N.B. As mentioned in Section 2.2, there may be a small issue regarding potential double-counting of measures across multiple years, due to the data formatting in the high-resolution GIS database made available, resulting in some multiple applications for similar measures for some fields that could not be fully resolved. Careful scrutiny of the available data indicates that the overall implications may be a very minor overestimation of $NH_3$ emission reductions achieved by agri-environment schemes. However, it is difficult to quantify as it is not possible to separate valid duplicates (i.e. multiple applications of a measure in a field concurrently) and duplicates due to the reapplication of a measure (i.e. a farmer reapplying for a measure that has been funded in the past and therefore appears twice in the database, but maybe with different quantities).

**Table 2.** Uptake of measures for schemes – summary areas for all measures per scheme

| Scheme | Total area of measures ($km^2$)** | Total area of measures where $NH_3$ emission reductions can be quantified ($km^2$) | Proportion of area where $NH_3$ emission reductions can be quantified (%) |
|---|---|---|---|
| Countryside Stewardship scheme | 20,762 | 971 | 5 % |
| English Woodland Grant Scheme | 175 | 0## | 0 % ## |
| Environmental Stewardship Scheme | 78,086 | 295[2] | 0.4 % |
| Farming Ammonia Reduction Grant Scheme | 0.15 (149,962 $m^2$) | 0.15 (149,962 $m^2$) | 100 % |

** Only measures where area of uptake are provided are represented here. All measures given in terms of length and volume were classified to have a negligible impact on reducing N. If there is more than one $NH_3$ relevant measure applied in a field, each measure has been credited separately.

## N.B. Farm woodland is generally seen as secondary abatement measure, i.e. it may assist with recapturing atmospheric $NH_3$ emitted from sources. Additional woodland planting is not estimated to reduce emissions from $NH_3$ sources here, as the woodland has not been planted to maximise $NH_3$ abatement, but to increase woodland area more generally. Therefore the EWGS woodland is not estimated to contribute to emission reductions here.

While substantial numbers of $NH_3$ relevant measures were identified under Task 1 (Section 3.1 above), for example, >10% of measures available under ES or CS, the uptake of these measures is relatively small, with only 0.2% (300 $km^2$) and 5% (970 $km^2$) being recorded under ES and CS measures that are considered relevant for reducing $NH_3$ emissions (Table 2, Figure 4), respectively. By contrast, the relatively small areas under FARG slurry store covers (0.15 $km^2$), is 100% relevant and highly effective in reducing $NH_3$ emissions, and all woodlands planted under EWGS are likely to provide some secondary benefits in terms of uptake of atmospheric $NH_3$ and dispersion/dilution if located near emission sources. This is due to the higher deposition velocity of woodland compared with low-growing semi-natural vegetation (e.g. Fowler et al. 2004).

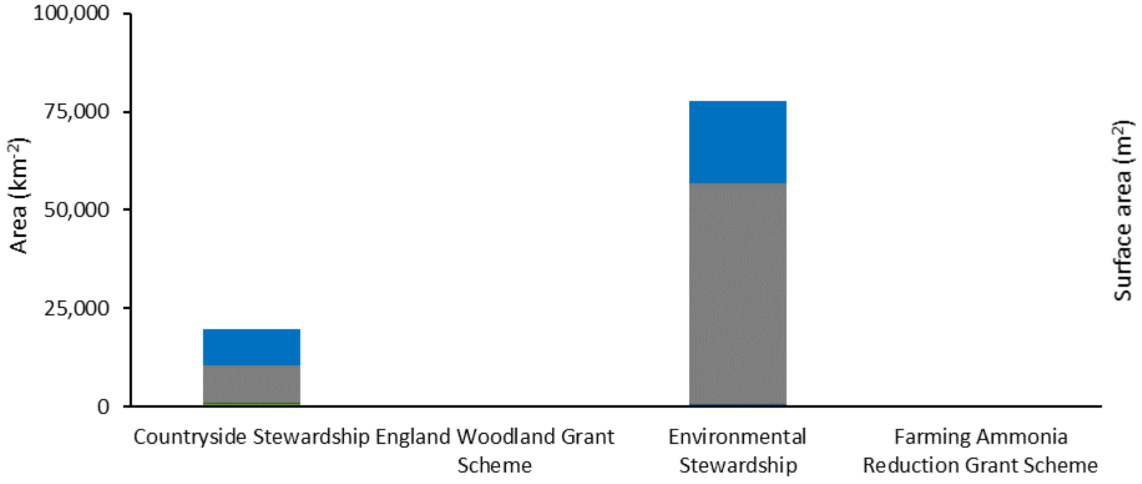
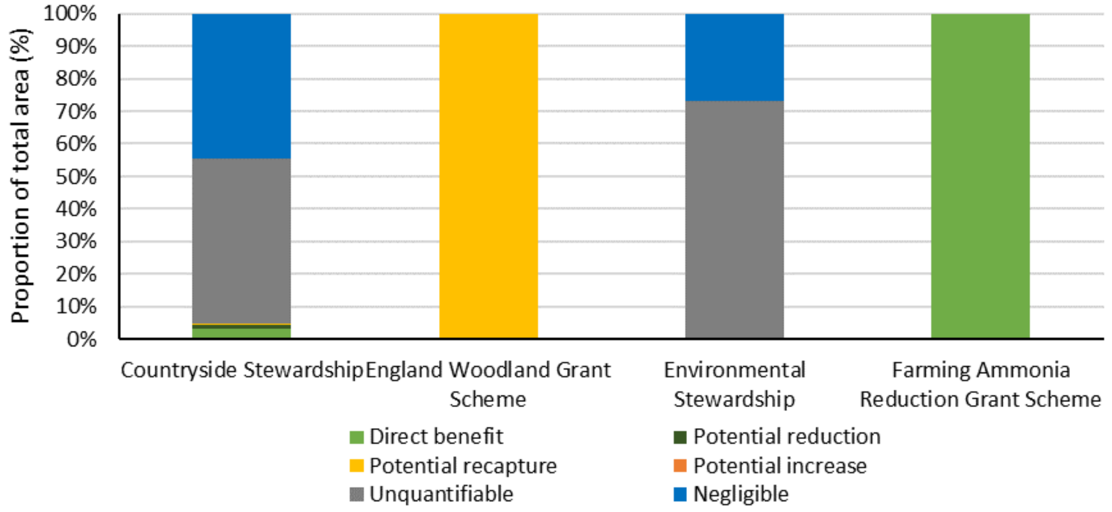


**Figure 4a** – Area covered by ammonia relevant measures under the schemes where data were available for England - absolute areas.

a)




b)

**Figure 4b** – Area covered by ammonia relevant measures under the schemes where data were available for England - relative proportions (%)

It should be noted that, of the 512 Countryside Stewardship scheme measures analysed under Task 1, only 291 had recorded uptake in the detailed data provided (57%). For the Environmental Stewardship Scheme, 172 out of 254 measures (68%) had been implemented at least once. Of the measures not taken up at all, only a small number had been estimated to be $NH_3$-relevant, four under CS and 13 under ES. These measures are listed in Table 3 below (full list presented in Annex 2).

For example, CS Option RP29 (self-supporting covers for slurry stores) do not have any recorded uptake in the database extract, whereas Option RP30 (floating covers for lagoons) had a number of entries in the database, all pre-dating the opening of the FARG scheme. The introduction of the FARG scheme provided a much more attractive option to farmers, which, despite the very short window of opportunity during its first year, has been very successful with ~ 60 successful implementations. Under ES, it is of interest to note that neither of the specific maize crop measures (EJ2, OJ2) nor the undersown spring cereal measures (EG1, OG1) were taken up. In terms of measures related to taking cultivated areas out of cropping for ground-nesting birds, two measures listed in Table 3 (EF13, OF13) had no uptake, however, similar measures (HF13NR, OHF13NR) were very popular. While the ranking of measures in terms of $NH_3$ emission reduction is discussed fully under Section 3.3 below, it is appropriate here to mention that both these measures featured relatively highly up on the list of most $NH_3$-relevant measures (HF13NR in 22$^{nd}$ place, contributing 0.7% of total estimated $NH_3$ emission savings by all quantifiable measures, with OHF13NR in 56$^{th}$ place, see Annex 5 for details described in Section 3.3 below).

**Table 3** – $NH_3$-relevant measures with no recorded uptake in the measures datasets

| Scheme | ID | Option Description | $NH_3$ relevance |
|---|---|---|---|
| CS | LH3 | Creation of heathland from arable or improved grassland | Direct |
| CS | RP29 | Self-supporting covers for slurry stores | Direct |
| CS | SW13 | Very low nitrogen inputs to groundwaters | Direct |
| CS | CT4 | Creation of inter-tidal and saline habitat on arable land | Potential reduction |
| ES | OL1 | Take field corners out of management in SDAs | Direct |
| ES | OF11 | Uncropped cultivated margins for rare plants | Direct |
| ES | EJ2 | Management of maize crops to reduce soil erosion | Direct |
| ES | OJ2 | Management of maize crops to reduce soil erosion | Direct |
| ES | EG1 | Undersown spring cereals | Direct |
| ES | OG1 | Undersown spring cereals | Direct |
| ES | HP3 | Creation of coastal vegetated shingle and sand dunes on arable land | Direct |
| ES | HG7 | Low-input spring cereal to retain or recreate an arable mosaic (rotational) | Direct |
| ES | EF13 | Uncropped cultivated areas for ground-nesting birds on arable land | Direct |
| ES | OF13 | Uncropped cultivated areas for ground-nesting birds | Direct |
| ES | HF20 | Cultivated fallow plots or margins for arable plants (rotational or non-rotational) | Potential reduction |
| ES | EK21 | Legume- and herb-rich swards | Potential reduction |
| ES | OK21 | Legume-and herb-rich swards | Potential reduction |

As has been described earlier (Section 2.4), the creation of additional woodlands under the schemes (264 km$^2$, Table 4) is not an $NH_3$ emission reduction measure as such, and reductions in atmospheric $NH_3$ concentrations and deposition are difficult to quantify without detailed information on their design and relative location compared with nearby emission sources. However, their presence in the wider landscape will have a positive effect in terms of taking up atmospheric nitrogen, regardless of the woodland design, age and spatial location relative to emission sources and sensitive habitats, especially in areas with larger uptake (Figure 5). Bealey et al. (2016) estimated that adding an extra 50 % of woodland into the UK landscape (14,000 km$^2$) would reduce UK N deposition to sensitive ecosystems by recapturing on the additional woodland by a low proportion. The 264 km$^2$ recorded under the schemes amount to 1.9% of the extra woodland area modelled above, i.e. a very small area.

**Table 4** – Farm woodland planted under agri-environment schemes

| Scheme | Total area of measures which offer potential recapture of $NH_3$ emissions | Uptake of measures which offer potential recapture of $NH_3$ emissions (*n = number of successful applications/installations*) |
|---|---|---|
| English Woodland Grant Scheme | 175 km$^2$ | 8,489 |
| Environmental Stewardship | 20 km$^2$ | 1,617 |
| Countryside Stewardship | 69 km$^2$ | 296 |

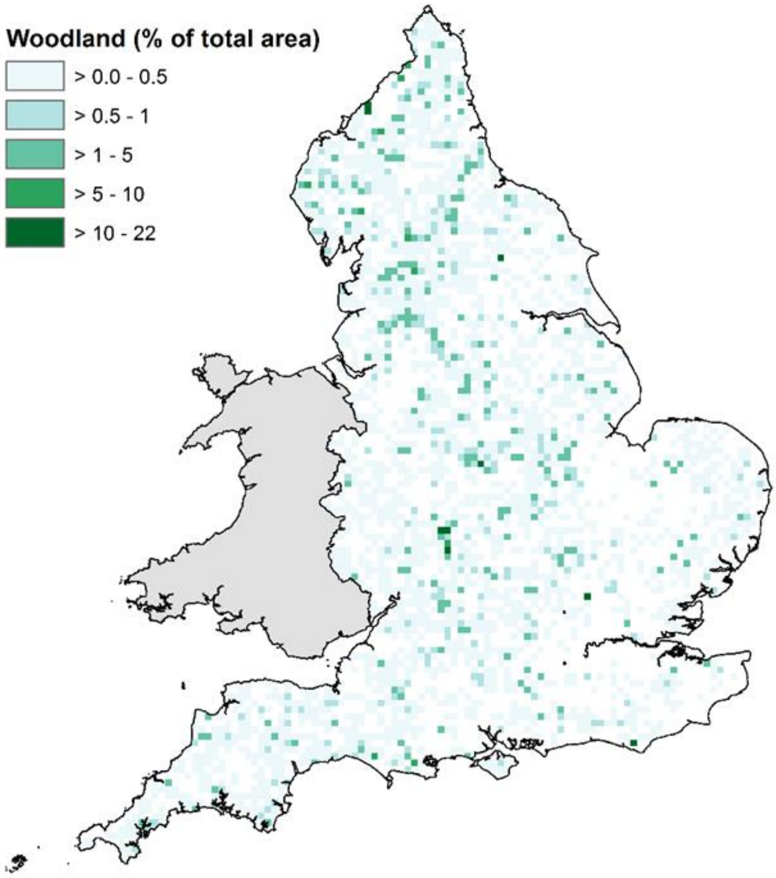



**Figure 5** – Woodland planted under agri-environment schemes (proportion of 5 km grid squares) for England.

## 3.3. Task 3 - Assess uptake of ammonia relevant scheme measures relative to sensitive receptors

The uptake of measures was quantified for areas within 2 km, 5 km and 10 km of SACs, SSSIs, SPAs and RAMSAR sites. Table 5 provides a summary of the uptake of measures within 2 km of SACs with nitrogen sensitive features (number of SACs = 206), illustrating the difference in spatial patterns for the different schemes. Existing schemes so far have been utilised to give a small benefit of $NH_3$ mitigation and related reduction in impacts on sensitive receptors For example, although the majority (~64 %) of all measures under the Environmental Stewardship Scheme are located within a 2 km buffer zone of an SAC, they only offer 0.1% emission reduction in this area. The Countryside Stewardship scheme and the English Woodland Grant Scheme however, have less spatial correlation, with the proportion of measures within 2km of SACs being ~20%. The detailed spatial relationships between measures and designated sites (SSSI, SAC, SPA, RAMSAR) at buffer distances of 2 km, 5 km and 10 km can be found in Annex 3.

**Table 5** - Uptake of measures within 2 km of SACs

| Scheme | Total area of measures within 2 km of an SAC ($km^2$) | Proportion of all measures within 2 km of an SAC (%) | Total area of $NH_3$ emission reduction measures within 2 km of an SAC | Proportion of $NH_3$ emission reduction measures within 2 km of an SAC (%) |
|---|---|---|---|---|
| Countryside Stewardship scheme | 4,765 | 22 % | 138 | 3 % |
| English Woodland Grant Scheme | 30 | 17 % | 0 | 0% |
| Environmental Stewardship Scheme | 49,925 | 64 % | 56 | 0.1 % |
| Farming Ammonia Reduction Grant Scheme | 0.042 (42,277 $m^2$) | 28 % | 0.042 (42,277 $m^2$) | 100 % |

The uptake of measures surrounding RAMSAR sites and N-sensitive designated sites (SACs, SSSIs, SPAs), within distances of 2 km, 5 km and 10 km is presented in Figure 6. RAMSAR sites have not been included in this analysis, as the designated N-sensitive features of these sites are not currently known and/or easily accessible (unlike for SACs, SSSIs and SPAs, where agreed datasets are available from the agencies/JNCC). Figure 5 illustrates the large number of SSSI sites spread widely across England, with virtually all measures being within 10 km of a SSSI and a large proportion being within 5 km. As there are fewer SPA and RAMSAR sites, with larger areas of England not containing any sites, a smaller proportion of measures are located in the vicinity of these sites.

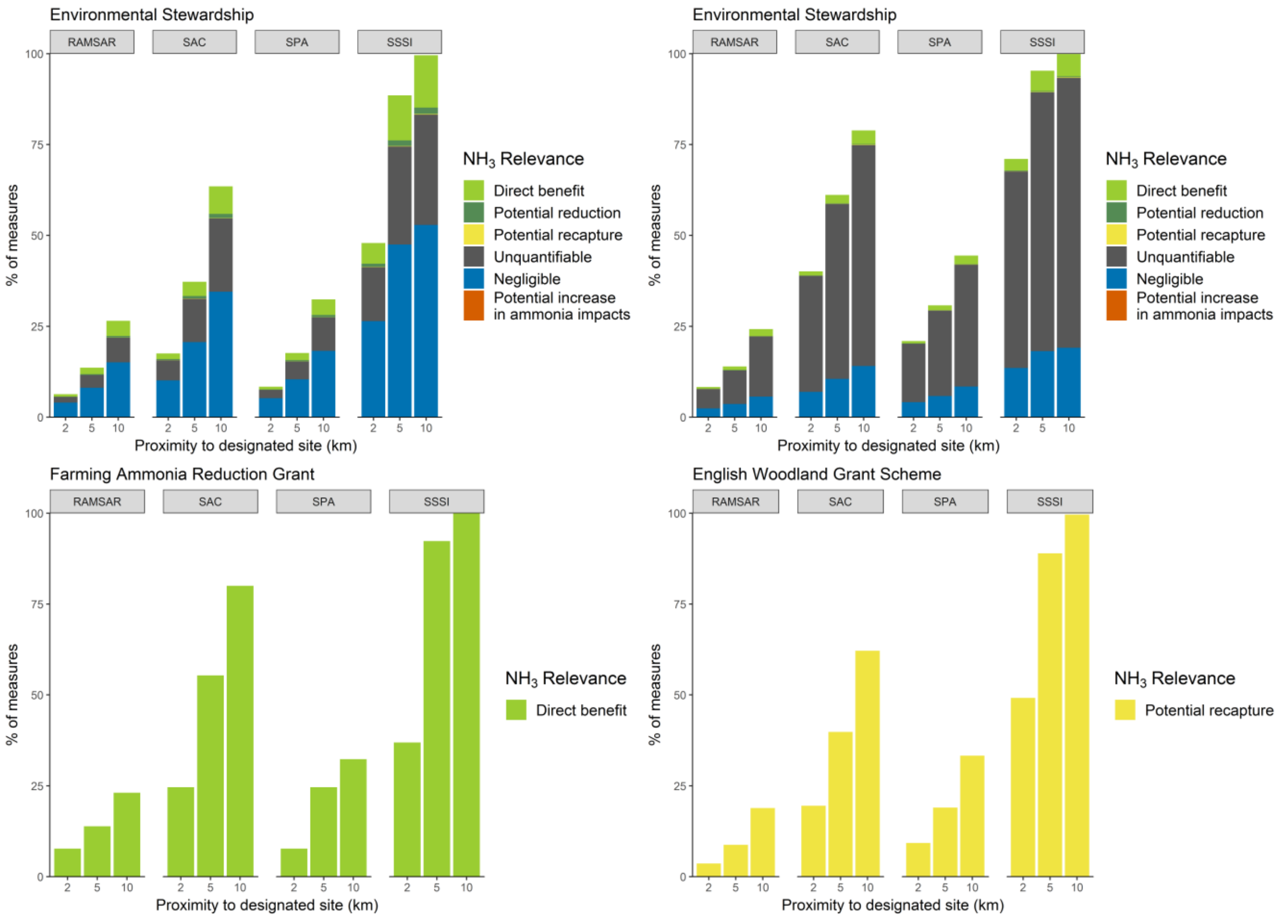



**Figure 6** - Uptake of measures within 2 km, 5 km and 10 km of RAMSAR sites and nitrogen sensitive SACs, SSSIs, SPAs.

## 3.4. Task 4 - Estimation of air quality benefits from ammonia relevant measures at the local/national scale

The current uptake of $NH_3$ relevant measures (where emission reductions could be quantified) are estimated to have delivered a reduction in agricultural $NH_3$ emissions of 0.77 kt $NH_3$. This represents a 0.5 % reduction of the total agricultural emissions for England (~150 kt $NH_3$).

Agricultural emission estimates with and without the current uptake of $NH_3$ relevant measures were spatially disaggregated and are presented in Figure 7. The overall spatial distributions of emissions under scenarios S0 and S1 (see Section 2.4 for full definition) are very similar, as the reduction represents a small proportion of total agricultural emissions. Figures 7c and 8 show the absolute and relative spatial distribution of $NH_3$ reduction achieved through current uptake of measures as a proportion of S0. There are a number of small local areas where the $NH_3$ reductions achieved are estimated > 10% of total agricultural $NH_3$ emissions (prior to uptake, i.e. S0), however for most areas the estimated $NH_3$ emission reduction is below 1%.

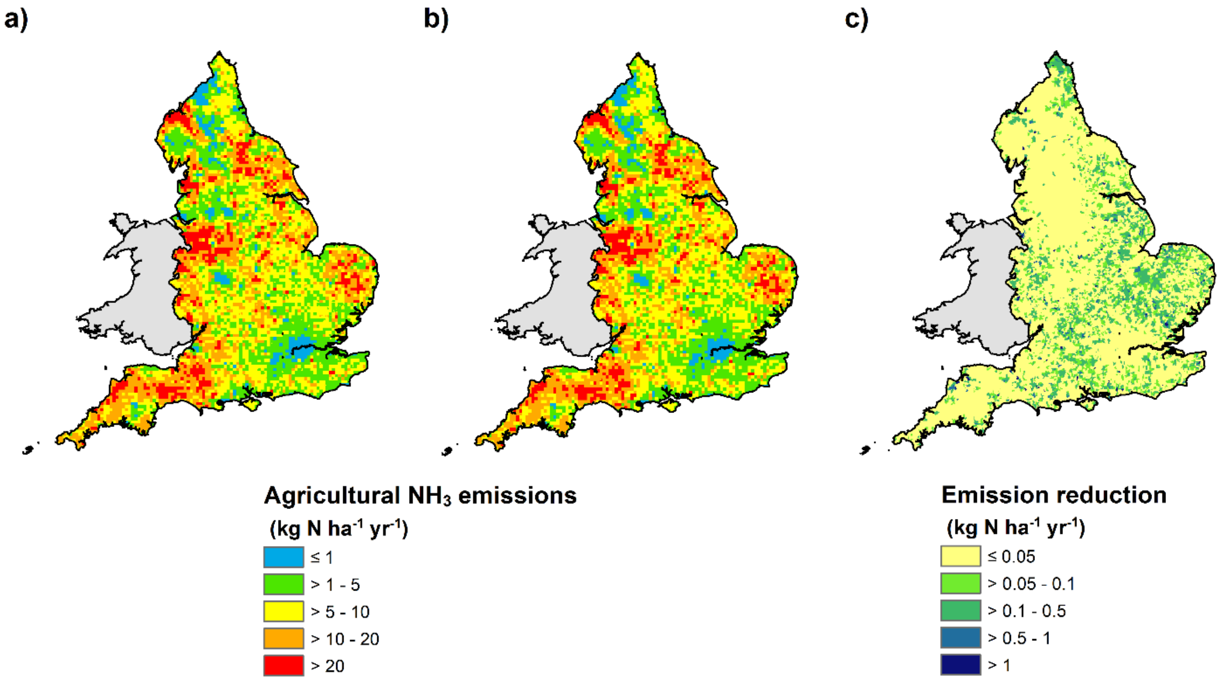



**Figure 7** – agricultural $NH_3$ emissions for a) scenario S0 (without current uptake of $NH_3$ relevant measures under agri-environment schemes); b) scenario S1 (with current uptake of $NH_3$ relevant measures under agri-environment schemes); c) absolute difference in emissions between S0 and S1 (i.e. the emission reduction achieved by current uptake of ammonia relevant measures) under agri-environment schemes

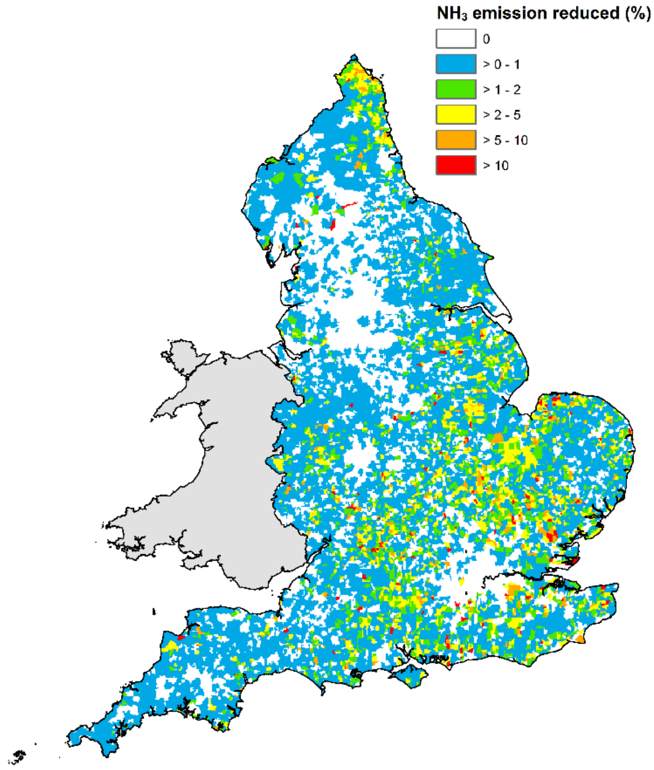



**Figure 8** – Estimated relative $NH_3$ reduction achieved through current uptake of $NH_3$ relevant measures under agri-environment schemes (as a proportion of scenario S0)

Table 6 shows the top ten measures in terms of $NH_3$ emission reductions achieved through current uptake under agri-environment schemes. Approximately 75 % of the total 0.77 kt $NH_3$ reductions achieved from the current uptake of measures is estimated to be due to these top ten measures. The measure delivering the highest $NH_3$ reduction is the Countryside Stewardship scheme measure SW1 (4-6 m buffer strips), achieving ~35 % of the total emission reduction. The high uptake of this measure (Figure 9), with 36,812 ha no longer receiving N fertiliser application, achieves a reduction of agricultural emissions by 0.27 kt $NH_3$.

**Table 6** – Top-10 measures in terms of $NH_3$ reduction achieved

| Rank | ID | Description | Scheme | Area | $NH_3$ emission reduction (kg $NH_3$) | % contribution to total $NH_3$ emission reduction from all relevant measures |
|---|---|---|---|---|---|---|
| 1 | SW1 | 4-6 m buffer strip on cultivated land | CS | 36,812 ha | 266,415 | 34.7 |
| 2 | EE3 | 6 m buffer strips on cultivated land | ES | 9,121 ha | 66,012 | 8.6 |
| 3 | AQ30 | Floating covers for slurry stores and lagoons | FARG | 120,456 $m^2$ | 65,776 | 8.6 |
| 4 | SW7 | Arable reversion to grassland with low fertiliser input | CS | 7,165 ha | 38,888 | 5.1 |
| 5 | SW4 | 12-24 m watercourse buffer strip on cultivated land | CS | 4,264 ha | 30,857 | 4.0 |
| 6 | AB11 | Cultivated areas for arable plants | CS | 3,901 ha | 28,229 | 3.7 |
| 7 | GS4 | Legume and herb-rich swards | CS | 15,413 ha | 22,955 | 3.0 |
| 8 | AQ29 | Self-supporting covers for slurry stores | FARG | 29,507 $m^2$ | 21,483 | 2.8 |
| 9 | HJ3 | Arable reversion to unfertilised grassland to prevent erosion or run-off | ES | 2,879 ha | 20,833 | 2.7 |
| 10 | EE2 | 4 m buffer strips on cultivated land | ES | 2,814 ha | 20,363 | 2.7 |

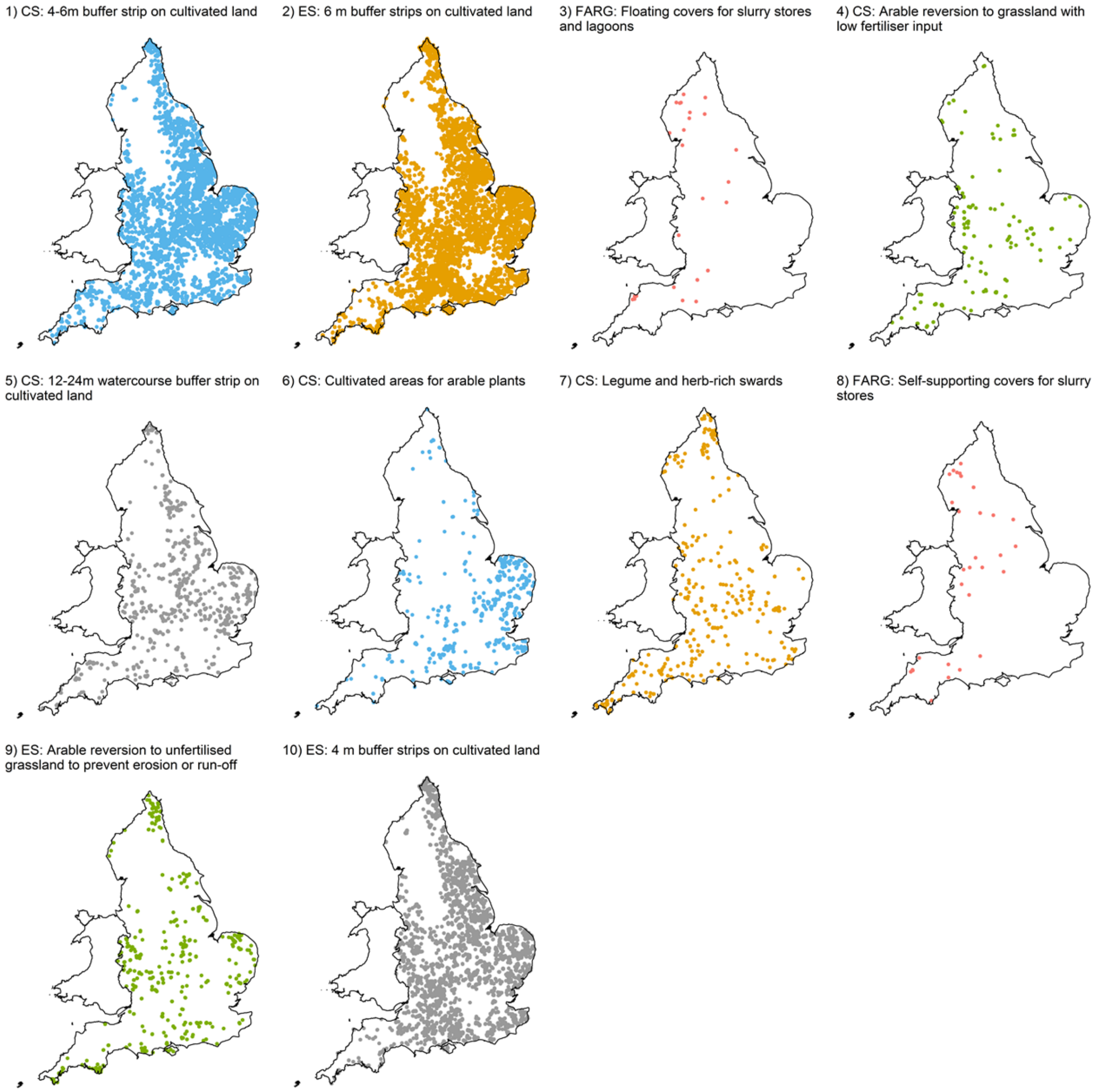



**Figure 9** – Spatial distribution of the top 10 measures delivering the highest $NH_3$ reduction.

Analysing quantifiable $NH_3$ emission reductions by scheme, the CS scheme achieves the largest proportion of mitigation, followed by ES and FARG (see Table 7).

**Table 7** – Quantification of $NH_3$ emission reductions through agri-environment scheme measures by scheme (average over the lifetime of the scheme)

| Scheme | Total area of measures where $NH_3$ emission reductions can be quantified ($km^2$) | $NH_3$ emission reduction (t $NH_3$) | Total uptake (*n of successful applications/ installations*) | Average reduction per measure (kg $NH_3$) |
|---|---|---|---|---|
| Countryside Stewardship | 971 | 505 | 30,156 | 16.6 |
| Environmental Stewardship | 294 | 174 | 61,911 | 2.8 |
| Farming Ammonia Reduction Grant Scheme | 0.149 (149,962 $m^2$) | 87 | 65 | 1,338 |

However, this does not show the complete picture, as there are large numbers of measures where it was not possible to quantify the $NH_3$ emission savings, due to a lack of information on prior management practice in terms of N input to arable land or grassland (Table 8). It is likely that some further $NH_3$ emission savings have been achieved, however to give quantitative credit for their $NH_3$ relevance is not possible without further information being collected under future schemes. For example, if it is not clear whether/how much N was applied prior to implementation of a measure, fertiliser N savings cannot be assumed. While it was possible to quantify average N applications to arable cropland and credit N application savings for any areas taken out of production, the same is not possible where prior use/intensity of N fertilisation is unknown, e.g. for marginal upland grazing that may not have received any/very much N input before adoption of a relevant measure. Table 8 shows that there are large areas containing measures where $NH_3$ emission reductions are "unquantifiable" nationally. If prior use/intensity information was collected as part of the application process, this would enable the quantification of ammonia reductions achieved. However, given that many measures relate to less intensively managed/used grassland, and likely $NH_3$ emission reductions are limited, this is not expected to contribute very large impacts per unit area, on average, compared with more intensively managed areas being taken out of production, or $NH_3$-targeted measures such as the FARG slurry store covers.

Another type of measure, which has not been possible to quantify relate to concrete yard surfaces, rainwater separation, roofing of areas potentially used by livestock at different frequency/duration (collecting yards etc.). This is because the emission reduction depends on circumstance and the documentation on implemented measures does not provide details of the actual use of the area to be treated, which could be storage of farm machinery, a cattle collecting yard, feeding yard or areas used by livestock more infrequently. These measures however, have the potential for substantial benefits in terms of $NH_3$ emission reduction. These measures are available under the CS scheme (e.g. RP15, RP16, RP28) and could be highly effective for enabling effective scraping of yards, stopping precipitation mixing with slurry/manure on large surface areas and thereby substantially reducing $NH_3$ emissions. This is especially the case in the high rainfall areas of western and NW England (Chris Turner, NE, pers. comm.), with 1-2m annual rainfall diluting slurry and requiring large amounts of extra storage capacity and/or labour to spread the dilute slurry.

For example, RP15 (concrete yard renewal) could be contributing to reducing $NH_3$ emission reductions through replacing broken concrete in collecting yards (with slurry pooling etc.) by creating smooth surfaces that can be cleaned easily and properly. At the same time, it also ensures that there is no leakage and water pollution through the broken surfaces, which is the stated aim of the measure.

RP28 (Roofing (sprayer wash down area, manure storage area, livestock gathering area, slurry stores, silage stores)) is expected to similarly provide $NH_3$ emission reductions, while being primarily designed for water issues, and would additionally provide health benefits for cattle by keeping the floor area drier and removing slurry effectively through regular scraping and functioning drainage.

**Table 8** – Summary of measures where $NH_3$ emission reductions are "unquantifiable"

| Scheme | Number of measures where $NH_3$ emission reductions are "unquantifiable" | Total area of measures where $NH_3$ emission reductions are "unquantifiable" | Number of *successful applications/installations* where $NH_3$ emission reductions are "unquantifiable" (*n*) |
|---|---|---|---|
| Environmental Stewardship | 90 | 56,662 $km^2$ | 725,871 |
| Countryside Stewardship | 39 | 10,467 $km^2$ | 60,065 |

An analysis of modelled $NH_3$ concentration patterns (Figure 10) shows that, for much of England, concentrations are reduced by only very small amounts in the region of less than 0.05 µg $NH_3$ $m^{-3}$. Similarly, N deposition patterns (Figure 11) also only show very small changes of less than 0.05 kg N $ha^{-1}$ $yr^{-1}$, for most of the country, which is not surprising, given the relatively small change in $NH_3$ emissions that can be credited to the implementation of agri-environment scheme measures (0.5% of agricultural $NH_3$ emissions). Although these are small numbers at present, they show the potential of highly relevant $NH_3$ mitigation measures to make a difference, once implemented.

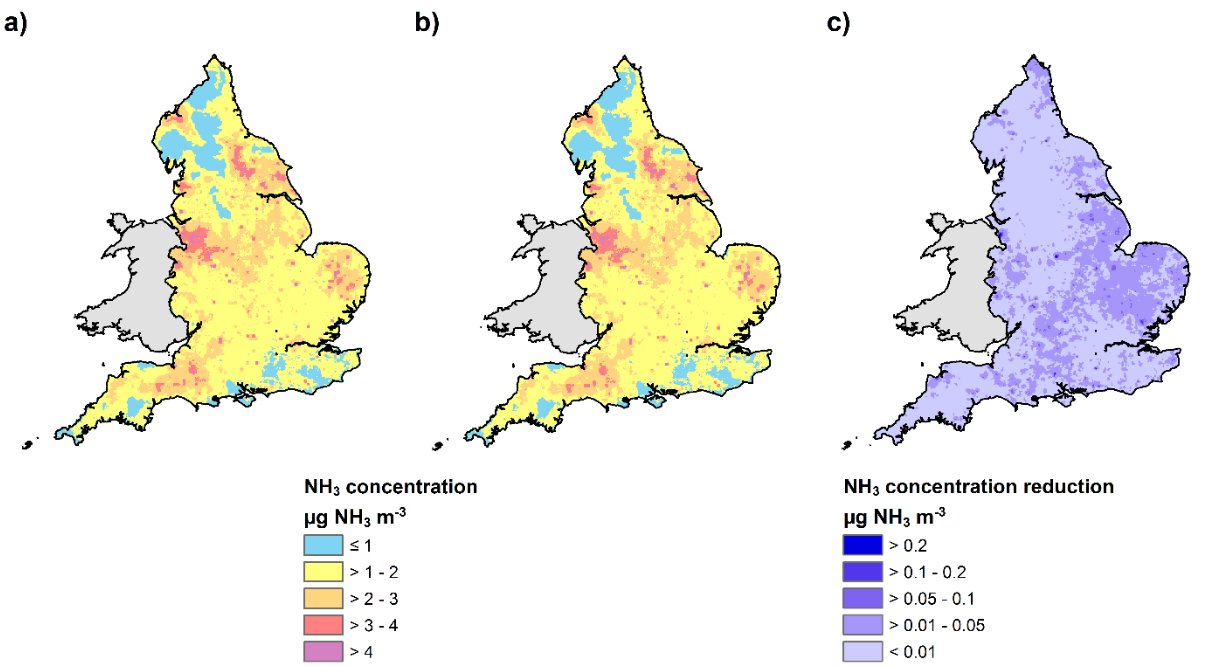



**Figure 10** – Estimated $NH_3$ concentrations for a) scenario S0 (without current uptake of $NH_3$ relevant measures under agri-environment schemes); b) scenario S1 (with current uptake of $NH_3$ relevant measures under agri-environment schemes); c) absolute difference in $NH_3$ concentrations between S0 and S1 (i.e. the $NH_3$ concentration reduction achieved by current uptake of quantifiable $NH_3$ relevant measures under agri-environment schemes)

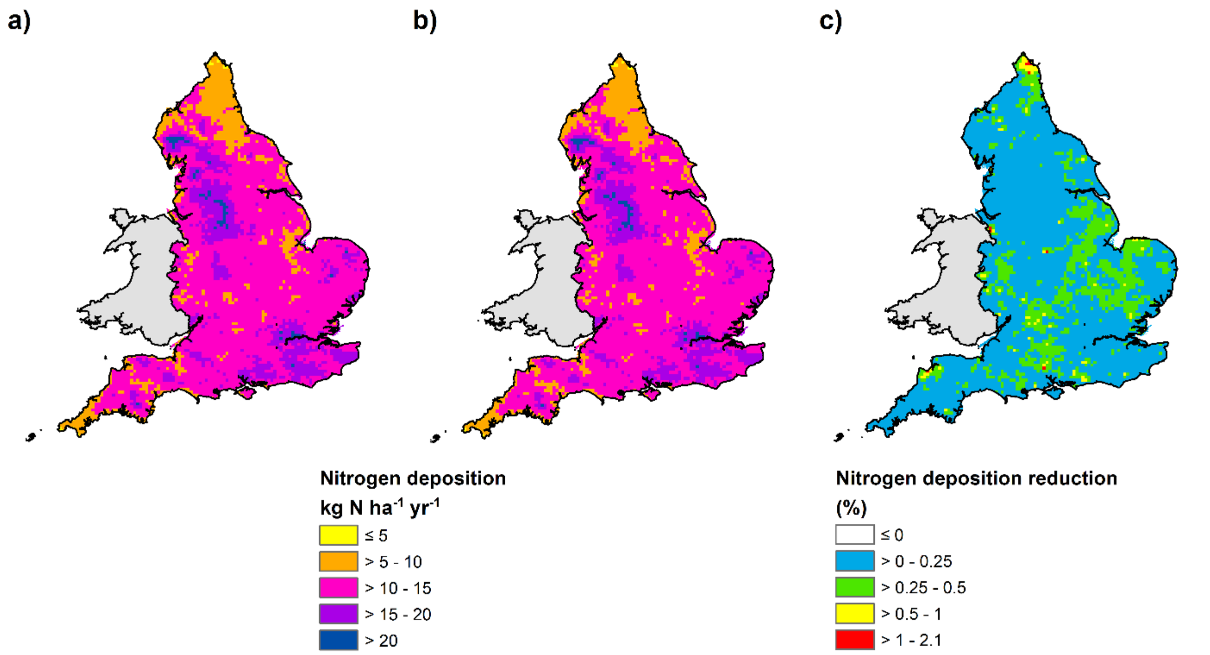



**Figure 11** – Estimated N deposition (grid square average) for a) scenario S0 (without current uptake of $NH_3$ relevant measures under agri-environment schemes); b) scenario S1 (with current uptake of quantifiable $NH_3$ relevant measures under agri-environment schemes); c) relative difference in N deposition between S0 and S1 (i.e. the N deposition reduction achieved by current uptake of quantifiable $NH_3$ relevant measures under agri-environment schemes)

In terms of critical levels exceedance, a small decline, from 86.5% to 86.3%, can be credited to quantifiable $NH_3$ relevant measures, in terms of the area of England where the 1 µg $m^{-3}$ critical level for sensitive lichen and bryophyte species is exceeded (Table 9). The area where the critical level for vascular plants (3 µg $m^{-3}$) is estimated to have been exceeded, remains (after rounding) at 4.4%.

**Table 9** - Ammonia critical level exceedance statistics for England under baseline (S0) and emissions reduction (S1) scenarios. Area exceeded is expressed in $km^2$ and as a percentage of total England area (i.e. 131,152 $km^2$).

| Scenario | Area ($km^2$) where 1 µg $m^{-3}$ is exceeded | % of total area where 1 µg $m^{-3}$ is exceeded | Area ($km^2$) where 3 µg $m^{-3}$ is exceeded | % of total area where 3 µg $m^{-3}$ is exceeded |
|---|---|---|---|---|
| S0 | 113,472 | 86.5 | 5,828 | 4.43 |
| S1 | 113,153 | 86.3 | 5,710 | 4.41 |
| Change | 319 | 0.2 | 118 | 0.02 |

Due to the small changes noted above, changes to the locations where critical level is exceeded for sensitive lichen and bryophyte species (Figure 2) and for vascular plants (Figure 13), when comparing the baseline and ammonia-abatement scenarios, are equally small, i.e. not discernible by eye from these maps.

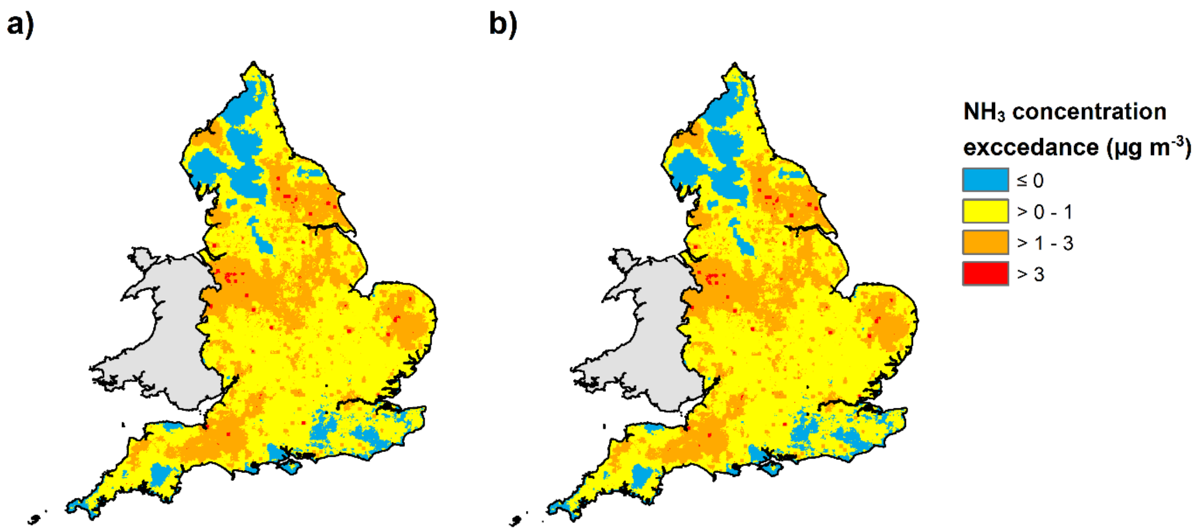



**Figure 12** - Spatial variation in exceedance of the ammonia Critical Level for lichens and bryophytes, i.e. 1 µg $m^{-3}$, under a) baseline (S0) and b) ammonia abatement scenarios (S1).

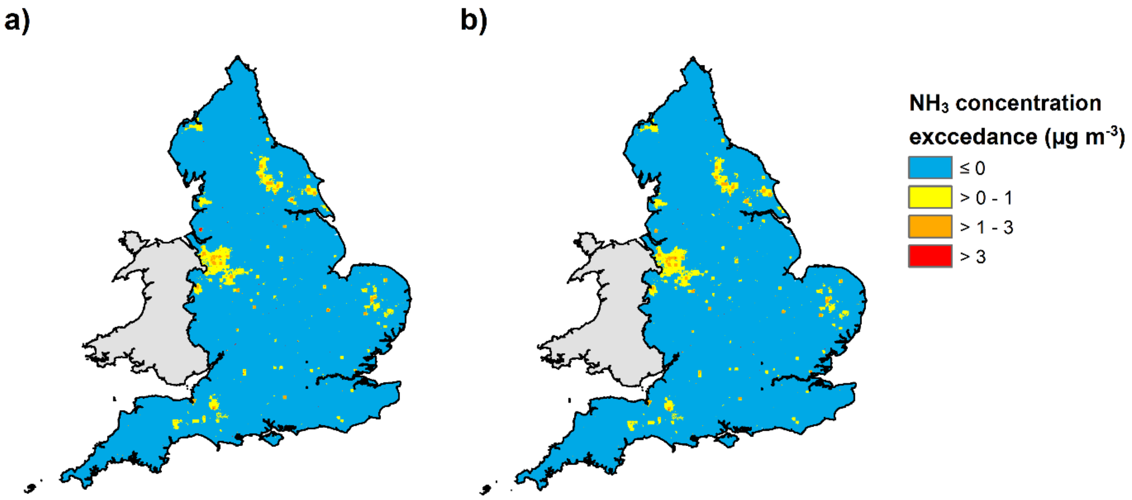



**Figure 13** - Spatial variation in exceedance of the ammonia Critical Level for vascular plants, i.e. 3 µg $m^{-3}$, under a) baseline (S0) and b) with $NH_3$ relevant measures credited (S1).

However, a closer inspection of the site-level data for designated sites reveals that there are a few sites where the exceeded area is estimated to have decreased below the respective critical level (1 and 3 µg $m^{-3}$) by small amounts of below 10% of the area of the site. The exceptions to this are Rook Clift (SAC and SSSI) and Duncton to Bignor Escarpment (SAC and SSSI) in southern England, with an estimated reduction by 61% and 19% of the site area, respectively, to below the 1 µg $m^{-3}$ critical level (Figure 14, and Annex 6). For SPAs, the differences in critical level exceedances at individual sites are small, with only 17 sites showing small decreases in the exceeded area, of 0.1-12% for 1 µg $m^{-3}$, with the largest difference at Lindisfarne SPA, and 1 site for 3 µg $m^{-3}$), at Lower Derwent Valley SPA, with a 3% decrease in the area exceeded. For SSSIs, there are 74 and 13 sites, for the 1 and 3 µg $m^{-3}$ thresholds respectively, where the area of critical level exceedance is estimated to have decreased. For the 1 µg $m^{-3}$ threshold, there are several sites with relatively large proportions of the site areas improving, e.g. Seale Chalk Pit SSSI at 94%, however this is a very small site of 1.2 ha, with a critical level of 1.01 µg $m^{-3}$ under scenario S0. This difference is therefore a result of a single grid cell changing below the 1 µg $m^{-3}$ critical level for lichens and bryophytes.

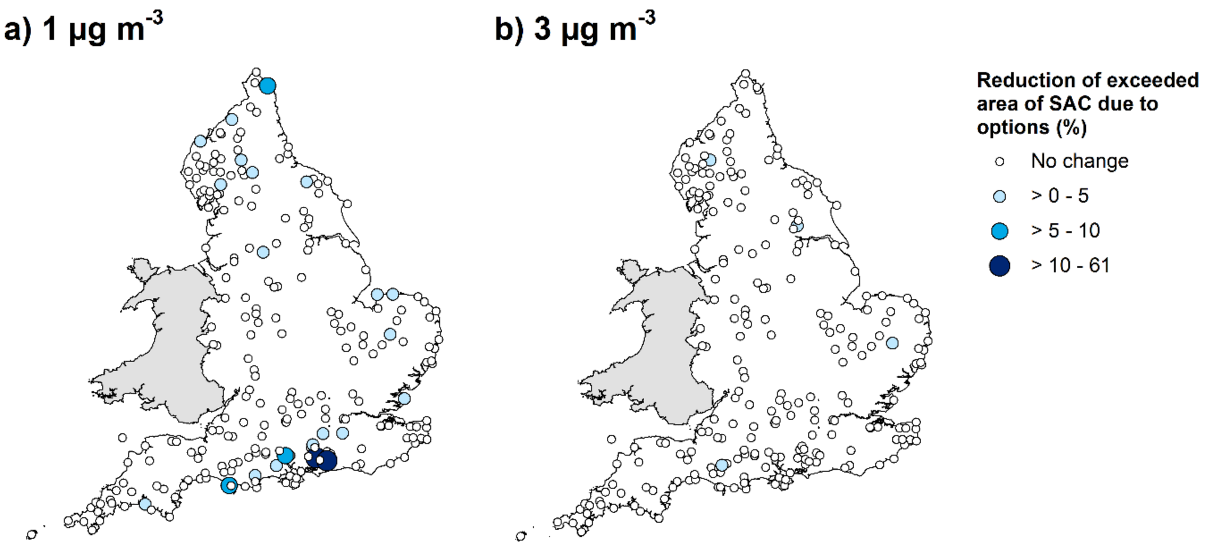



**Figure 14** – Site-based exceedance of $NH_3$ critical levels for SACs, where the exceeded area has decreased below a) the 1 µg $m^{-3}$ critical level and b) the 3 µg $m^{-3}$ critical level

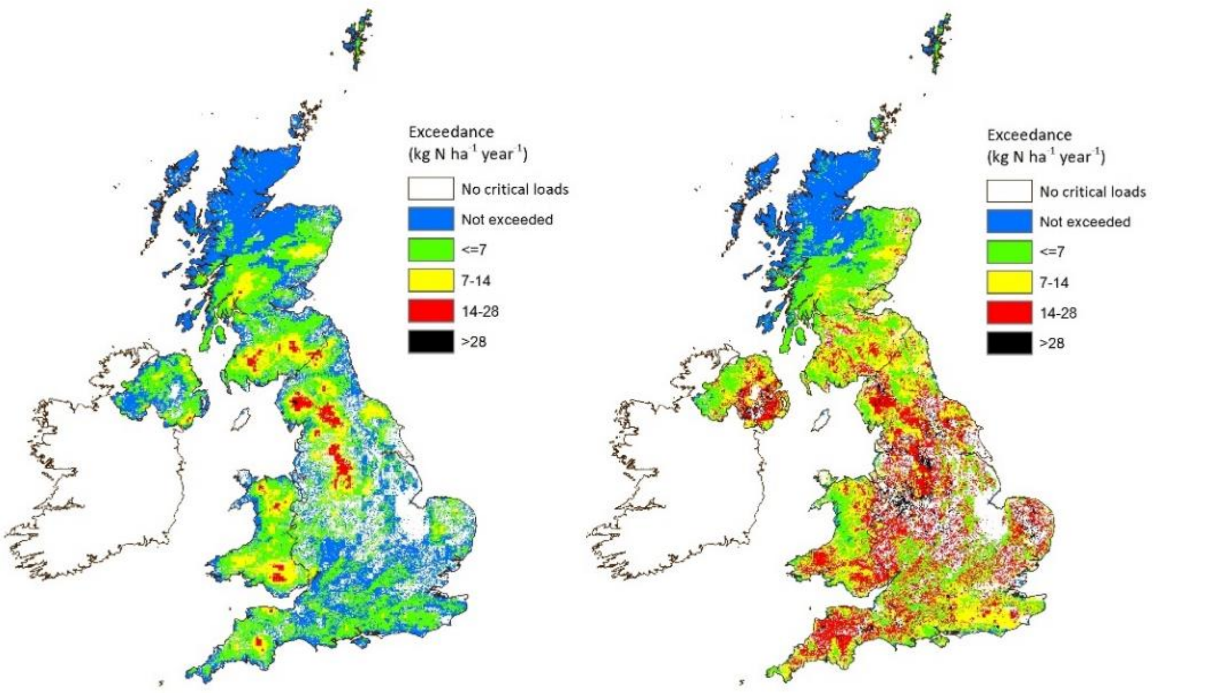
The analysis of areas of Critical Load Exceedance under scenarios S0 and S1 shows only a very minor reduction in the total area of N-sensitive habitats where the Critical Load is exceeded. Critical load exceedances are presented on an area basis (1 x 1 grid-cells that contain at least one nutrient-nitrogen sensitive habitat, Table 10) and a site basis (Table 11 & Annex 7), separately for Special Areas for Conservation (SACs), Special Protection Areas (SPAs), and Sites of Special Scientific Interest (SSSIs). The summary statistics and maps for site-based critical load exceedance present the 'worst case', since they are based on sites where at least one feature is exceeded; other features within a site may (a) have a smaller exceedance or (b) no exceedances. In addition, the Average Accumulated Exceedance (AAE) results are based on the maximum exceedance of any feature within a site.

The marginal reduction in agricultural $NH_3$ emissions achieved through uptake of $NH_3$ relevant measures (-0.75 kt $NH_3$-N) has produced a minor reduction in the area of England with critical load exceedances. There was only a small change in the AAE, with a decline from 12.8 to 12.7 kg N $ha^{-1}$ $yr^{-1}$ (Table 10).

**Table 10** Nutrient-nitrogen critical load exceedance statistics for England due to quantifiable $NH_3$ relevant measures.

| Scenario | Area of all N-sensitive habitats where Critical Load is exceeded ($km^2$) | % of total area where Critical Load is exceeded | Average Accumulated Exceedance (kg N $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|
| S0 | 18,703 | 95.87 | 12.8 |
| S1 | 18,702 | 95.86 | 12.7 |
| **Change** | **−1** | **0.01** | **−0.1** |

The overall change in the area of critical load exceedance for England under scenarios S0 and S1 (see Section 2.4 for full definition) is very minor (0.005%; N.B. total N deposition would not be expected to be decreasing at the same rate as $NH_3$ emissions, largely due to the other components such as $NO_x$, unchanged between S0 and S1). Changes to the locations where the total area of N-sensitive habitats where the critical load level was exceeded are difficult to discern in the maps, therefore Figure 15 presents the spatial distribution in exceedance of 5$^{th}$ percentile Critical Load for Nutrient-nitrogen under Scenarios S0 only, and does not include additional maps for S1.




a) b)

**Figure 15** - Spatial variation in a) exceedance of 5th percentile Critical Load for Nutrient-nitrogen, and b) in Average Accumulated Exceedance of Critical Loads for Nutrient-nitrogen under the baseline scenario. (N.B. this figure was created in conjunction with an existing project that is based upon UK perspective, with no England-specific mapping available due to the way the scripts producing these maps are set up).

Site-based statistics for designated sites (SACs, SPAs and SSSIs) show little or no changes in the percentage of protected sites where the nutrient-nitrogen critical load was exceeded for at least one nitrogen-sensitive feature (Table 11). The quantifiable $NH_3$-relevant measures resulted in a small decrease in the maximum Average Accumulated Exceedance of nutrient-nitrogen critical load (Table 12)

**Table 11** - Percentages of protected sites in England with at least one nitrogen-sensitive feature where the Site-Relevant Critical Load for Nutrient-nitrogen is exceeded, under S0 and S1 scenarios.

| Scenario | Special Areas for Conservation (SACs) | Special Protection Areas (SPAs) | Sites of Special Scientific Interest (SSSIs) |
|---|---|---|---|
| S0 | 94.9 | 88.9 | 87.5 |
| S1 | 94.4 | 88.9 | 87.2 |
| **Change** | **−0.5** | **0.0** | **−0.3** |

**Table 12** - Maximum Average Accumulated Exceedance of the nutrient-nitrogen critical load, kg N $ha^{-1}$ $year^{-1}$, for protected sites in England with at least one nitrogen-sensitive feature, under S0 and S1 scenarios.

| Scenario | Special Areas for Conservation (SACs) | Special Protection Areas (SPAs) | Sites of Special Scientific Interest (SSSIs) |
|---|---|---|---|
| S0 | 13.72 | 12.86 | 14.13 |
| S1 | 13.68 | 12.80 | 14.07 |
| **Change** | **−0.04** | **−0.06** | **−0.06** |

The ammonia abatement scenario resulted in only small changes to the maps of protected sites where at least one feature was exceeded in terms of nutrient-N critical load level, and of the maximum Average Accumulated Exceedance for protected sites, for SACs (Figure 16), SSSIs (Figure 17) and SPAs (Figure 18). The largest reductions in AAE for SACs are estimated for Mottisfont Bats/Hampshire (also designated as an SPA, with the largest reduction in AAE) and Bredon Hill/Worcestershire, at 1.0 and 0.6 kg N $ha^{-1}$ $yr^{-1}$. Several SSSIs (Dimminsdale, Calke Park, Ticknall Quarries - all Derbyshire/Leicestershire) are estimated to benefit from slightly larger reductions in AAE, at approx. 1.5 kg N $ha^{-1}$ $yr^{-1}$.

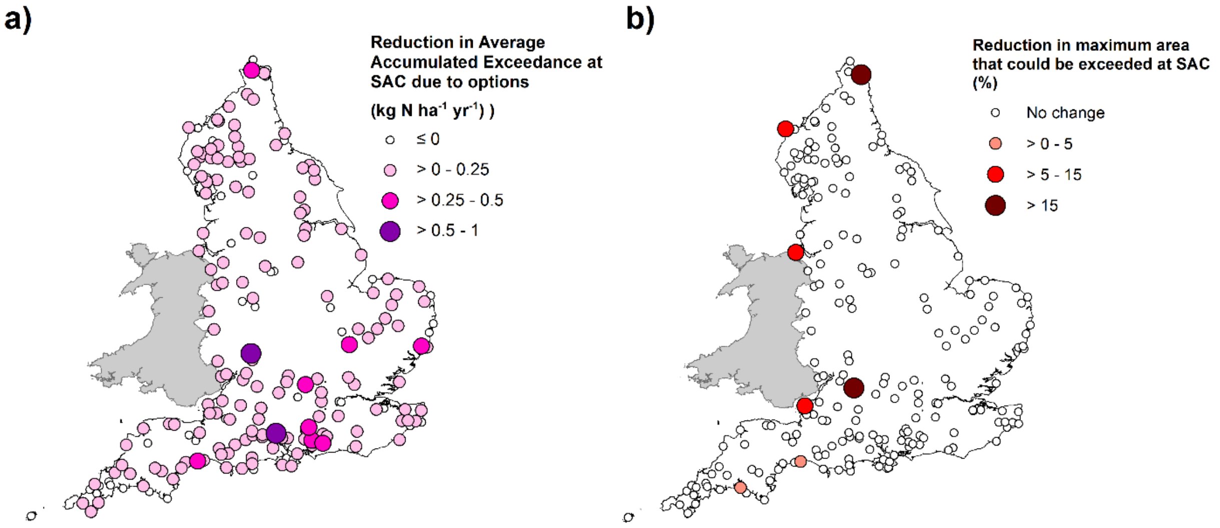



**Figure 16** - Site-based exceedance of nutrient nitrogen critical loads for SACs, where a) shows the reduction in average accumulated exceedance at each site due to $NH_3$ reductions achieved by measures and b) shows the reduction in maximum area that could be in exceedance of critical loads at each site

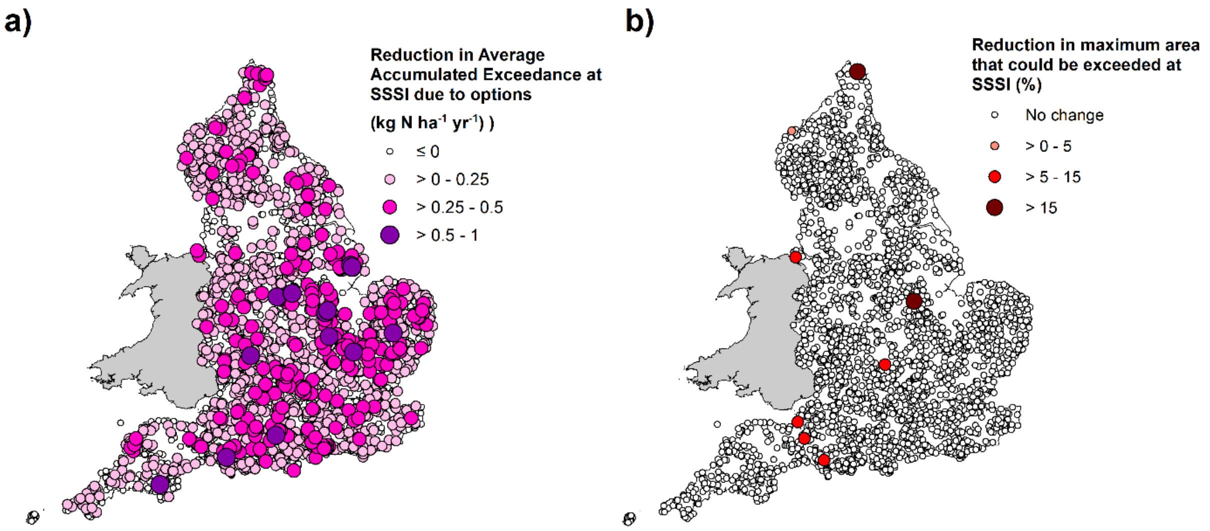



**Figure 17** - Site-based exceedance of nutrient nitrogen critical loads for SSSIs, where a) shows the reduction in average accumulated exceedance at each site due to $NH_3$ reductions achieved by measures and b) shows the reduction in maximum area that could be in exceedance of critical loads at each site

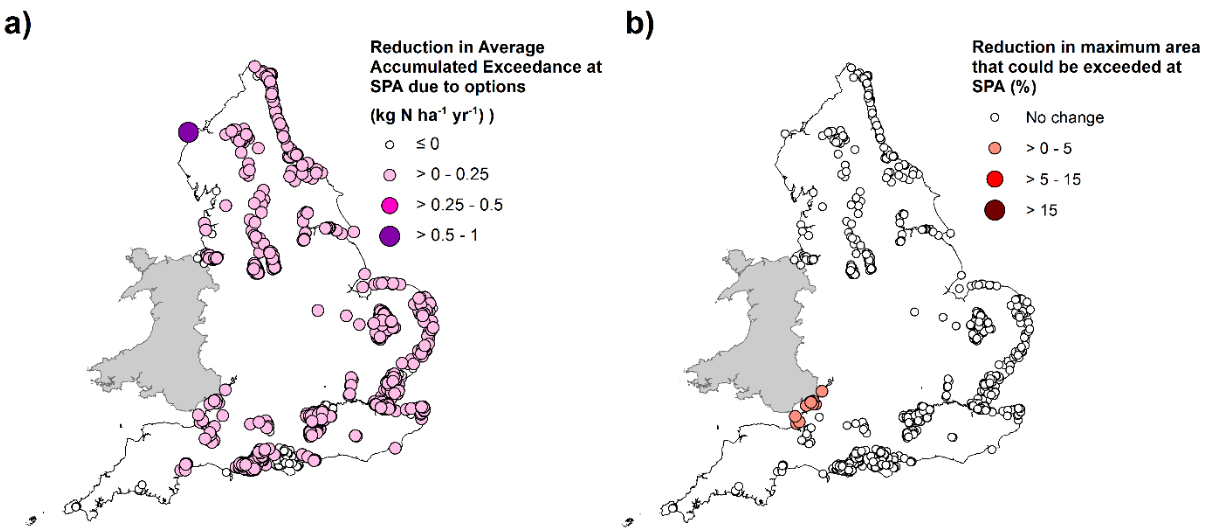



**Figure 18** - Site-based exceedance of nutrient nitrogen critical loads for SPAs, where a) shows the reduction in average accumulated exceedance at each site due to $NH_3$ reductions achieved by measures and b) shows the reduction in maximum area that could be in exceedance of critical loads at each site

## 3.5. Task 5 – Farm case studies

Although limited in number, the selected case studies provide a useful insight into the agri-environment schemes from the applicant's perspective. They also enabled the quantification of $NH_3$ relevance for some measures where the national databases provide insufficient information on management prior to the adoption of measures, and for the very specific tailored measures under the Countryside Productivity Scheme. The full case study questions that were used to guide the interview conversations and summarised answers can be found in Annex 9 (with questionnaire templates presented in Annex 8). The main findings from the case studies have been summarised below:

***Ammonia emission reductions and wider co-benefits:***

- **Countryside Productivity Scheme**
  The three case studies relating to CPS grants all involved purchase of low emission slurry application equipment and would therefore be expected to deliver appreciable reductions in $NH_3$ emissions at the farm level. In practice, estimated reductions in emissions at the whole farm level varied from 8 to 36%. There was actually an increase in 'farm gate' emissions for one farm (by 127%) where the equipment allowed for the import and spreading of much larger quantities of slurry and digestate. This was adjudged to equate to a 21% decrease in emissions if it was assumed that the imported materials had previously been applied by surface broadcast in the vicinity (N.B – import of manure onto the farm's land would likely mean a reduction in manure application elsewhere). The relative magnitude of the emission reduction depended on what other emission sources were present on the farm that were not influenced by the purchase of the low emission slurry application equipment (e.g. for the dairy farm, the cattle housing accounted for a large part of total farm emissions) and also by the proportion of manure on the farm managed using the new equipment (e.g. for the dairy farm there was a significant amount of solid manure being managed as well, for which there would be no emission reduction).

  The main co-benefits noted by the CPS applicants were a reduction in required nitrogen fertiliser purchase and a reduction in odours following slurry/digestate application. One farmer also noted cleaner grass and less scorching, while another noted reduced labour cost, 'healthier' soil and improved weed management. Another benefit noted was the flexibility of the scheme, enabling farmers to identify a bespoke technology solution for improving their application of slurry/digestate, with the three case studies providing examples of a trailing shoe slurry applicator, a deep injection unit together with GPS and slurry flowmeter and a boom trailing hose slurry applicator.

- **Farming Ammonia Grant scheme (FARG)**

  The main case study relating to FARG documents the installation of a floating cover for a large slurry lagoon on a dairy farm in Cumbria. In terms of $NH_3$ emission reduction, the cover is estimated to achieve an 60% decrease, amounting to >3t $NH_3$ $yr^{-1}$ from this single installation. The key incentive for the farmer, however, was not the $NH_3$ benefit, but an estimated saving of £6,000 in operational costs (labour, fuel) he calculated from preventing rainwater additions to the lagoon, for the winter months alone. This is a compelling case in high rainfall areas such as NW England, and the Catchment Sensitive Farming officer (CSFO) involved in the case suggested that other farmers in the area have been convinced by the opportunity for operational savings, and water quality has improved. Further information from another successful FARG application (not worked up into a full case study), at a dual dairy and arable farm in Nottinghamshire, indicates that nitrogen levels in the covered slurry lagoon increased from 5% to 14%, thereby enabling good agronomic use of this as a fertiliser on e.g. a rape crop. This highlights the triple benefits of a) avoiding dilution by precipitation and reduces the volume of slurry to be spread, b) facilitates the integration between the livestock and arable parts of the farm and c) reduces $NH_3$ emissions.

- **English Woodland Grant Scheme (EWGS) and predecessors**
  The case study carried out is typical of EWGS and its predecessor schemes, representing small areas of woodland planted in an agricultural landscape, on land that is generally less suitable for the main objectives of the farmer. The arable farm near Norfolk has gradually planted woodland on a number of small and awkwardly shaped fields that are not easy to manage with large modern farming equipment, in stages, starting 20 years ago (under WGS) and with the most recent grants in 2010 and 2014 (EWGS). Other motivations for planting trees are the use of fallen wood for craft and providing a habitat for birds, but not GHG mitigation, or the potential for $NH_3$ recapture. The farmer also stated that funding was not the main motivation for planting and they would have planted trees anyway, but the scheme helped to do this more quickly.

- **Facilitation Fund (ES and CS measures)**

  The $NH_3$ reduction achieved from uptake of measures by 62 holdings currently participating in the Farmer Guardians of the Upper Thames (FGUT, established 2015) was quantified using Single Business Identifier (SBI) numbers provided by the case study contact. The $NH_3$ reduction by current uptake of measures is estimated at ca. 7,300 kg $NH_3$. This equates to ~1 % of the total reductions achieved by current uptake of agri-environment quantifiable measures across England. The measure with the highest ammonia reduction from farms in FGUT was the CS measure SW1 "4-6 m buffer strip on cultivated land", which is estimated to achieve reductions of 3,650 kg $NH_3$ (i.e. approx. 50% of the total $NH_3$ emission reduction) by taking areas out of production. Figure 19 presents the estimated $NH_3$ reductions achieved across the Upper Thames catchment.

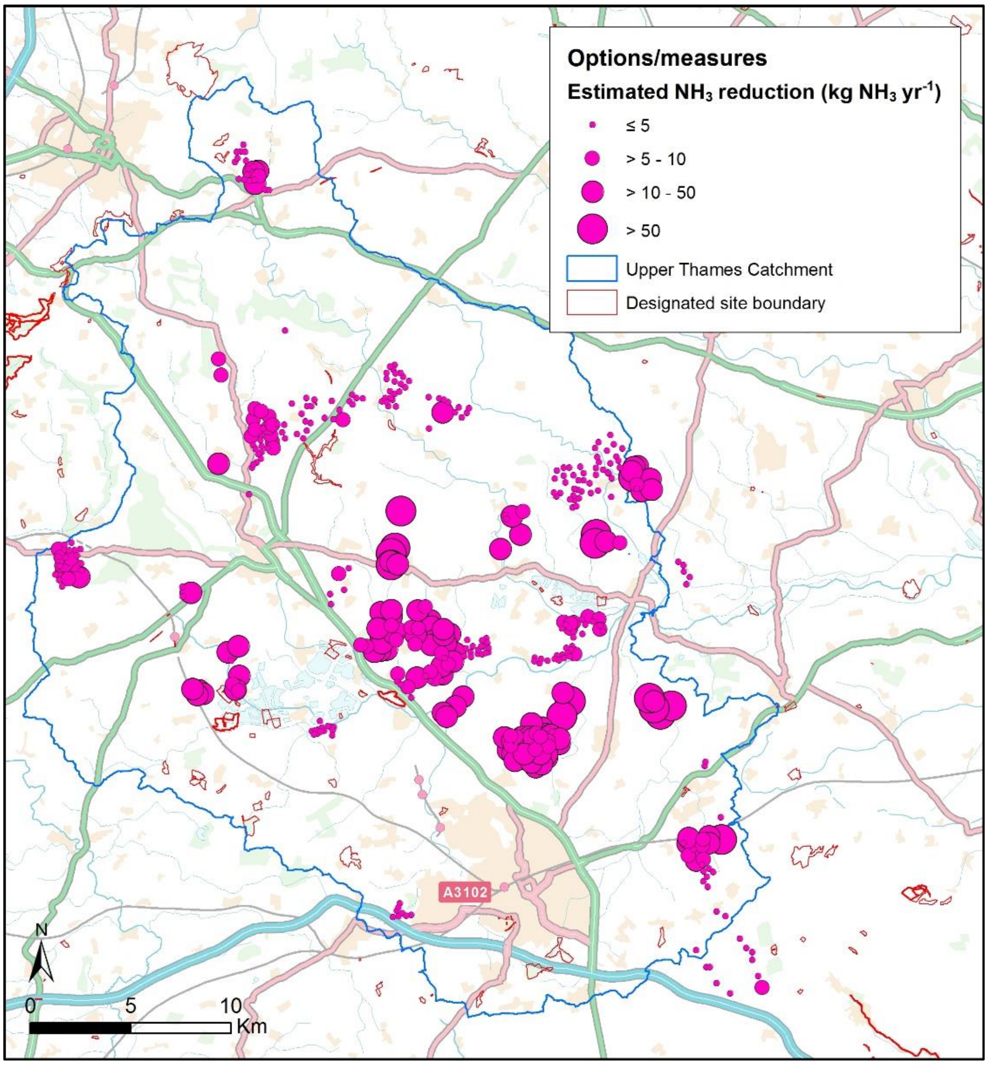



**Figure 19** – Estimated $NH_3$ reduction achieved by current uptake of agri-environment measures from farms in the Farmer Guardians of the Upper Thames.

Given the openness of the FGUT members to new ideas and learning from each other, for the benefit of the landscape and sustainable agricultural productivity into the future, the FF could provide a vehicle for informing farmers of the benefits of low-emission nitrogen management. This would deliver both environmental benefits and operational savings of appropriate measures, such as careful preservation and use of nitrogen present in livestock manures and slurries.

***Applicant's experience of benefits and barriers:***

- **Countryside Productivity Scheme**
  The CPS applicants reported differing experiences regarding the grant application process. Two found the process relatively straightforward, whereas the third found it too complicated and ultimately believes he lost out financially because of a lack of clarity. One farmer mentioned that the minimum grant award value is now set too high and would rule out many smaller family farms, where arguably the need for grant support is greatest, from applying.

His view was that one of the best pieces of equipment for which uptake should be encouraged is GPS for precision fertiliser application, but this would fall well below the current minimum grant award value. All farmers stated that they would not have gone ahead with the purchase of the low emission spreading equipment without the grant assistance. Interestingly, now that they have such equipment (with inherent residual value at the time of renewal), they stated that they would continue with such equipment in the future, even without further grant aid.

- **Farming Ammonia Grant scheme (FARG)**

  The farmer providing the case study information did not have any specific comments on how the FARG application process could be improved. However, the CSFO who helped with the application suggested that all CSFOs and other farm advisory bodies and businesses should be informed about the benefits and co-benefits of slurry store covers. They suggested that this would be extremely beneficial, as explaining the water quality and monetary benefits of FARG had been the key factor for persuading farmers to apply for FARG, rather than the air quality benefits. Anecdotal evidence (not from the case study described here) implied that the time frame between the application being accepted and the deadline for the works to be completed was tight, with a lagoon re-filling with rainwater during the conversion process, and completion being significantly delayed to deal with this. This caused concerns as to whether the grant would be withdrawn and the farmer would be left to pay for the installation if he missed the deadline, despite the farmer and contractors working as fast as they could under the circumstances.

- **English Woodland Grant scheme (EWGS) and predecessor schemes**

  The farmer did not have any specific comments on how the application process could be improved. However, he commented that any simplifications in the administrative process would be welcomed and specifically commended the Forestry Commission contact for his most recent application for their helpfulness.

- **Facilitation Fund (ES and CS measures)**

  The facilitator of the FGUT suggested that, while there was an excellent selection of measures potentially available under CS, the application process was too complex/prescriptive, with the eligibility of certain measures being restricted to high priority ‘red’ catchment zones only, i.e. focussing on water-related issues rather than having a more flexible multi-issue system. Most of the farms participating in FGUT are situated in medium priority ‘yellow’ catchment zones and are therefore not eligible for certain measures under CS. Despite the FGUT promoting the use of herbal lays and wetland restoration among the participating farmers, most CS applications were unsuccessful as they were not considered to be in a high priority area (in contrast with the ES, where there were no priority areas for Entry Level Stewardship). This is despite there being £2,000,000 underspend in CS. The FGUT facilitator thought that this underspend may be in part attributed to the complex application process of CS, with the multiple caveats and targeting in very specific high priority zones, thereby making many farms ineligible for measures. The FGUT is currently working with farmers to communicate their difficulty with the application processes to NE and communicate the considerable barriers with the current application process.

The facilitator thought that the now closed ES HLS was highly successful due to simpler administrative processes and the provision of advice by Natural England officers being included as part of the application process, enabling individual farmers to submit all the necessary details efficiently, with the advisors providing valuable input on measures, indicators of success, derogations etc.

The facilitator commented, *"The ES Higher Level Scheme was really good in design as farmers were given a grant for £3,000 for an external consultant to carry out a Farm Environment Plan (FEP). The FEP consultants were trained by Natural England on how to do the scheme application. If the consultants had a good relationship with Natural England they would work together to make sure the HLS scheme was put together to deliver local targets. Good advisers worked in partnership with NE to help their capacity and deliver good applications."*

In general, however, the FGUT facilitator believed that there were too many caveats and clauses in CS and ES, which makes/made the process too confusing for farmers, who often run relatively small businesses and are not used to the complex process to be followed, and often don't know how to plan for breaking out of conventional farming. There was also a suggestion that there is too much emphasis on capital items and that there are not enough revenue payments available, e.g. to replace foregone income while establishing new improved practices and provide resilience. If funding was allocated to provide more advice and support for farmers, then agri-environment scheme objectives could be delivered more efficiently and targeted where needed, based on trust built up locally and shared common goals (reducing soil loss, pollution, achieving cross compliance).

It was also seen as important that the wider landscape area needs to be factored in, including quality of the land, infrastructure etc. and mutual respect between farmers and grant providers, as many farmers are keen to improve the land they are managing for the long-term and wider benefit and to maintain/create viable agri-businesses that also look after the wider cultural landscape. In the case of CS, the priority red zone for water quality could not be overridden, and in this case, the single issue became a barrier to improving the wider agri-environment at a landscape scale, with its multiple intertwined environmental issues (water quality, soil, biodiversity, greenhouse gases, etc.).

Another concern raised was that there are many ELS/HLS measures (margins, leys etc. converted from through arable reversion to grassland over 20 years, under income foregone measures, initially under Environmentally Sensitive Areas scheme ESA) currently in place with end dates during 2019. A lack of measures to continue maintaining these into the future (and reassurances sooner rather than later) may result in large areas being ploughed up, with serious consequences on habitats and species, water quality, soil degradation, greenhouse gas emissions etc. In terms of $NH_3$ emissions, it can be anticipated that intensification of management practices (with higher N fertilisation) would result in emission increases.

## 3.6. Task 6 – Options for optimisation of schemes for ammonia relevance

**Upscaling the FARG slurry storage cover scheme to England**

Details from the FARG scheme uptake were compared with assumptions made in previous scenario studies regarding covering slurry stores (under the Defra-funded AQ0902 contract (SSNIP), ApSimon et al. 2012). A comparison of approximate volume to surface area ratio (FARG and assumed in SSNIP) and costs per $m^3$ of slurry stored (FARG and derived from ApSimon et al. (2012), SSNIP) is given in Table 13:

**Table 13 -** Comparison of volume/surface ratios for slurry tanks and lagoons, derived from ApSimon et al. (2012) and the FARG handbook and dataset provided by NE

| | Slurry tanks | | Slurry lagoons | |
|---|---|---|---|---|
| | FARG | SSNIP | FARG | SSNIP |
| Volume to surface area ratio | 6.6 | 3.1 | 4.0 | 2.0 |
| Cover cost, £ per $m^3$ slurry | 30.35 | 22.40 | 7.25 | 6.91 |

For both tanks and lagoons, the SSNIP assumption for slurry storage depth was below that based on the slurry store details as entered in the FARG scheme (approx. 60 data points). However, it should be noted that the FARG values were based on farmer estimates of store ***capacity***, so this likely overestimates the actual quantity of slurry stored at any given time. Nevertheless, it seems likely that the SSNIP scenarios may have underestimated the volume to surface area ratio for slurry tanks. Despite this, estimated costs per $m^3$ of stored slurry were still greater from the FARG scheme than the assumptions made in SSNIP, although not too different for slurry lagoon covers. The data from the FARG scheme show that costs can vary considerably on a farm to farm basis.

Based on the FARG scheme values as derived above, costs to cover the remainder of UK slurry storage (cattle and pig slurry currently stored in above-ground tanks or lagoons and currently not covered, a total of approximately 12 million $m^3$) would require a capital cost of approximately £240M. This compares well with the estimate based on the SSNIP assumptions of approximately £200M additional capital cost. These costs are based on slurry volumes, rather than numbers of holdings, which may also influence total costs estimates, e.g. it is probably more cost-effective to cover fewer, larger stores than many smaller ones. Total costs are therefore uncertain, but the above estimates give some bounds.

Ammonia emission reduction achieved by covering all currently not covered cattle and pig slurry tanks and lagoons is estimated to be 6.2 kt $NH_3$ (2% of 297.7 kt $NH_3$ from all sources[2]

[2] including natural emission sources listed as "memo items" (such as wild animals, seabirds and human sweat and breath), in addition to all $NH_3$ emission sources that count against the UK's national emission ceilings. Memo items (total 8.7 kt $NH_3$) are routinely included in atmospheric transport and deposition modelling, so that modelled concentration and deposition surfaces can be compared against monitoring/measurements without bias due to locally important sources being excluded; see http://naei.beis.gov.uk/data/data-selector for details. Excluding memo items, $NH_3$ emissions for the UK in 2016 are estimated at 289.1 kt.

or 2.5% of 253 kt $NH_3$ from all agricultural sources in 2016 for the UK) Capital cost per kg of ammonia emission reduction is therefore estimated to be between £32 and £38 (or an annualised cost of £3.19 per kg $NH_3$ abated).

**Upscaling low emission slurry application techniques (CPS)**

There are insufficient data from the three CPS case studies on which to conduct a costed-upscaling of implementing low emission slurry application techniques across the UK. Costs for individual farm equipment will be very specific and farm size/volumes of slurry applied will greatly influence both costs and cost-benefits.

Under the Defra-funded SSNIP project, scenarios were run with costs of the low emission application techniques based on the additional estimated contractor cost (partly capital, partly operational) compared with broadcast splash-plate application for a typical day-spreading scenario. This might be taken to be equivalent to the additional cost for a contractor spreading operation. Additional costs were estimated in this way to be £0.73, 0.61 and 0.50 per $m^3$ of slurry applied for shallow injection, trailing shoe and trailing hose, respectively. Note that these costs do not take into account any potential savings on fertiliser application which the farmer might make by accounting for the improved use of slurry nitrogen.

Running a scenario in which all slurry applied to grassland is assumed to be by trailing shoe and all applied to arable by trailing hose results in an emission reduction across the UK[3] of 14.0 kt $NH_3$ (4.7 % of 297.7 kt $NH_3$ from all sources or 5.5% of 253 kt $NH_3$ from all agricultural sources in 2016) at an additional annualised cost (rather than up front capital cost) of £14.21M. Based on a 7-year lifetime for the slurry application equipment, capital cost required to achieve this would be approximately £60M, giving a total capital cost per kg $NH_3$ emission reduction of £4.27 (annualised total cost of £1.01 per kg $NH_3$ abated).

It should be noted that funding under CPS is currently only available to farmers but not to contractors due to EU regulations. If funding eligibility could be widened to include contractors (post-Brexit), the $NH_3$ emission reduction benefits of low-emission spreading equipment would benefit much wider areas of the countryside instead of single farms. This could result in a substantial increase in slurry application being carried out using low-emission spreading techniques, and this could help meeting the UK's NEC Directive's targets as well as contribute towards the ambitions of Defra's 25 Year Plan.

**Options appraisal and general issues for future schemes – Environmental Stewardship & Countryside Stewardship**

The following points were discussed with stakeholders and the Project Steering Group, or resulted from the analysis of the data and are summarised here:

- CS seems to be more challenging for applicants in terms of administrative requirements than ES. Case study contacts stated that forms for ES were simpler and that there was

[3] Figures above are given for the UK to relate to NEC Directive ceilings; calculations for England can be summarised as follows: Emission savings are estimated to amount to 7.2 kt $NH_3$ (or 4.5% of 161 kt $NH_3$ from all agricultural sources in 2016). The capital cost required to achieve this is estimated at approx. £7.3M.

funding available under ES/HLS for Farm Environment Plans to support putting applications together. Overall, there appear to be bigger administrative hurdles under CS (with more complex forms and restricted eligibility, and farmers e.g. required to pay for advice themselves). It was suggested that a more flexible system in terms of eligibility (with many CS measures very spatially restricted based on single-issue priority of “red zone” catchments focusing on water quality issues), with appropriate support and guidance available and an as-simple-as-possible application process, would enable better joining up measures for a multitude of benefits, including $NH_3$.

- A concern is the large area of long-term grassland established under ES (which may back-date to earlier ESA schemes) agreements that have either expired or are due to expire in the near future. If no suitable replacement measures are made available under current or future schemes, these low-intensity grasslands may be ploughed up and returned to arable use, with the associated negative effects on soils, biodiversity and $NH_3$ emissions (assuming increased nitrogen fertiliser input). From discussions with case study contacts and the Steering Group, it appears that there has been less uptake of such measures under CS compared with ES.
- For a large number measures under ES/CS supporting low-nitrogen application rates, it is currently not possible to quantify their impact on $NH_3$ emissions, as no data are collected on N application rates pre-application. For many extensively managed grasslands, for example, N application rates may not differ pre-/post implementation of a measure, however the adoption of the measure ensures that the N application regime is not radically altered towards a more intensive use. A simple additional question for all such measures on the current N application rate (pre-measure, in kg N $ha^{-1}$), with no pressure to show a reduction for eligibility (and recording of the rate in the measures database) would allow the $NH_3$ impact for a large number of measures to be quantified and therefore reduce uncertainty in future assessments of the benefit provided. In fact, this simple additional data point on N application rates, collected more widely, where it does not influence eligibility, would enable the derivation of additional insights into the spatial variability of N application rates across large areas of England (while not trying to replace the systematic and carefully stratified annual reviews of fertiliser use by crop of the British Survey of Fertiliser Practice[4]).
- A joined-up approach on measures linked with keeping precipitation off surfaces used for livestock housing, collecting yards, manure and slurry storage (e.g. CS RP28, RP15 etc) could also provide many additional benefits (as has been shown clearly by the FARG Scheme, in terms of increasing storage capacity by keeping out precipitation and reducing the need for additional efforts required to spread diluted slurry in high-rainfall areas). A joint effort with the veterinary service (animal health benefits), smart advice and more efficient livestock building design (welfare, water use, scrubbers/filters for air pollution, ease of cleaning/keeping floors clean) could, over time, create more resilient and efficient systems and deliver across multiple objectives.

[4] https://www.gov.uk/government/collections/fertiliser-usage

**Woodland grants for creation and maintenance of woodland specifically for $NH_3$ recapture**

Under previous and current schemes, woodland creation has been supported by grants. None of these grants are/were specific to designing and planting woodland for the purpose of recapturing $NH_3$ emissions from sources such as livestock houses or manure storage facilities, or close to sensitive receptors, as a buffer zone. Tree belts designed and planted specifically, in terms of location relative to the emission source or sensitive area to be protected, width and structure of the woodland, suitable species etc. could provide substantial secondary mitigation (i.e. mainly reduction of elevated $NH_3$ concentrations or deposition rather than reduction of primary emissions). It would however, be essential that the woodland is carefully designed and maintained to achieve maximum possible recapture efficiency (for details on tree belt design see WA0719, Appendix 7, Theobald *et al.* 2003 and Theobald *et al.* 2001), and would take time for the trees to grow to fulfil the recapture role for maximum benefit.

If areas of woodland of similar dimension to those in the case study (approx. 30m width) were planted immediately downwind of ammonia emission sources such as pig or poultry houses, they are estimated to recapture ~ 17% of the emissions. This estimate is based upon full growth to 10m height and a relatively dense canopy with a Leaf Area Index (LAI) of approx. 6 (Bealey et al. 2014, Theobald et al. 2003). However, a specially designed area of woodland, optimally located downwind of or surrounding an emission source such as a livestock house (Figure 20 below), can achieve up to 27% recapture.

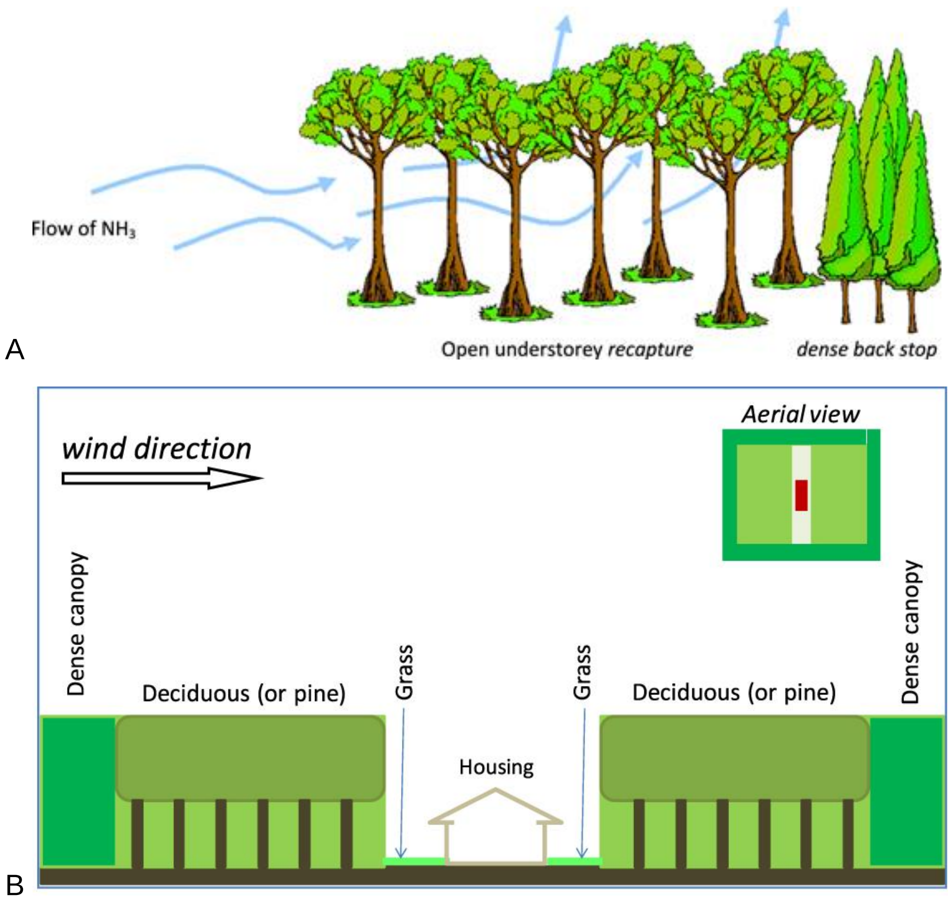



**Figure 20** – a) schematic diagram of a tree belt designed to maximise ammonia recapture (Theobald et al. 2003). b) Example tree belt surrounding a livestock house (from Bealey et al. 2014)

It should be noted that in prime arable areas (such as East Anglia/Lincolnshire), it would be difficult to encourage woodland creation on good quality agricultural land, as income from high-value crops such as potatoes, onions or carrots) is at least one but often more orders of magnitude higher than the grants per unit area of woodland offered. As shown in the EWGS/WGS case study in Norfolk, the farmer only considered converting small and awkwardly shaped fields that were difficult to manage with large modern farm machinery. Also, larger areas of woodland may provide wood fuel in due course, but narrower strips are not seen as providing economic value, compared with high-value arable crops.

**Other potential measures/policy options not currently widely used in the UK**

Further options to reduce $NH_3$ emissions from agricultural land use (not necessarily through agri-environment or equipment bases schemes such as CS, FARG, CPS but also wider measures) could include:

- Promoting the use of lower-emission mineral fertilisers over high-emission options such as urea (i.e. by regulating the cost per unit of N to the farmer and making, e.g., ammonium nitrate a more attractive option than urea)
- Promoting the use of additives such as urease inhibitors to reduce emissions (e.g. by subsidising low-emission options country-wide; not suitable for equipment-based schemes such as CPS or FARG)
- Providing training and supporting the purchase of systems to enable safe acidification of slurry (and digestate) to reduce $NH_3$ emissions from landspreading (e.g. in a similar way to Denmark, where this has been successfully introduced). In particular, if contractors could be supported, in addition to individual farmers, this could be rolled out relatively quickly, as the investment in new equipment/turn-over of existing equipment tends to be faster than on many farms. Training would also need to include looking after the soil to avoid acidification where this may be an issue.

Some of these options are already included for in the current CPS (e.g. mild acidification equipment, with the scheme documentation stating that “this must include mixing tank, acid storing and dosing equipment), and the first grants have recently been implemented on pig farms (David Sillett, RPA, pers. comm). However blanket policy approaches would be the obvious way forward for e.g. making one type of fertiliser more attractive than another for all users (farmers, managers of other types of grassland such as golf courses, parks and gardens, sports facilities etc.). Other mitigation measures, such as rapid incorporation of manures, are included in guidance for good agricultural practice, and e.g. lower protein diets for livestock are already widely used in the pig and poultry sectors.

# 4 Conclusions

The aim of the study was to **assess existing agri-environment schemes and other grant schemes in England for their ammonia ($NH_3$) mitigation potential**. This included desk studies to assess $NH_3$ emission relevance, quantify uptake, spatial patterns and benefits of the measures on emissions, concentrations and impacts on sensitive habitats and designated sites, as well as a number of case studies, and to consider options for future scheme designs for optimising $NH_3$ mitigation. The schemes investigated here were the **Countryside Stewardship scheme** (CS), **Environmental Stewardship scheme** (ES), **Countryside Productivity Scheme** (CPS), **Farming Ammonia Grant scheme** (FARG) and **England Woodland Grant Scheme** (EWGS).

All measures were assessed for $NH_3$ relevance and categorised into 6 groups: **direct emission reduction** (e.g. reduced N input, slurry store covers), **potential emission reduction** (may temporarily displace emissions but not reduce at the farm level), **potential recapture** (by trees), **potential increase** (typically through removal of trees), **unquantifiable** (i.e. highly dependent on local circumstances) and **negligible** (i.e. unlikely to result in emission reductions, e.g. restoration of historic buildings, management of hedges). Of the nearly 800 measures assessed, 16% were considered $NH_3$ relevant, through direct emission reduction (12%), potential emission reduction (2%) and recapture (2%), with 65% estimated as negligible and 18% as unquantifiable. FARG is the only scheme directly targeted at reducing $NH_3$ emissions (100% relevant), whereas only ca. 10 and 16% of all CS and ES measures are considered to provide quantifiable $NH_3$ emission reductions. EWGS woodland planting measures are relevant in terms of potential recapture, but this is difficult to quantify. The CS scheme's main objective is to improve farm productivity, but the policy objective of reducing $NH_3$ emissions influenced scheme design to include relevant technologies.

In terms of **uptake across England**, a relatively small proportion of the area taken up by measures was for $NH_3$-relevant measures (5% of CS, 0.4% of ES, 100% of FARG). Uptake of measures **near designated sites** (N-sensitive SACs, SPAs, SSSIs and all RAMSAR sites) was quantified within zones of 2, 5 and 10 km from the sites' boundaries. For SACs, ca. 200 $km^2$ of $NH_3$-relevant measures are located within 2 km distance to at least one site. Virtually all measures are within 10 km of at least one SSSI, however, the proportion of directly $NH_3$-relevant measures as part of all measures is relatively small.

The **emission reductions** associated with measures/options identified as achieving a quantifiable $NH_3$ reduction were implemented in the national scale emission maps as two scenarios, with (S1) and without (S0) the measures' $NH_3$ reductions included. Overall, there is a **very small difference in emissions that can be associated with quantifiable $NH_3$ relevant measures difference, at 0.75 kt $NH_3$-N, equivalent to 0.6% of agricultural $NH_3$ emissions** in England. **The Top-10 current measures contributing to $NH_3$ reduction are associated with buffer strips, slurry store covers, arable reversion, legume and herb-rich swards and unharvested cereal headlands, which together contribute 75% of the total emission reduction by relevant measures**. CS dominates overall, contributing $^2/_3$ of the emission reductions, with ES contributing 23% and FARG 10%.

Measures classified as "Unquantifiable" are likely to add further emission reductions, however it was not possible to quantify these, as no information was available on management practice with regard to N input prior to implementation. In summary, despite covering by far the smallest area of land and the smallest number of grants awarded, FARG was by far the most effective scheme in terms of reducing $NH_3$ emissions, as it was targeted specifically. Following on from the small reductions in emissions, atmospheric concentration and deposition and effects modelling showed only small reductions in critical loads and levels exceedances for sensitive habitats and designated sites England-wide, as expected. However, for some individual designated sites, exceeded areas were estimated to have decreased, depending on the vicinity to relevant measures.

For the **case studies**, information was gathered through an initial questionnaire to assess each farm's specific situation and any measures present, with a tailored follow-up interview by telephone to discuss the benefits of the measures, in terms of ammonia and other aspects, any barriers and further perspectives. The selected case studies provide a useful insight into the agri-environment and CS schemes from the applicant's perspective. They also enabled the quantification of $NH_3$ relevance for some measures/options for the case study example where the national databases provide insufficient information on management prior to the adoption of measures, and for the very specific tailored measures under CPS.

Experience from applicants varied, with some finding the processes relatively straightforward (for ES, EWGS, FARG generally compared with CS), whereas others found it too complicated, in terms of eligibility (CS), the minimum grant award set too high (CPS, effectively ruling out smaller family farms that would welcome support for purchasing less expensive equipment). From the three CPS case studies, all farmers stated that they would not have upgraded their equipment without grant assistance, but that they would continue with the new systems in the future, even without future grant aid.

Farmer collectives such as the Facilitation Fund which help farmers with their applications for agri-environment schemes and other grants as part of a catchment/landscape approach could be an ideal mechanism to deliver ammonia-relevant measures at the landscape/catchment scale. If additional scheme funding was allocated under CS (or future schemes) to provide advice and support for farmers, then this could be targeted where needed based on expert advice, systematically delivering on multiple environmental objectives. This would also enabling local/landscape scale targeting for air quality benefits (e.g. could link with NE's Shared Nitrogen Action Plans (SNAPS). Given the openness of the FGUT members to new ideas and learning from each other, for the benefit of the landscape and sustainable agricultural productivity into the future, the FF could provide a vehicle for informing farmers of the benefits of low-emission nitrogen management. This would deliver both environmental benefits and operational savings of appropriate measures, such as careful preservation and use of nitrogen present in livestock manures and slurries.

In terms of **optimising existing schemes and measures and identifying gaps** to deliver an integrated approach, it is clear that, to achieve substantial $NH_3$ emission reductions through future schemes and grants, $NH_3$-relevant measures need to be specifically targeted, as $NH_3$ co-benefits from existing schemes mainly targeted at biodiversity, water, cultural landscapes, access and soils are currently relatively small. The main exception to this under current schemes and grants are FARG and CPS, where tailored systems such as covering slurry stores and enabling low-emission landspreading of slurries can be very effective. Grants for planting woodlands (EWGS & predecessors), if adapted to design, plant and maintain tree belts specifically for $NH_3$ recapture close to emission sources, could be very effective at providing secondary mitigation (currently woodland planted under grant schemes is rarely in a suitable location or of appropriate size and structure for specific $NH_3$ benefits). A joined-up approach on measures to **keep precipitation off surfaces used for livestock housing, collecting yards, manure and slurry storage** could also provide many additional benefits (as shown by FARG), e.g. increasing storage capacity by keeping out precipitation and reducing the need for additional landspreading effort in high-rainfall areas. This could also result in animal health benefits, reduced water use etc. and, over time, create more resilient and efficient systems to deliver across multiple objectives. **Providing training and supporting the purchase of systems to enable safe acidification of slurry (and digestate)** could reduce emissions from landspreading, and the first related CPS grants have recently been implemented on pig farms, Other measures to reduce $NH_3$ emissions from agricultural land use, such as promoting the use of lower-emission fertilisers over high-emission options or inhibitors, through regulation are likely to be better suited for **country-wide implementation** rather than on an individual grant basis. If this was implemented, emission reduction benefits would be wider than the farming sector, including public and private use of fertilisers for parks, gardens, sports facilities etc.

The motivations for applying for grants are diverse, and it is interesting to note for that for FARG (with its specifically designed $NH_3$ reduction measures), **the key benefits incentivising the applicants are operational and economical**. In the case of FARG, the potential for substantial reductions in slurry dilution through preventing precipitation into slurry stores provide significant annual savings in labour and fuel costs through reduced amounts of slurry volume. Highlighting these co-benefits and better agronomic use of the retained N (as also evidenced in the CPS case studies for low-emission slurry spreading equipment) could make such highly $NH_3$ relevant measures very attractive for farmers and encourage uptake, thereby resulting in **substantial $NH_3$ emission reductions and improved N use efficiency.**

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# 7 Appendices

## Annex 1 – Table of measures (Task 1)

## Annex 2 – Measures with zero uptake in the data provided by NE (Task 2)

## Annex 3 - Proximity of measures to designated sites (Task 3)

## Annex 4 – GIS datasets of $NH_3$ relevant measures relating to distance from designated sites (SSSI, SAC, SPA, RAMSAR)

## Annex 5 - Table of reductions in $NH_3$ emissions per relevant measure for England (Task 4)

## Annex 6 – Critical levels exceedance summary statistics per designated site (Task 4)

## Annex 7 - Critical load exceedance summary statistics per designated site (Task 4)

## Annex 8 – Case study questionnaire templates (Task 5)

## Annex 9 – Case studies per farm/farm group (Task 5)

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