Identification of Potential "Remedies" for Air Pollution (nitrogen) Impacts on Designated Sites (RAPIDS)

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Defra project AQ0834

13 October 2015

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Client Defra

Client reference AQ0834

CEH reference NEC0534

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Date 13/10/2015

Executive Summary

- **Atmospheric nitrogen (N) deposition** is a significant threat to semi-natural habitats and species in the UK, resulting in on-going erosion of habitat quality and declines in many species of high conservation value.
- The **main sources** of atmospheric N deposition are **nitrogen oxides (NO_x)** from vehicles, industry and electricity generation and **ammonia (NH_3)**, mainly from agricultural sources. The range of sources affecting designated sites was summarised into five key ***scenarios***, which were generated in order to develop and illustrate a generic framework to target mitigation measures:
    1. Lowland agriculture (many diffuse sources)
    2. Agricultural point source(s)
    3. Non-agricultural (point) source(s)
    4. Roads
    5. Remote (upland) sites affected by long-range N input
- It is estimated that 68% of UK habitats receive **damaging levels of N deposition** (i.e. exceeding critical loads, 2010 data). At the same time, a substantial proportion of sites is estimated to exceed the 1µg m^{-3} NH_3 critical level (67% in 2010), with similar numbers predicted for 2020. This means that the UK will struggle to meet its national and international biodiversity commitments.
- The project focused on impacts and remedies for designated conservation sites, especially **Natura 2000 sites** protected under the EU Habitats Directive. However, the approach and certainly the measures could be equally applied to other areas of high conservation value. Evidence was drawn together to develop a **framework for identifying key N threats at individual sites** as a basis to **target mitigation options** in the context of **potential legislative, voluntary and financial instruments**.

Identifying and quantifying key sources of atmospheric N pollution on individual designated sites

- Key data for identifying N pollution sources for individual designated sites are **UK-scale atmospheric N deposition, concentration and emission maps** and related datasets. Through modelling, the contribution from different emission sources can be determined at any location **(‘source attribution’**). This information (5 km grid) is also available via the public **UK Air Pollution Information System** (APIS).
- It is important that the national scale (5 km grid) datasets are complemented with more detailed information, due to the **large spatial variability of N deposition at a landscape scale**, especially with regard to point sources (e.g. large intensive livestock farms, industry) and line sources (e.g. busy roads). Key datasets include the **large point source databases** maintained under the Industrial Emissions Directive (IED) from environmental regulators and **road traffic data** from the Department for Transport.
- For detailed local/landscape scale, the most relevant existing tools include the publicly available **source-receptor screening tool** SCAIL and bespoke **local scale atmospheric dispersion modelling**.

Potential measures and delivery mechanisms

- **Implementation of measures and policies** has resulted in **substantial reductions in NO_x deposition** over recent decades, for vehicle, combustion and industry sources, under strong regulatory frameworks. The main barriers for further reductions are the need for technology advances and behavioural change to limit resource use. Emissions and deposition of NH3 have much lower levels of reduction except in Denmark and the Netherlands where significant reductions have followed the implementation of strict regulatory frameworks.

- A suite of most promising **potential measures/remedies** was identified from the large body of evidence, including measures for a) reducing emissions from nearby sources and b) reducing deposition through secondary measures such as tree belts.
    - The main groups of measures targeted at reducing NH_3 emissions from **diffuse and point agricultural sources** are (in order of cost-effectiveness): improvements to manure spreading (e.g. slurry injection where possible), manure storage (e.g. covering of stores) and agricultural livestock housing. These measures can be tailored specifically to reduce emissions from locally relevant agricultural sectors and management practice. Landscape measures such as **tree buffers** are highly relevant for large intensive pig and poultry farms, as they work best around well-defined emission sources such as concentrated livestock houses. However, they are not a substitute for emission reductions and will take at least a decade to grow to the necessary size to become fully effective (N.B. Near designated sites, they would have to be carefully assessed for unwanted hydrological or other ecological side-effects). In planning applications for new sites, local protection of a designated site may be much improved by landscape-planning, i.e. siting the development further away.
    - Options for **emission reductions from non-agricultural (point) sources** are often relevant for NO_x, though some processes can also emit NH_3. The suitability of measures depends very much on source characteristics and may be very specific to the local site, for sources as diverse as combustion plants, industrial processes or shipping. Many processes under this group fall under either or both the IED or Large Combustion Plant directive, which provide stringent requirements for emission levels. Where sources comply with BAT but are still estimated to contribute substantially to adverse effects at a Natura 2000 site, a permit review in relation to the Habitats Directive may require further mitigation (e.g. BAT+).
    - For reducing the impact of emissions from **major roads** near designated sites, remedies include improved traffic management (e.g. optimising traffic flows, re-routing of traffic, traffic charging schemes), physical measures such as roadside barriers (with catalytic surfaces and/or to disperse NO_x to lower atmospheric concentrations), and/or trees fulfilling a similar role.
    - For sites where most of the N deposition received originates from **long-range transport** (especially many of the upland locations), locally targeted measures are rarely effective, as they typically focus on dispersing or recapturing the gaseous or aerosol fractions at or close to the sources. For such sites, the only effective approach is to **reduce regional/national scale emissions**, and with the UK’s location with regard to prevailing winds, the UK will be the largest beneficiary of any national actions to reduce N emissions.
- A wide range of **current and potential future delivery mechanisms** are relevant for reducing N threats to sensitive habitats: incentive, advice and policy and regulatory options. However, most current instruments lack options for atmospheric N (and NH_3), but these could be built into incentive schemes (e.g. environmental stewardship schemes, catchment sensitive farming, woodland grant schemes).Much more emphasis on the reduction of atmospheric emissions of N should be given in good practice documents, especially for agricultural NH_3.
- An **emphasis on voluntary approaches** for UK agricultural NH_3 mitigation has resulted in a very slow uptake of measures, in contrast to mandatory mechanisms elsewhere. The restriction of the IED to large pig/poultry farms represents a gap in agriculture-related mechanisms, with plans or projects often not assessed regarding the Habitats Directive (cattle, medium pig farms, arable farms). While locally targeted remedies may be particularly effective for a number of designated sites, this is not a substitute for overall national and international efforts to reduce emissions, which are necessary to reduce large-scale regionally elevated background N concentrations and deposition.

- The EU is currently preparing to revise its air quality policy, including the **National Emissions Ceilings Directive** (NECD), with a 21% cut in NH_3 emissions proposed for the UK by 2030[1] (compared with 2005 levels). This will require coordinated and targeted measures to achieve.
- At the regional/international scale, increased vehicle usage, international shipping, consumption of animal products and energy show the need to address gaps in policies, which may benefit from **integrating climate, air pollution, human health and water policies** to avoid unintended trade-offs.
- Cost-effective N abatement could be much larger through NH_3 measures rather than further NO_x measures, with environmental benefits exceeding the costs for 3 times as much reduction of NH_3 than for NO_x. Average costs of additional NH_3 and NO_x control for the UK (technical measures only) are estimated at €2.7 and €1.2 per kg of N, respectively (based on GAINS modelling).

Time scales for implementation of measures and recovery of habitats

- **Achieving emission reductions** with **agricultural measures** is immediate for manure or fertiliser application measures (if equipment available). Retro-fitting of housing and manure storage measures is often prohibitively expensive, with measures more cost-effective when facilities are replaced (10-50 yrs). For **road transport**, emission reductions are mostly derived from technological advances which typically take 5 -10 yrs to filter through the fleet. Acceleration may be possible through legislation (e.g. London Congestion Charge). **Landscape-scale measures** (e.g. low emission zones around sites) could provide immediate benefits, while tree belts need 10-20 yrs of growth to become fully effective.
- **Timescales for recovery of ecosystems** depend on the receptor, the decline in N input and the amount of N already accumulated. First signs of improvement are likely within 4 yrs (especially for epiphytes), although substantial recovery may take decades and systems may not return to pre-impact states. The speed and nature of the recovery may be affected by on-site restoration measures.

Evidence to demonstrate success of remedies

- Evidence for success can take various forms, and be measured in terms of:
  - Reduced emissions through uptake of measures quantified/verified by resulting changes in N concentrations/deposition (requiring atmospheric monitoring and/or modelling of change).
  - Local habitat-based biological/biogeochemical indicators, such as floristic change, tissue N content, plant-available N in soils, nitrate concentrations in aquatic habitats. Such evidence for success needs to be considered together with timescales for recovery of the habitats and species.
- A key requirement for demonstrating success at a site level is baseline monitoring (especially for N concentration and deposition rates, and the more responsive indicators) before measures are implemented, and a consistent methodology for detecting change over time. At the UK scale, data from monitoring networks or, Countryside Survey are available and have been used as evidence.
- For designated sites, the current Common Standards Monitoring is not designed to detect or attribute gradual trends in species composition change, but could be augmented by the inclusion of permanent monitoring quadrats. Other repeatable surveys at sites with historical data could provide alternatives. The 'biomonitoring chain' concept links key indicators from emission to deposition with species responses for evidence of success.

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[1] The 2020 target for NH_3 (8% reduction from 2005 baseline) reflects ambition already agreed by member states.

Draft framework for producing site action plans & case study examples

- An 8-step draft framework was developed under RAPIDS, guiding the user through:
    - Identifying major atmospheric N sources for each designated site (with national & local scale data)
    - Selecting suitable measures from for each site, based on local conditions
    - Checking local availability of spatially targeted instruments (e.g. agri-environment schemes)
    - Detailed assessment of measures or, for remote sites, referral for higher-level actions.
- The draft framework was piloted for UK SACs and A/SSSIs, and illustrated for several **case studies**. It clearly showed that there is no single 'one size fits all' solution, and spatial considerations of relevant N sources at sites are needed for cost-effective mitigation.

Main uncertainties in the evidence, evidence gaps & potential future work

- **Key uncertainties** for source attribution lie in the **UK scale model data**, due to the relatively coarse resolution of model input and output data for use at the scale of individual designated sites. The UK scale data are the best source for providing rapid initial best estimates for source attribution, but need to be supplemented with local evidence of source characteristics for identifying effective measures.

- **Evidence gaps** can be grouped into different **priorities for future work**, based on the evidence analysed and summarised under RAPIDS. These include a) **field demonstration/experimental evidence of cost-effective measures** for guidance on planning locally targeted landscape remedies, b) further **experimental studies on long-term effects of N deposition and quantification of the rates of recovery**, c) **improved spatial resolution of UK N deposition** datasets and d) a **new source attribution dataset** that reports the different chemical N species in more detail, allowing proportions of local/ medium/ long distance atmospheric transport for each source type to be distinguished. The outcomes of the RAPIDS project (and the subsequent IPENS projects) could be made available to conservation and regulatory agencies in the form of a **decision support tool**, for assessment of all sites.

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Contents

1. Background

Summary

- **Atmospheric nitrogen (N) deposition** is a significant threat to semi-natural habitats and species in the UK, resulting in deterioration of habitat quality and declines of many species of high conservation value due to nutrient imbalances.
- The main sources of atmospheric N pollution are **nitrogen oxides (NO_x)** from vehicles, industry and electricity generation and **ammonia (NH_3)**, mainly from agricultural sources.
- **Implementation of measures and policies** has resulted in substantial reductions in NO_x deposition over recent decades, however NH_3 emissions and deposition reductions have generally not achieved the same levels except in Denmark and The Netherlands where strict regulation has resulted in large emission reductions.
- The present project focuses on impacts and remedies for designated conservation sites, especially **Natura 2000 sites** protected under the EU Habitats Directive. However, the approach is equally applicable to sensitive habitats outside protected sites. Evidence is drawn together to develop a **framework for identifying key N threats at individual sites** as a basis to **target mitigation options** in the context of **potential legislative, voluntary and financial instruments**.

Atmospheric nitrogen (N) deposition represents a significant threat to habitats and species in the UK. It leads to nutrient imbalances associated with eutrophication and acidification that result 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. In the UK, 68% of habitats are subject to excess atmospheric N deposition, i.e. exceed the critical load for eutrophication (Defra, 2013). Atmospheric N threats result from the emissions of both **nitrogen oxides (NO_x)** to the atmosphere from vehicles, industry and electricity generation, and of **ammonia (NH_3)** to the atmosphere mainly from agricultural sources. Substantial efforts have been placed in UK and European policies over the last years to reduce air pollution emissions, including the use of 3-way catalytic converters on cars, and these have substantially reduced NO_x emissions. By contrast, so far, much less has been achieved in reducing NH_3 emissions in the UK.

In this context, UK ecosystems, including habitats and species listed in the **EU Habitats Directive** (under Article 17 reporting) remain under substantial threat. The EU is currently preparing to revise its air quality policy, including the **National Emissions Ceilings Directive** (NECD), with a 21% cut in NH_3 emissions proposed for the UK by 2030[2] (compared with 2005 levels). This will require coordinated and targeted measures to achieve. This project therefore synthesises current knowledge on the available opportunities for reducing NO_x and NH_3 emissions, their atmospheric concentrations and deposition to designated nature conservation sites, providing the conditions to avoid further damage and allow recovery of UK ecosystems.

More generally, poor air quality is forecast to be the world’s main environmental cause of premature mortality by 2050 (OECD 2012). Air pollution has profound effects on a range of human health issues, e.g. causing or exacerbating conditions such as respiratory illness, heart disease and cancers (WHO 2013). In 2010 the UK Environmental Audit Committee recorded that the costs to the UK are similar to those caused by smoking and obesity[3]. Poor air quality in the UK reduces life expectancy by an average of 6 months at a health care cost of £16 billion per annum (Defra 2010). A number of parts of the UK

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[2] The 2020 target for NH_3 (8% reduction from 2005 baseline) reflects ambition already agreed by member states.

[3] House of Commons Environmental Audit Committee Report, Air Quality: A follow up report. Ninth Report of Session 2010-12, Hc1024. http://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/inquiries/air-quality-a-follow-up-report/

breach ambient legal limits for NO_x and will require a range of measures to reduce impacts. Improving air quality for human health offers many co-benefits to reduce impacts on sensitive habitats. For example, controls on NH_3 emissions in the rural environment will greatly reduce concentrations of ammonium nitrate, which form a major component of particulate matter ($PM_{2.5}$) in many urban environments. According to AQEG (2012), regional background concentrations are dominated by secondary $PM_{2.5}$, primarily ammonium nitrates and ammonium sulphates.

Within the context of nature conservation it is particularly important to relate the extent of the N air pollution threat to habitats and species, especially given the significant extent to which thresholds for air pollution effects on **designated conservation sites** are exceeded across the UK (e.g. Special Areas of Conservation, SACs, Sites of Special Scientific Interest, SSSIs and Areas of Special Scientific Interest, ASSIs). This report therefore focuses on drawing together the evidence to develop an approach that can be used to identify and target options for N pollution mitigation on designated sites. The options include both **off-site[4] source-oriented measures and landscape-oriented measures** that optimise spatial relationships between emission sources and sensitive habitats, supported by cost information to identify the most promising measures. This evidence is then considered in the context of **potential legislative, voluntary and financial instruments** that can be used to provide incentives to support N pollution mitigation, especially in the context of strengthening the UK Green Economy.

To guide users through the identification of measures, a selection of **case studies** is analysed in more detail, as a basis to inform how options might be worked out in practice. Particular attention is given to NH_3 emissions from **agriculture**, but other types of local sources, including transport and industry, are also included. The project has been established on a rapid timescale during late 2013/early 2014 to provide scientific evidence, scenario analysis and technical advice in direct support of the revisions of EU air quality policy and the Improvement Programme for England’s Natura 2000 Sites (IPENS[5]).

2. Objectives of the project

The key objectives of the project are:

a) To identify (off-site[6]) measures and delivery mechanisms to reduce reactive nitrogen (N) deposition on freshwater and terrestrial Annex I Habitats[7] within designated nature conservation sites, and in the wider countryside.
b) To provide a detailed assessment of key aspects surrounding the implementation of identified measures and remedies for reducing N deposition, and
c) To develop a framework for identification of the key N threats for each site and for site-level application of the measures.

While the focus of this report is on local agricultural and road transport sources, other sources for both reduced N and oxidised N, including industry, are considered. The contract documents also contain specific sub-objectives that are covered in the report below. It is worth emphasising that, while the focus of this report is reducing deposition to designated sites, the actions can also benefit sensitive habitats outside of designated sites. The extent of this depends on the approach of each measure as outlined in the results.

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[4] Off-Site interventions are defined here as such as a) **emission reduction measures** primarily designed for use outside designated site boundaries (e.g. low-emission manure spreading) and b) **secondary measures to recapture emissions** (e.g. planting of trees belts), rather than c) **on-Site habitat management-type measures** (e.g. burning, cutting, shrub removal, grazing management of sensitive habitats), which were agreed to be beyond the project boundaries. As measures under a) and b) may be equally applicable inside and outside Site boundaries, the distinction for inclusion of measures under RAPIDS is made using types of measures rather than strictly geographical boundaries.

[5] http://www.naturalengland.org.uk/ourwork/conservation/designations/sac/ipens2000.aspx

[6] See footnote 2

[7] Annex I habitats and Annex II species in the UK: http://jncc.defra.gov.uk/page-1523

3. Methods and results

The main report is supplemented by a series of Appendices, to provide more detailed descriptions of background, methods, evidence and datasets used in the project and case study examples. For clarity in this section, the project work packages (WPs) these documents contribute to are shown in brackets.

- **Appendix 1. Definition of source attribution scenarios**
  Definition of five main scenarios of contrasting source attribution to illustrate the key nitrogen (N) threats to designated sites across the UK, to illustrate typical case studies for the development of a generic/practical framework for identifying the main N threats for each site. (WP1.1)
- **Appendix 2. Background and data sources for source attribution**
  Description of information/data and models/methods required for identifying and quantifying N threats for a robust assessment of sites, available data sources, including limitations and gaps. (WP1.2, WP4, WP5, WP6.1, WP6.2, WP6.4)
- **Appendix 3. Table of key measures for mitigating N pollution**
  Description of measures, including N pollutant targeted, allocation to scenarios, emission sectors, effectiveness, costs, applicability, barriers to uptake, co-benefits and trade-offs, current and potential future delivery mechanisms (WP1.3, WP2.1, WP2.2, WP3.1, WP3.2, WP3.3)
- **Appendix 4. Mechanisms for the delivery of reduced N emissions, concentrations and deposition**
  Collation of key mechanisms available in the UK (and devolved administrations), including regulatory, incentive, advice and other possible financial-based schemes, and relevance to the aims of the project. (WP1.3)
- **Appendix 5. Pilot scenario allocation to UK SACs and A/SSSIs**
  Method and results for initial allocation of all UK designated sites to the five RAPIDS scenarios of key N threat, using key data sources available to the project (WP6.1, WP6.3, WP6.4)
- **Appendix 6. Case studies to illustrate source attribution and assessment of potential mitigation measures (‘remedies’) to reduce N pollution impacts on UK SACs and A/SSSIs**
  Illustrative description of draft framework at case study sites, to identify key N threats and suitable measures for reducing N concentrations/deposition to each site (WP6.3)
- **Appendix 7. Critical Loads and Levels**
  Summary and illustration of current critical loads and critical levels assessment UK-wide and at the individual site level (site-relevant critical loads), including limitations of available data (WP4, WP5, WP6.4)
- **Appendix 8. Challenges in the implementation and benefits of voluntary agri-environment schemes and tax/subsidy systems**
  Review of economic issues/challenges in the implementation of agri-environment schemes, contrasting voluntary and tax/subsidy schemes (WP1.2, WP3.2)
- **Appendix 9. Timescales of intervention and recovery, and evidence of success**
  Review of current knowledge on timescales for implementation of measures, N impacts on habitats and recovery from N pollution, as well as evidence required to demonstrate the success of measures using indicators, on-site monitoring and interpreting vegetation change (WP2.3, WP4, WP5, WP6.1, WP6.2)
- **Appendix 10. Guidance note on draft framework for producing site action plans**
  Detailed guidance on the proposed approach, including flow diagrams and walk-through example for the draft framework (WP6.1)
- **Appendix 11. Contributors to the project** (including delivery team and affiliations of the Steering Group) who have influenced the work, for transparency.

3.1. Source attribution, identification of potential measures ("remedies") and delivery mechanisms

3.1.1. Definition of scenarios

Summary

- The wide range of N sources affecting designated habitats were summarised into a set of five key ***scenarios***, for the development and illustration of a generic framework to target mitigation measures.
- The five scenarios were defined as follows:
    1. Lowland agriculture (many diffuse sources)
    2. Agricultural point source(s)
    3. Non-agricultural (point) source(s)
    4. Roads
    5. Remote (upland) sites affected by long-range N input

Five scenarios were developed and illustrated with case studies to demonstrate key issues from a range of N sources affecting sensitive receptors in the UK. These scenarios and associated case studies were presented as generic examples to illustrate the key N threats to designated sites across the UK (see ***Appendix 1***, Definition of Scenarios). The case studies represent actual (but anonymised) examples selected from the Natura 2000 network of Special Areas of Conservation (SACs), Sites of Special Scientific Interest (SSSIs, Great Britain) and Areas of Special Scientific Interest (ASSIs, Northern Ireland). It should be noted that some modifications were made regarding site details, local emission sources and potential measures, for illustrative purposes.

The scenarios agreed with the Project Steering Group (StG) are:

Scenario 1: Lowland agriculture (many diffuse sources)
Scenario 2: Agricultural point source(s)
Scenario 3: Non-agricultural (point) source(s)[8]
Scenario 4: Roads
Scenario 5: Remote (upland) sites affected by long-range N input

It was found that most sites fall under more than one single scenario, and therefore the case studies used (Section 3.6.3, ***Appendix 6***, case study examples) to illustrate the scenarios often reflect more than one key threat. The case studies should therefore be seen as exemplifying the numbered scenarios, while not excluding other key N pollution sources. The factors considered in defining the scenarios and case studies include:

- N deposition composition and transport (e.g. wet vs. dry N deposition, oxidised vs. reduced N, near- vs. long-range sources),
- Receptor types (e.g. size, habitat types, neighbouring conditions, surrounding area)
- Sources of N pollution (e.g. intensive livestock agriculture, arable farming, transport)
- The UK perspective with regard to the views of Devolved Administrations, i.e. scenarios and case studies selected to represent the breadth of UK conditions

The fact that many designated conservation sites are influenced by more than one type of N from a mixture of sources is reflected in the decision tree/flow approach (Section 3.6) for identifying both key N threats and potential measures or 'remedies'.

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[8] Given the need for a simple system with a maximum of five major source attribution categories, a number of different source types were aggregated under this scenario (Sc3), including both regulated sources (e.g. large combustion plants and industrial processes) and a wide variety of miscellaneous non-agricultural or road transport sources (domestic combustion, waste processing, shipping, etc.)

3.1.2. Identification of tools for identifying emission sources/source attribution

Summary

- Key data sources for identifying N pollution sources for individual designated sites are **national-scale atmospheric N deposition, concentration and emission maps and related datasets**. Through modelling, the contribution from different emission source types can be estimated for any location **('source attribution modelling'**). This source attribution information is also available via the **UK Air Pollution Information System** (APIS), a public online portal, which provides the data at a 5 km grid resolution.
- Another key group of datasets for identifying emission sources close to designated sites are the **large point source databases** held under the Industrial Emissions Directive (IED) from environmental regulators and the **road traffic data** from the Department for Transport (DfT).
- In addition to these public data sources, further data such as high resolution agricultural census/ survey data may be available under license to authorised government agencies and public bodies.
- For more detailed local scale assessments, i.e. at the landscape level, the most relevant existing tools include the publicly available **source-receptor screening tool** SCAIL and bespoke **local scale atmospheric dispersion modelling**.
- It is important that the national scale (5 km grid) datasets are complemented with more detailed information, due to the **large spatial variability of N at a landscape scale**, especially with regard to point sources (e.g. large intensive livestock farms, industry) and line sources (e.g. busy roads).

Threats from atmospheric N compounds may originate from gaseous concentrations (NO_x, NH_3) or atmospheric deposition of different forms of N, the latter by either wet or dry deposition. The identification of sources and quantification of their contributions ('*source attribution*') can then inform the targeting of measures to protect the sites in question.

To enable conservation agency staff to carry out comprehensive source attribution assessments for a site/habitat, both national-scale datasets, models and tools as well as local knowledge/assessment (or access to local expertise) are required. Currently, there are a number of interactive tools and data download sites available to help with identifying pollution sources for individual designated sites (for more details on the tools and datasets, see ***Appendix 2***, source attribution data). The most relevant tools are summarized briefly below:

- UK national datasets (atmospheric N concentrations and deposition maps from the CBED (available on APIS) and FRAME models, Critical Loads and Levels exceedance maps, Defra's long-term atmospheric concentration and wet deposition measurement networks etc.)
- Information portals on source attribution (e.g. the Air Pollution Information System, APIS) and local scale source-receptor screening (e.g., the Simple Calculation of Ammonia Impacts Limit tool, SCAIL)
- Other national spatial datasets on emissions for diffuse, line and point emission sources (atmospheric emission datasets from the National Atmospheric Emission Inventory NAEI, the large point source databases under the Industrial Emissions Directive (IED) from environmental regulators (EA, SEPA, NRW, NIEA) and Department for Transport (DfT) road traffic counts).

In addition to the publicly available data listed above, further data sources (such as the high-resolution agricultural census/survey data) may be available under license to authorised government agencies and public bodies. However their use would be governed by any data agreements negotiated, to satisfy the data providers who are responsible for safeguarding the data.

In many cases, national scale deposition or concentration datasets and related tools (such as APIS) will identify major threats and source attributions for each 5 km grid square (current best available resolution) and any designated sites present. However, they should, where possible, not be used in isolation for site assessment , but together with relevant more detailed information, due to the spatial variability of nitrogen at a landscape scale, especially with regard to point sources (e.g., large intensive livestock farms, industry) and line sources (busy roads). Another limitation of the national scale source attribution data is that they are only updated periodically (due to cost reasons), hence sources and associated N threats present at the last revision may have changed. Local-scale atmospheric dispersion models are also an important tool applied by specialists (e.g. environment agencies, consultants). Such models are employed to support permit applications and renewal, and results may be available for a number of designated sites already. However, these are resource-intensive tools, requiring detailed bespoke input data on emission sources (location, source characteristics and emissions, local meteorological data, land use, topography etc.) and expert knowledge.

3.1.3. Identification of remedies

Summary

- A suite of most promising potential measures/remedies was identified from the large body of evidence available, including measures for a) reducing N emissions from nearby sources and b) reducing N deposition through secondary measures such as tree belts and other barriers.
- The main groups of emission reduction measures include modification/improvements to agricultural livestock housing and diet, manure storage and landspreading for NH_3, and technical combustion and road transport measures for NO_x.

For each of the scenarios developed, a suite of off-site remedies were investigated. These provide a range of options and an initial prioritisation based on semi-quantitative and qualitative criteria.

Suitable remedies or measures are identified, these include measures for:

a) reducing N emissions from nearby sources at the source and
b) reducing N deposition (and/or NO_X/NH_3 concentrations) through secondary measures such as tree belts and other barriers, which intercept and dilute/disperse the pollutant and thereby reduce N input at the sensitive receptor.

There are a large number of potential measures for reducing N emissions from specific sources or for reducing N deposition (and/or NO_x and/or NH_3 concentrations) at sensitive sites. A large body of literature exists relating to NO_x and NH_3 mitigation. For agricultural NH_3 mitigation measures, the key source documents are the UNECE Guidance Document on Preventing and Abating Ammonia Emissions from Agricultural Sources (UNECE, 2014), the Mitigation Methods User Guide (Newell Price et al., 2011) developed as part of Defra project WQ0106, and additional information on costs from ApSimon et al. (2012). A full table of the most relevant measures (including sources of information) is presented in ***Appendix 3***, including existing and potential future delivery mechanisms.

An overview of these measures, grouped by emission source or activity, is given in Table 1, together with an indication of their effectiveness (based on the sources in the paragraph above) and the scenario for which they are appropriate. It should be noted that the implementation of relevant measures (regionally, nationally or internationally), irrespective of the emission sector targeted, will reduce concentration and deposition across wider areas and benefit sites particularly affected by long-range deposition, where local sources may only contribute small proportions of the atmospheric N input.

It should be noted that **Table 1** includes both measures related to emission reduction (e.g. technical measures, behaviour change) and those related to the optimization of source-sink relationships. In the case of the latter, Agroforestry for Ammonia Abatement (AAA) uses both the dispersive effect of tree belts as a barrier and the uptake of NH_3 into the tree canopy to mitigate the effects of NH_3 emission/ deposition[9]. Case studies under Defra project AC0201 illustrated that tree belts are being used on UK

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[9] The recent Defra AC0201 project (Agroforestry for ammonia abatement) showed how tree belts can result in NH_3 concentration reduction of 10-25% depending on the structure of the trees when used in a downwind shelter belt

farms for many purposes including silvo-pastoral applications and therefore AAA can be achieved as a side benefit to those purposes if the tree planting density and geometry are optimized for AAA. It should be noted that such local measures are primarily of benefit to nature areas in source regions with high gas and aerosol concentrations. By comparison, it would require substantial regional tree planting activity in order to affect N deposition at the UK scale.

Table 1. Overview of types of remedies or measures available to reduce N emission and deposition to designated nature conservation sites and their effectiveness. For a detailed list of potential measures see Appendix 3.

Measure category	**Target impact**	**Effectiveness, % emission reduction†**	**Scenario**	
Modify livestock diet (match protein intake to requirement)	NH$_3$ emission	10-30	Lowland agriculture (diffuse), Agricultural point source	Remote (upland) sites affected by long-range N input
Modify/improve livestock housing facilities/practices	NH$_3$ emission	30-80	Lowland agriculture (diffuse), Agricultural point source	
Modify/improve manure storage facilities/practices	NH$_3$ emission	50-90	Lowland agriculture (diffuse), Agricultural point source	
Modify manure application practices	NH$_3$ emission	30-90	Lowland agriculture (diffuse)	
Modify fertiliser application practices	NH$_3$ emission	40-80	Lowland agriculture (diffuse)	
Combustion measures	NO$_x$ emission	10-70	Non-agricultural (point) source	
Road transport	NO$_x$ emission	10-90	Roads	
Consumer behaviour measures (transport, energy, dietary choices)*	NO$_x$ and NH$_3$ emission	20-45	All scenarios	
Buffer strips (low-emission agriculture or conversion to semi-natural vegetation)	NH$_3$ and N deposition	5-40	Lowland agriculture (diffuse), Agricultural point source	
Agroforestry for Ammonia Abatement	NH$_3$ and N deposition	5-60	Agricultural point source	

†Emission reduction refers to the specific source that the mitigation measure targets, not to the sector or scenario as a whole. Wide ranges reflect the availability of several different measures within the listed category and differences in implementation rather than the uncertainty of specific measures in each category, as compared with the reference situation, which reflects the common practice prior to implementation of the abatement remedies. * For example scenarios considered in work by the UNECE Task Force on Reactive Nitrogen (see Westhoek et al., 2014).

3.1.4. Summary of delivery mechanisms (current and under development)

Summary

- A wide range of current and potential future delivery mechanisms are relevant to the implementation of measures to reduce N threats to designated sites, including incentive, advice, and policy and regulatory options.
- Many of the currently available instruments are not directly targeting measures to reduce atmospheric N near designated sites, however they could be revised to include relevant options to specifically deliver on NH$_3$ reduction. In particular, this applies to incentive schemes, such as environmental stewardship schemes, catchment sensitive farming and woodland grant schemes.

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configuration, and up to 60% when livestock are housed under the canopy. The effectiveness of these measures can be modelled by applying different leaf area indices and densities (LAIs, LADs), different tree belt widths and canopy structure, percentage NH$_3$ recapture is varied for realistic densities of vegetation.

There are a range of instruments relevant to the implementation of measures to reduce N concentrations and deposition on sites of conservation importance (and the wider landscape, more generally). These include incentive, advice and regulatory schemes, some of which have a specific aim of targeting N air pollution, while others provide co-benefits from measures suggested for other purposes. Instruments have been identified through a review of relevant policy and literature and discussions with experts within Defra and other relevant organisations. It is recognised that delivery mechanisms need to be seen in combination, not only between pollution threats but also together (Sutton et al., 2013).

Many of the current instruments are not directly suitable for targeting measures to reduce atmospheric N near designated sites, however they could be revised to include relevant options to specifically deliver on NH_3 reduction. In particular, this applies to incentive schemes, such as environmental stewardship schemes or catchment sensitive farming grant schemes. These are currently focusing on wildlife/biodiversity and nitrate leaching, with measures often less effective for atmospheric NH_3 emissions and N deposition. Woodland grant schemes are currently focusing on increasing woodland coverage, biodiversity, amenity and carbon benefits, and their benefits with regard to NH_3 are not realised, as tree belts are not specifically located and designed to maximise NH_3 or NO_x recapture near sources or designated sites.

Instruments relevant to each of the scenarios are given in Table 2 and are described in more detail in ***Appendix 4***. Thirteen relevant regulatory instruments were identified, ranging from protocols of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) to national regulations. Five types of incentive scheme were identified, although a number of these varied in their details between the Devolved Administrations (Table 3). Advice also is available through a range of schemes and strategies (see ***Appendix 4*** for further details). In addition there are industry-led schemes, such as the Campaign for the Farmed Environment that includes the Greenhouse Gas Action Plan[10] which could deliver reductions in NH_3 emissions as a co-benefit, however these are not covered in detail in RAPIDS.

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[10] http://www.nfuonline.com/science-environment/weather-and-climate-change/ghg-emissions-agricultures-action-plan/

Table 2. Policy and regulatory, incentive, advice and potential future instruments relevant for each scenario. Instruments shown in brackets are not directly relevant to the scenario in question, but have the potential to provide some benefit. Supra-national level instruments are highlighted in *blue*, national level instruments in *green* and local level instruments in *purple*. Explanations of abbreviations below.

	Relevant instruments			
Scenario	Policy and Regulatory	Incentive	Advice	Future
Diffuse agriculture	CLRTAP	CSF Grants	Biodiversity Framework	Clean Air policy
	NECD	(Agri-environment)	CoGAP	NECD revision
	Habitats Directive	(PES)	CSF	Natura 2000 Theme
	IED/IPPC			(CAP reform)
	EIA and SEA Directives			
	(WFD)			
	(Nitrates Directive)			
Agricultural point source	IED /IPPC Review of Consents	Agri-environment	Biodiversity Framework	CAP reform
	EIA	Woodland grants	CoGAP	Natura 2000 Theme
	Habitats Directive	Woodland carbon	Catchment	CSF Ammonia
	WFD	CSF Grants		(Clean Air policy)
	Nitrates Directive	PES		(NECD revision)
	Water resources			
	UNECE Guidance			
	(CLRTAP)			
	(NECD)			
Non-agricultural point source	IED/IPPC Review of Consents	Woodland grants	Biodiversity Framework	Natura 2000 Theme
	EIA	Woodland carbon	AQMA	LAQM review (Scot)
	Habitats Directive	PES	EMS	(Clean Air policy)
	LCPD			(NECD revision)
	AAQM			
	BREFS			
	(CLRTAP)			
	(NECD)			
Roads	EIA	Woodland grants	Biodiversity Framework	Natura 2000 Theme
	Habitats Directive	Woodland carbon	DMRB	(Clean Air policy)
	AAQM		AQMA	(NECD revision)
	EES			
	(CLRTAP)			
	BREFS			
	(NECD)			
Remote (uplands)	CLRTAP		Biodiversity Framework	Natura 2000 Theme
	NECD			Clean Air policy
	Habitats Directive			NECD revision
				(Shipping)

Abbreviations: AAQM - Ambient Air Quality Assessment and Management Directive, **AQMA** - Air Quality Management Areas, **BREFS** - Best Available Techniques Reference Documents**, CAP reform** - Common Agricultural Policy (CAP) reform, **Catchment** - Catchment based advice schemes, **Clean Air policy** - Clean Air Policy Package, **CLRTAP**- Convention on Long-range Transboundary Air Pollution, **CoGAP** - Codes of good agricultural practice, **CSF** - Catchment Sensitive Farming, **CSF Ammonia** - Catchment Sensitive Farming Ammonia Pilot scheme, **CSF Grants** - CSF capital grant scheme, **EES** - European Emission standards, **DMRB** - The Design Manual for Roads and Bridges, **EIA** - Environmental Impact Assessment Directive, **EES** - European Emission standards, **EMS** - Environmental Management Systems, **Habitats Directive** - The Conservation of Natural Habitats and of Wild Fauna and Flora Directive, Gothenburg Protocol **IED** - Industrial Emissions Directive, **IPPC** - Integrated Pollution Prevention and Control Directive (now replaced by IED), **LAQM review (Scot)** - Review of Local Air Quality Management in Scotland, **LCPD** - Large Combustion Plant Directive, **Natura 2000 Theme** - Natura 2000 Theme Plan, **NECD** - National Emission Ceilings Directive, **NECD revision** - National Emission Ceilings Directive revision, **PES** - Payment for Ecosystem Services Schemes, **SEA** - Strategic Environmental Assessment Directive, **Shipping** - Shipping Emission Control Area, **Strategies** - National Biodiversity, land use air quality and environment strategies, **UNECE Guidance** - UNECE Guidance Document for the prevention and control of ammonia emissions, Water resources **Woodland carbon** - Woodland carbon code, **Woodland grants** - National woodland grant schemes, **WFD** - Water Framework Directive.

Table 3. Names of voluntary schemes relevant for reducing N deposition to designated conservation sites where they differ between the Devolved Administrations.

	Agri-environment schemes	Woodland grants	Priority catchment schemes
England	Entry Level Stewardship and Higher Level Stewardship	English Woodland Grant Scheme	Catchment Sensitive Farming
Wales	Glastir Entry and Advanced schemes	Glastir Woodland Creation Grant	Welsh Catchment Initiative
Scotland	Land Managers Options and Rural Priorities	Scottish Farm Woodland and Forestry Grant schemes	Priority Catchments
Northern Ireland	Northern Ireland Countryside Management Schemes	DARD NI Woodland Grant Scheme	River Basin Management Planning Northern Ireland

3.1.5. Description of remedies according to the source sector scenarios

Scenarios 1 and 2: Remedies for diffuse agricultural sources and agricultural point sources

Summary

- A wide range of potential measures to reduce N threats to designated sites from agriculture is available, from a large body of evidence, both for sources of a more diffuse character (application of manures and mineral fertiliser to arable crops and grass, small livestock houses with associated manure storage) and larger installations of a point source type (large livestock houses).
- One focus area for diffuse emissions is the application of manures and fertilisers, which are one of the main UK emission sources (approx. 40% of agricultural emissions in 2012), and measures are cheaper, faster and easier to implement than those related to livestock housing, which are expensive to retro-fit. Such measures could be implemented through a combination of incentive schemes including environmental stewardship and capital grants (e.g. via CSF).
- A range of other measures, for low emission manure stores or animal housing could be promoted via capital grant schemes, but this would necessarily be on a much longer time scale than measures related to manure and fertiliser application, due to the slower implementation rates.
- Reducing N deposition (or atmospheric concentrations) through secondary measures such as tree belts is another focus area for agricultural measures, which is relevant to both diffuse and point sources. Tree belts can be targeted both around point sources and upwind of designated sites, which can be more effective where there are a large number of diffuse sources. Ammonia-specific tree belt options and designs could be strategically located with woodland grant schemes.
- Strategies for improved N use efficiencies and reduced N surpluses (including optimised animal diets) can be very efficient and contribute to the Green Economy. While the market may act automatically to select such approaches, both awareness raising and guidance are needed if wide adoption should be achieved voluntarily.

Consideration of agricultural remedies focuses on the control of NH_3 emissions, especially from livestock manures and use of fertilisers. Remedies to agricultural NH_3 emissions include both **classical emission abatement techniques**, such as low emission housing systems and manure spreading techniques, or covering of slurry stores (as summarised by the UNECE Guidance Document on Ammonia), as well as **landscape approaches including buffer zones and tree belts** (e.g. Defra projects AC0109 – Ammonia Future Patterns, AC0201 – Agroforestry for ammonia abatement).

Remedies related to agricultural point sources (Scenario 2) are also included here, as many of the measures, in particular those relating to livestock housing, animal diets and manure storage are relevant to both agricultural scenarios, despite differences in emphasis.

The decision regarding which package of measures to apply as remedies for a designated site will often depend on local circumstances and the main contributing sources identified. **Characteristic diffuse sources of NH_3** include the land-spreading of livestock slurries and farmyard manures, together with contributions from livestock grazing and application of urea based fertilisers. These add into a mix of diffuse sources in the rural environment with small-scale (i.e. non-IED[11]) livestock housing and manure storage. Among these options, the UNECE Task Force on Reactive Nitrogen (UNECE, 2011) identified low-emission application of manures and fertilisers to land as the highest priority of existing measures, based on availability, applicability, cost and significance of contribution. The measures analysed by UNECE (2011) include the following main groups:

a) **Manure application**: immediate or fast incorporation into the soil, using trailing hose, trailing shoe and other band spreading and injection methods, and slurry dilution via irrigation.

b) Low-emission application of urea **fertilisers:** immediate or fast incorporation into the soil, coated pellets, urease inhibitors and fertiliser substitution.

c) Other priorities: **improved animal feeding strategies**, low emission techniques for new **manure stores**, and strategies for **improved nitrogen use efficiencies and reduced nitrogen surpluses**.

The importance of these measures has also been highlighted in the European Commission's proposal for revision of the National Emissions Ceilings Directive, by their incorporation of a new technical annex of measures (Annex III). This draws on experience from the revision process of Annex IX in the Gothenburg Protocol (European Commission, 2013; UNECE, 2011[12]).

Measures focusing on reducing emissions from **land spreading** are a priority not only because land spreading represents one of the major emission sources nationally and because they can be implemented at relatively low cost. They are also important because measures targeted at manure management stages prior to land spreading (i.e. livestock housing, manure storage), will be less effective across the overall manure management cycle if they are not combined with land spreading measures. For example, there will potentially be greater N loss at land spreading if N losses are minimised 'upstream' during the manure management cycle and more N is retained in the manure pre-land spreading). These factors combine with the spatial location of manure spreading which can allow intense NH_3 emissions and concentrations (exceeding critical levels) in the immediate vicinity designated conservation sites. In the absence of any legislative requirement (as adopted in NL, DK and Flanders), such measures could be implemented through a combination of incentive schemes including

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[11] The Industrial Emissions Directive (IED) covers intensive pig and poultry farms above specified size thresholds (See http://www.defra.gov.uk/industrial-emissions/eu-international/industrial-emissions-directive/ for further information)

[12] http://ec.europa.eu/environment/air/clean_air_policy.htm

Annex: https://www.google.co.uk/url?q=http://www.ipex.eu/IPEXL-WEB/dossier/files/download/082dbcc5429d1f4a01430ef7f26f44bb.do&sa=U&ei=LxJRU5f0J4avO6zRgagO&ved=0CCwQFjAD&usg=AFQjCNF-JwjIOrnb7EvAWnHEQlEK_jRv1w

environmental stewardship for targeting low-emission spreading zones and capital grants for supporting the uptake of the necessary equipment (e.g. via CSF).

Strategies for improved nitrogen use efficiencies and reduced nitrogen surpluses (including optimised animal diets) can be very efficient. However, they require reliable and accurate advice and promotion of the benefits and savings if they are to be adopted voluntarily and widely.

It is important to consider measures to reduce NH_3 emissions from livestock and fertiliser practices alongside long term trends in rates of production and consumption of livestock products, since increasing consumption may offset the efficiency gains from reducing NH_3 emissions. (This is analogous to Scenario 4 in the trade-off between emissions per car versus vehicle miles). A recent analysis at the European scale illustrated that the potential emission reductions from reducing meat and dairy consumption were comparable in scale with what could be achieved by technical measures (Westhoek et al., 2014). Regional full-chain nitrogen use efficiency will depend on each of these factors, and its improvement can be an important focus emphasising both the green economy benefits of improved efficiency, while offering flexibility on how such improvements may be achieved (Sutton et al., 2013)

Measures specific to large intensive livestock farms (including those covered by the IED) are largely related to NH_3 emissions from animal housing and manure storage. However, the same measures are also potentially applicable under Scenario 1 (diffuse agriculture). One of these options is **Agroforestry for Ammonia Abatement (AAA)**, which is relevant to both diffuse and point sources. Tree belts can be targeted both around point sources and upwind of designated sites, with the latter potentially more effective where there is a large number of diffuse sources. Ammonia-specific treebelt options and designs could be strategically located using woodland grant schemes.

Under the broad concept of AAA, the potential profitability/ practicality of tree belts as a remedy for NH_3 deposition to natural habitats was assessed given knowledge of designs, performance, and recent price/grant information in the Defra project AC0201 (Agroforestry for ammonia abatement). In determining the potential profitability there are two key questions: 1) What is the farm giving up when land is taken for the new purpose, and 2) what is the farm gaining by adopting this new land-use. The project results suggest that on a case-by-case basis tree belts could be economically profitable, depending on the local situation and the availability of grants. It would be useful to further develop the mechanisms for AAA development to incorporate both the potential drawbacks for farmers (land opportunity costs, commercial rates for labour and machinery, establishment timescales, drawing in predators and wild avian species) and designated sites (source of invasive seeds, localised shading and drying) against the benefits (*e.g.* silvo-pastoral agriculture, animal welfare considerations, public policy benefits, biodiversity/ecosystem services, odour mitigation etc).

The overall case for AAA is likely to be favourable if NH_3 emissions are very high, vulnerable habitats are nearby and if there are additional benefits for farm privacy and landscape character (even if this is harder to value explicitly). Payments for public benefits would help mitigate opportunity costs. A mechanism which incorporates AAA into climate change mitigation has also been assessed in ***Appendix 3***. Financial valuation of other ecosystem services (e.g. water quality, amenity and health benefits) associated with tree planting, as well as carbon sequestration benefits, could be expected to further increase the estimated cost-effectiveness of the agroforestry options.

Scenario 3: non-agricultural (point) sources

Summary

- Measures to reduce N threats to designated sites from non-agricultural (point) sources focus mainly on NO_x from combustion sources, which can be broadly separated into primary measures designed into the process technology to minimise emissions at source (e.g. flue-gas recirculation), and secondary measures which control emissions to the atmosphere, such as catalytic reduction.
- The implementation of combustion measures can be challenging, if they have to be retro-fitted to existing installations and may not be cost-effective during the lifetime of the plant.

- Large combustion plants are already strictly regulated, and there is little room for further improvement under normal operating conditions, unless the size threshold is reduced (as proposed in the EU Clean Air Policy Package).

The largest N emissions from these point sources are associated with NO_x emissions from large combustion plants, especially in the electricity supply industry. However, the wide diversity of industrial processes results in both NO_x and NH_3 emissions. The remedies for the non-agricultural point source scenario can be broadly separated into primary and secondary measures. Primary measures are those which are integrated into the source technology by design to minimise emissions at source or during combustion. An example of a primary measure is the recirculation of flue-gas in the combustion zone, in order to reduce oxygen levels and consequently minimise thermal NO_x production. Secondary measures (end-of-pipe technologies) are those which control NO_x emissions, which have been formed in the combustion zone, in the flue gas stream. Examples for secondary measures are selective catalytic or non-catalytic reduction techniques (SCR/SNCR).

Mitigating the threats from these non-agricultural sources can be challenging as most of these measures have to be taken into consideration at the design stage of a plant. While existing plants can be retrofitted with certain secondary techniques such as SNCR, which uses a reagent such as NH_3 to reduce the NO_x formed during combustion, retrofitting costs may not be economically feasible, depending on the remaining lifetime of the plant. These secondary techniques are often as efficient as the primary measures in controlling emissions, but less cost-effective (due to the substantially larger investment and operating costs) and often have considerable environmental trade-offs to consider (e.g. ammonia slip in SCR[13] units increasing NH_3 emissions in order to reduce NO_x). Large combustion plants are strictly regulated already, and if they are operating normally, there will be little room for additional measures that could physically be taken to further reduce their emissions. Fuel switch could be another option (from coal to natural gas, with lower NO_x emissions), however many coal fired plants are already being phased out. If medium size combustion plants were to be regulated more strictly (e.g. as proposed in the EU Clean Air Policy Package[14]), there would be further scope for reducing emissions. However, as the implementation of further emission control legislation at the EU and national level is currently under negotiation, it is at this time difficult to quantify what impact such measures will have on emissions and hence on future deposition levels.

Other emission sources under this Scenario include, for example, anaerobic digestion (AD) and composting plants, domestic combustion, etc. Mitigation measures for AD are still under development, however a critical parameter for reducing NH3 emissions from this source is to reduce the pH of the digestate, which could be achieved through acidification. For smaller sources such as domestic emissions, the use of clean fuel and efficient technology and consumer behaviour measures are the most promising options.

The opportunity for further developing the Green Economy through Nitrogen Oxides Recapture and Utilization (NCU) technologies (harvesting the resulting nitrates) has recently been highlighted, given the substantial potential fertiliser value of the NO_x produced (globally $40 billion annually, Sutton et al. 2013). Significant new technological investment would be needed in order to gain the economic benefits of such an approach in future.

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[13] ***Ammonia slip*** refers to emissions of un-reacted ammonia that result from incomplete reaction of the NO_x and the reagent. Ammonia slip may cause: 1) formation of ammonium sulphates, which can plug or corrode downstream components, and 2) ammonia absorption into fly ash, which may affect disposal or reuse of the ash. In the U.S., permitted ammonia slip levels are typically 2 to 10 ppm. Ammonia slip at these levels is not considered to result in plume formation or human health hazards. Process optimization after installation can lower slip levels. Source: http://www.epa.gov/ttncatc1/dir1/fscr.pdf

[14] http://ec.europa.eu/environment/air/clean_air_policy.htm

Scenario 4: Remedies for road transport sources

Summary

- Measures to reduce N threats to designated sites from road transport sources focus mainly on NO_x from combustion sources, with NH_3 emissions from early types catalytic converters (introduced to reduce NO_x emissions) also contributing substantially to N deposition from roads during the late 1990s/early 2000s. However, the NH_3 threat has decreased from this peak, with newer technologies filtering through the vehicle fleet.
- Local scale threats of N air pollution from road traffic include both the effects of existing busy roads and of proposed road developments, with the most acute threat to designated sites largely limited to areas in close proximity of a major road, around 200 m in most cases.
- Therefore, mitigation measures need to be spatially targeted, rather than relying on new technologies (which are of wider benefit). Localised measures could be implemented through Air Quality Management Areas and the Design Manual for Roads and Bridges, however instruments are primarily aimed at human health effects and less likely to reduce ecological N threats to rural designated sites under current practice.
- Physical measures aim to reduce the pollution threats by road redesign or the installation of roadside barriers to either divert pollution or increase the distance of dispersion.
- Traffic management measures (e.g. adjusting speed levels to traffic conditions or improved traffic flow) and measures to promote public transport aim to reduce congestion and promote greener driving conditions, as well as reduce traffic levels.

Because of the mobile nature of the transport fleet, remedies for road transport sources need to distinguish between national scale approaches (influencing emission rates per car and amount of vehicle use) and local approaches (focused on traffic management).

The development of nitrogen emissions from transport is principally governed by the current state and future improvements to vehicle technology and the overall level of traffic. Modern vehicles emit considerably less N than their predecessors per km driven. The most notable measure has been the introduction of the three-way catalytic convertor in the 1990s, with subsequently more stringent EURO emission standards being introduced. The initial focus of emission limit values for road vehicles on NO_x, CO and PM emissions initially led to a large increase of NH_3 emissions, caused by the reducing conditions inside the early types of catalytic converter (Sutton et al., 2000). Cape et al. (2004) showed that NH_3 was responsible for around half of the total traffic-derived N deposition to roadside verges, due to the larger deposition velocity of NH_3 compared with NO and NO_2. As more recent generations of catalytic converters are filtering through the vehicle fleet, NH_3 emissions from road transport have decreased substantially over recent years, as reflected by decreasing NH_3 roadside concentrations in London (UKEAP monitoring data for Cromwell Road[15]).

Currently, all vehicle standards are introduced by and governed at European Union level. A considerable fraction of these gains for improved air quality have been lost by the overall increase in vehicle km driven over the last decade. The overall level of car use is influenced especially by national scale measures linked to taxation, incentives and the availability and quality of alternative public transport options.

Local scale threats of N air pollution from traffic sources include both the effects of existing roads and of proposed road developments. A new road development (if sufficiently large or if there is a risk of adverse effects on a designated nature conservation site) will typically require an Environmental Impact Assessment (EIA) to be conducted prior to its approval. Potential remedies at the local scale

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[15] http://uk-air.defra.gov.uk

may include re-routing of (existing/proposed) roads as well as the incorporation of tree belt buffer zones into plans. Reference should be taken of the Design Manual for Roads and Bridges (DMRB 2007). In the cases of existing roads, if they fall within Air Quality Management Areas (AQMAs), management plans (for NO_x) need to be prepared, which are carried out at a Council Level. In principle, such plans would be subject to compliance with the provisions of the Habitats Directive. However, given that the criteria for the establishment of AQMAs are based on air quality objectives, such AQMAs are predominantly found in urban centres and are less relevant to rural sites. In addition, for AQMAs which are near Natura 2000 sites, current practice may fail to test the AQMA as a “plan or project” in relation to the Habitats Directive. This highlights an opportunity for improved linkages between health and ecosystem goals of existing legislation.

As the most acute threat from vehicle N pollution to designated sites is mostly limited to areas in close proximity to major roads[16] (Cape et al., 2004), targeted mitigation measures are often necessary, as a complement to the use of low-emission vehicle technologies. This points to the potential benefits of both physical or traffic management measures. Physical measures aim to reduce the pollution threats by road redesign or the installation of roadside barriers to either divert pollution or increase the distance of dispersion. Catalytic surfaces or barriers have recently been publicised as complementary options to take up some of the NO_x (e.g. Eurovia 2013, Armitage and Ryan (2014)). Physical measures can primarily be adopted by the local authorities overseeing road projects or tackling air quality limit value attainment in AQMAs, including the use of buffer zones/tree belts etc. Traffic management measures (such as adjusting speed levels to traffic conditions or improved dynamic signage to trunk roads to increase flow) aim to reduce congestion and promote greener driving conditions.

Scenario 5: Remedies for long-range transport pollution sources

Summary

- The atmospheric N threats to designated sites in remote and upland locations are typically due to long-range transport of N, with potentially substantial N input through wet deposition.
- Measures to reduce the atmospheric N input to remote sites needs to focus on the national and international scale, and the commitment of the UK Government and Devolved Administrations to the Gothenburg Protocol and NECD emission ceilings is critical if reductions in impacts to such nature conservation sites in the UK should be achieved.
- Substantial reductions in NO_x emissions have been achieved across the UK and Europe, and measures to reduce NH_3 emissions are now the most cost-effective option to make further progress in reducing long-range N deposition. Both traditional technical measures and behavioural measures (e.g. consumption, dietary and transport choices, food waste reduction) can play a role.
- There is potentially the opportunity for strategic environmental assessment (SEA) to play a more significant role in evaluating the potential threat of regional and national plans or projects in relation to long-range transboundary nitrogen deposition. For example, regional plans to increase livestock production would presumably need to be tested by linking the SEA and Habitats Directives to ensure the plan contributed no worsening of current adverse effects.

The main source of nitrogen pollution at designated sites in remote and upland locations will typically be wet deposition resulting from long-range air pollution transport. Such sites are characterized by low levels of dry deposition, as large distance from source ensures low levels of primary pollutant gases. By contrast, secondary pollution products, such as aerosols, may still remain significant, especially when combined with high levels of precipitation in upland areas, potentially causing substantial inputs of N through wet deposition. Such ecosystems are typically also extensive in nature with high N inputs

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[16] N.B. Road transport emissions of NO_x and NH_3 also contribute to long-range transport N deposition.

over wide areas. As a result, direct landscape measures in this scenario, such as buffer zones become both ineffective and expensive.

Remedies for this scenario are therefore focused on both national scale pollution emissions and on international agreements, since a considerable fraction of deposition inputs result from trans-boundary pollution sources. The commitment of the UK Government and Devolved Administrations to both the Gothenburg Protocol and NECD emission ceilings is therefore critical if N emissions and associated long range transboundary pollution are to be reduced from both UK sources and from other Parties/Member States.

Traditionally, the measures being addressed in these agreements have focused on technological options, in industry and transport. As a result, substantial reductions in NO_x emissions have been achieved at UK and European scales. By contrast, much less attention has been given to reducing NH_3 emissions from agriculture, which now represents the main opportunity for further cost-effective mitigation of regional scale N emissions (van Grinsven et al., 2013). In parallel, while much attention has been given to technical measures, much less attention has been given in the context of the CLRTAP to the societal consumption patterns that are especially driving increased N emissions. Options here include measures related to transport choice, energy consumption and dietary choice (Sutton et al., 2011). There are opportunities here for linking strategies between climate and N policies, for instance via the improvement of nitrogen use efficiency, reducing costs to farmers and at the same time N losses (e.g. emissions into air of NH_3 and N_2O), thus contributing to both air pollution and climate change mitigation (UNEP, 2013). In addition, reducing food waste and animal protein intake would affect the whole agricultural production chain, with a wide range of environmental benefits (Westhoek et al., 2013).

In considering the balance between technical measures and policies that affect production/consumption patterns, there are opportunities for remedies where policies explicitly target an increase in production. In the transport sector, although vehicle use has increased, policies such as improved public transport have attempted to curb the ongoing increases in emissions. By contrast, a recent picture is emerging where certain countries in the European Union are specifically targeting to increase livestock production in their countries. In such a situation, there is potentially the opportunity for strategic environmental assessment (SEA) to play a more significant role in evaluating the potential threat of regional and national plans or projects. For example, such regional or national plans to increase livestock production would presumably need to be tested by linking the SEA and Habitats Directives to ensure the plan contributed no worsening of current levels of adverse effects (Sutton et al., 2011b).

3.1.6. Gaps in remedies and delivery mechanisms

Summary

- It is evident from the persistently high levels of exceedance of the N critical loads and NH_3 critical levels across the UK in general and for designated sites, that measures implemented so far do not provide sufficient protection to sensitive habitats and species. This is mainly due to a lack of implementation of potential remedies, which in turn is largely due to the absence of suitable current delivery mechanisms.
- A wide range of technological and spatial mitigation measures for agriculture are available and many have been implemented successfully elsewhere (e.g. The Netherlands, Denmark), while maintaining profitable agricultural sectors. The main exception is a shortage of economically feasible options for naturally ventilated cattle housing (with the main solution being to allow cattle to graze outdoors at least for part of the year, thus avoiding year-round cattle housing).
- In the UK, the emphasis on voluntary approaches for agricultural NH_3 mitigation has resulted in a very slow uptake of measures, in contrast to the adoption of mandatory mechanisms elsewhere. The restriction of the IED to large pig and poultry farms represents a gap in agriculture-related

delivery mechanisms, resulting in agricultural plans or projects often not being assessed in relation to the Habitats Directive (e.g. cattle, medium size pig farms, arable farms).

- The introduction of NH_3-specific options to future environmental stewardship schemes, catchment sensitive farming grant schemes and woodland grant schemes could make a contribution to targeted implementation of measures around sensitive habitats. To be able to quantify the resulting reductions in emissions and N deposition in general and to designated sites in particular, however, would require an overhead in data collection and record keeping.
- At present in the UK there are air quality objective values for many air pollutants including SO_2, NO_2, O_3 and particulate matter. Future inclusion of an air quality objective for NH_3 concentrations into this suite would increase the tools available to reduce N deposition to Natura sites.
- At the regional/international scale, increased vehicle usage, international shipping, consumption of animal products and energy show the need to address gaps in international policies, which may benefit from linking climate, air pollution and water policies to strengthen the N green economy. Such joined-up thinking requires the integrated assessment of emission control options, technologies, costs and effects, to ensure effective and efficient policy developments and to avoid unintended adverse effects due to the measures targeted at a specific source or pollutant.

Based on the current high level of critical loads and critical levels exceedance for nitrogen across the UK and over designated conservation sites (Hall et al., 2011; Hallsworth et al., 2010; APIS, 2014, Appendix 7), it is obvious that there remain significant gaps in the combination of remedies and delivery mechanisms. The focus is first on the possible measures and then the potential delivery mechanisms are considered.

In the agricultural sector, technologies have been available for many years to reduce NH_3 emissions substantially. These range from ambitious, low-emission manure spreading (mandatory in Netherlands for the past 20 years; and in Denmark for 10 years) and chemical air scrubbing techniques for livestock buildings to low-emission manure stores, with similar measures available to reduce NH_3 emissions from urea-based fertilisers. The fact that the Netherlands and Denmark have reduced their emissions by c. 50%, while maintaining profitable agricultural sectors, shows that action to reduce N deposition threats from NH_3 in the UK is not limited by a lack of available measures. A partial exception here applies to cattle farming, where economic approaches to reduce NH_3 emissions substantially from naturally ventilated cattle housing have yet to be developed[17] (in contrast to measures for low-emission spreading and storage of cattle manure; the main measure in this instance is to avoid year-round cattle housing, since grazing is associated with lower NH_3 emissions).

In the non-agricultural point source and transport sectors (Scenarios 3 and 4), substantial progress has been made in reducing NO_x emissions – indicating the effectiveness of technological solutions, such as 3-way-catalytic converters and SCR/SNCR. This points to good availability of measures, although there are indications of diminishing returns as emission limits become more stringent (e.g. challenges in meeting current EURO vehicle emission standards[18]).

The main gaps at the national scale are therefore not associated with the availability of measures, but with the effectiveness of current delivery mechanisms. In the case of agriculture, the dependence on

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[17] The scope for reducing NH_3 emissions from intensive pigs is also rather limited, due to the need for a high level of ventilation to avoid over-heating.

[18] The EURO emission standards refer the legal framework which consists of a series of directives, each amendments to the 1970 Directive 70/220/EEC, staging the progressive introduction of increasingly stringent standards. These standards are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4 and Euro 5 for Passenger Cars and Light Duty Vehicles. The corresponding standards for Heavy Duty Vehicles use Roman, rather than Arabic numerals (Euro I, Euro II, etc.)

voluntary approaches has been associated with a much slower reduction in NH_3 emissions than in countries that have adopted mandatory approaches.

In the present UK context, agri-environment schemes have represented an opportunity for NH_3 measures that have until now not been emphasised, and there is potential to focus on NH_3 related schemes in the future (Defra project AC0109). The introduction of NH_3-specific options to future environmental stewardship schemes, catchment sensitive farming grant schemes and woodland grant schemes could make a significant contribution to targeted implementation of measures around sensitive habitats in general and designated sites in particular.

Compared with mandatory requirements, such voluntary approaches also impose a greater requirement for collecting information on current levels of adoption of low-emission techniques (for which there is no comprehensive data collection system in the UK), to allow accounting for the reduced emissions in the national inventory. Such outcomes should then be taken into account in national emission maps at the location where the measures have been implemented, to allow the subsequent reduction in local NH_3 concentrations and deposition close to sources being quantified and ‘credited’ for reduced N threats to habitats and species. Additional challenges associated with voluntary schemes are listed in Appendix 8. For example, farmers entering into voluntary schemes may not be situated in the areas of greatest environmental need, while participants may enter schemes because the requirements of such schemes do not deviate significantly from their existing practices (Hodge and Reader, 2010).

At the regional/international scale, the increase in vehicle usage and consumption of livestock products, as well as international shipping, point to the need to address gaps in international policies, which may benefit from linking climate, air pollution and water policies in strengthening the nitrogen green economy (Sutton et al., 2014). Tackling effects across country boundaries, environmental media and economic sectors requires an integrated assessment of emission control options, technologies, costs and effects, to ensure effective and efficient policy developments and to avoid spill-over effects or unintended consequences leading to adverse effects, due to the implementation of remedies targeted at a specific source or pollutant.

When it comes to remedies for nature conservation sites under Scenarios 1-4, there is much that can also be done through complementary regional and local measures. The limitation of the IED to large pig and poultry farms is an obvious example of a gap, which means that certain agricultural plans or projects (related to cattle and medium size pig farms, arable farms) may not be assessed in relation to the provisions of the Habitats Directive. In some other European countries, national regulations to implement the Environmental Impact Assessment (EIA) Directive have been used to address this gap. For example, in Denmark, if a proposal for any farm (including cattle farms) has a floor space>500 m^2 (0.05ha) or is close to a Natura site, then an EIA needs to be conducted before permission can be granted.

Addressing such gaps could be aided by the further application of the SEA Directive to regional and local plans linked to both livestock and traffic sources (see Section 3.1.5). At the local level, AQMAs are currently targeted at health related pollution with little emphasis on ecosystem protection. There is an obvious gap in this system which does not currently include an NH_3 concentration standard/objective in UK or EU legislation. Such a NH_3 limit could in future be specifically linked to AQMAs for the projection of designated natural habitats (Sutton et al., 2011), e.g. through the Air Quality Directive.

3.2. Cost effectiveness of the remedies and potential for co-benefits

3.2.1. Estimation of cost-effectiveness of the remedies

Summary

- Cost-effectiveness in the context of mitigation measures is commonly expressed as cost per unit reduction in N emissions. It can also be seen in the context of improvement of environmental quality at a sensitive receptor. The latter is however difficult to quantify for specific sites without detailed assessments of the local spatial context, which is likely to include modelling. It is therefore important to be specific about the benchmark used for effectiveness.
- This review focuses primarily on cost-effectiveness in terms of emission reductions, including both capital and operational costs, as well as additional benefits.
- From recent assessments of cost curves for agricultural NH_3 abatement, measures targeting manure spreading are the most cost-effective, followed by those targeted at manure storage, with livestock housing measures generally being least cost-effective, with costs ranging from €-0.5 (i.e. negative cost) to €20 per kg NH_3-N abated. It is therefore recommended to implement measures in this order for diffuse agricultural sources (Scenario 1). For the other scenarios, the selection of measures depends on the source characteristics and may be more related to local site.
- A recent analysis by van Grinsven et al. (2013) showed that a much larger level of cost-effective N abatement could be achieved through NH_3 measures rather than further NO_x measures, with the environmental benefits exceeding the costs for 3 times as much reduction of NH_3 than for NO_x.

Costs of reducing N emissions to the atmosphere have been tabulated across different sectors in **Appendix 3**. As far as possible, these estimates specify the cost-effectiveness of mitigation, expressed as price per unit reduction in N emission (e.g. £ per kg N).

Cost effectiveness can also be seen in a wider context, since reductions of emissions in different locations will contribute differently to improvement in environmental quality, and different N forms (e.g. wet vs. dry deposition, NO_y vs. NH_x) will have different consequences on the environment per unit N deposition. In this context, it is important to be specific about the benchmark for effectiveness. At a national scale, the contribution to reducing total N emissions is a useful common currency. However, if the purpose is to protect one or more key sites, effectiveness will depend on spatial context. This means that landscape measures prioritising action in the vicinity of these sites can be considered as more effective than national reductions, where the specific purpose is to protect these sites. In this way, Defra project AC0109 (NH_3 Spatial Futures) found that targeting NH_3 mitigation measures within 2 km of SACs was 7 times more cost effective in reducing critical loads exceedance to these sites than an equivalent strategy applied nationally.

Another element that should be considered when assessing cost-effectiveness is the time frame to which it should relate. For example, if a target is specified in terms of improving site condition at a designated site, then the lag time between emission at source and improvement in site condition can span several years.

For simplicity in this review, the assessment of measures focuses primarily on a cost-effectiveness assessment (i.e. identifying the least-cost options to achieve a certain emission reduction). For a full cost-benefit assessment, the methodology applied in the Cost-Benefit Assessment (CBA)[19] studies around the Clean Air For Europe (CAFE) strategy and tools such as the UK Integrated Assessment Model (UK IAM), and local spatial interactions would need to be further explored. While the focus of this report is on emissions and measures to reduce the impact of N species on designated sites (and

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[19] e.g. http://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol1.pdf

sensitive habitats in general), the wider remit of the CBA and IAM activities is at present primarily focused on human health effects and includes additional aspects (in *italics* in the following list):

- Quantification of emissions
- *Description of pollutant dispersion*
- Quantification of exposure *of people*, environment *and buildings* affected by air pollution
- Quantification of the impacts of air pollution
- *Valuation of the impacts, and*
- *Description of uncertainties*

The objective of a full-scale cost-benefit assessment is to quantify (in monetary terms), as far as possible, all costs and benefits associated with policies to compare options for actions both in relative and absolute terms. In the case of ecosystem effects, the valuation of impacts (again, in monetary terms) is only just emerging, for instance in the context of ecosystem services (Jones *et al*. 2012; 2013; 2014). Activities such as the Valuing Nature Network (VNN[20]) and the UK National Ecosystems Assessment (NEA[21]) contribute to advances in this area.

Many measures will incur both capital and operational costs, which need to be considered in relation to the mitigation achieved. Measures may also be associated with benefits other than the mitigation of the pollutant to which they are targeted, and these additional benefits to the polluter as well as to society should be included in cost calculations as far as possible. Costs may also vary according to business size, and consideration should therefore also be given to strategies which take account of this. Finally, costs and benefits may not occur at the same location.

In the case of agricultural air pollution (Scenarios 1, 2, 5), an NH_3 abatement cost curve was developed as part of Defra project AQ0602 (June 2008) using cost estimates derived by Ryan (2002) and mitigation measures as then included in the National Ammonia Reduction Strategy Evaluation System (Webb and Misselbrook, 2004; Webb et al., 2006). While the figures are now out of date and there have been developments in both the national NH_3 model and the available mitigation measures, the relative ranking of cost-effectiveness of the measures is still broadly relevant. From the derived cost-curve, it was apparent that implementing measures targeting emissions from manure applications to land were the most cost-effective, followed by those targeted at manure storage with, in general, measures targeted at livestock housing being the least cost-effective. Cost-effectiveness estimates are given for some mitigation measures in the UNECE Guidance Document (Bittman et al., 2014). While the range of costs given for the different mitigation measure categories are quite large, the general order of cost effectiveness is the same i.e. manure application to land (€-0.5-2.0 kg^{-1} NH_3-N abated) < manure storage (€0.3-5.0 kg^{-1} NH_3-N abated) < livestock housing (€0-20 kg^{-1} NH_3-N abated). For diffuse agricultural sources (Scenario 1) it therefore makes sense to implement mitigation measures in this order. For the agricultural point source(s) (Scenario 2), selection of measures will be very source-specific and therefore may be less driven by overall cost effectiveness and more related to site suitability.

It is relevant to compare the cost-effectiveness of measures to reduce NH_3 emissions (mainly from agriculture) with those to reduce NO_x emissions (mainly transport, industry and combustion plant). This can be illustrated by the analysis of van Grinsven et al. (2013), who compared the mitigation costs from the GAINS model (Winiwarter and Klimont, 2011) with the estimated cost-benefits of reduced environmental threats on ecosystems, health and climate, based on an update of estimates derived for the European Nitrogen Assessment. The broad pattern that emerges is that a much larger total level of NH_3 abatement could be achieved in Europe, with the environmental benefits exceeding the costs of taking action (i.e. cost-benefit ratio >1), than could be achieved by further NO_x abatement

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[20] http://www.valuing-nature.net/

[21] http://uknea.unep-wcmc.org/

(**Figure 1**). The basis of such estimates is being further refined as a fuller picture of monetary valuation of ecosystem services develops.

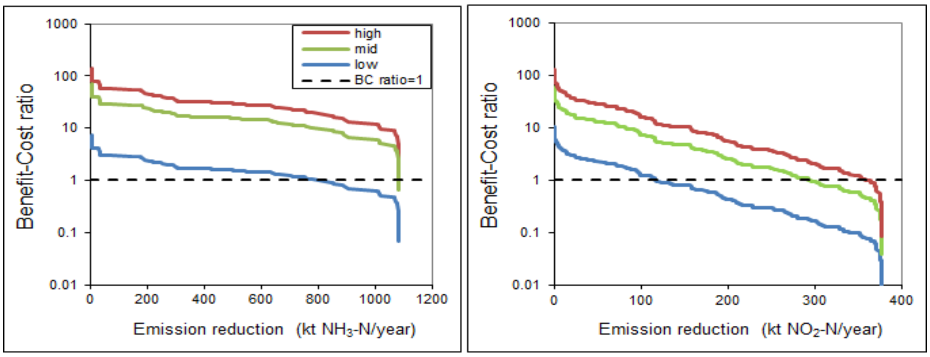

Figure 1: Benefit-cost ratio for N emission reduction across the EU (van Grinsven et al., 2013). Mitigation costs estimated with the GAINS model are compared with estimated health, ecosystem and climate benefits based on updated estimates from the European Nitrogen Assessment. Left: NH_3 mitigation; Right: NO_x mitigation.

3.2.2. Co-benefits and side-effects of remedies

Summary

- Most of the measures included in the shortlist are associated with both significant co-benefits and/or detrimental side effects in other policy areas.
- All agricultural measures which reduce NH_3 emissions from manure management have the potential to increase the fertiliser N value of the manures, thereby reducing costs of mineral fertilisers. Amounts will vary, but could typically save 5-25 kg N ha^{-1} yr^{-1}, depending on location.
- Detrimental side effects of manure application measures include risks of increased N_2O emissions and NO_3 leaching at the field scale, however these can be minimised by following good practice. By assessing co-benefits and trade-offs at a farm and landscape scale, the improvement in nitrogen use efficiency provides the opportunity to reduce overall N_2O and NO_3 emissions.
- Other major co-benefits of manure management measures include reduced odour emissions, primary particulates, overspills from slurry stores, etc.
- Co-benefits of road transport measures include fuel use reduction, reductions in a number of pollutant emissions, and minimising of traffic noise in the case of barriers.

The measures identified have been screened in Appendix 3 for significant co-benefits and potential detrimental side effects concerning other policy areas, by reviewing the evidence base provided and the wider literature. Most of the mitigation measures reviewed are associated with both significant co-benefits and/or detrimental side-effects concerning other policy areas (see Table, Appendix 3). It is important to recognize however, that such a table provides a qualitative view and that more work is needed to quantify the interactions.

For the **agricultural mitigation measures**, all of the measures which directly reduce NH_3 emission from a manure management source have the potential to increase the fertiliser N value of the manure when applied to land. This will be most apparent for the manure application to land measures (reduced emission slurry application techniques; rapid incorporation of manure), where the N saved through reducing NH_3 emissions is effectively available for crop uptake.

With emission reductions at the housing or manure storage stages, subsequent manure management may result in other N losses or transformations, so that the full potential benefit in terms of fertiliser replacement is not realised unless the full sequence of mitigation options is applied at each stage (e.g. low emission manure storage should be followed by low emission manure spreading).

In practice, natural variability in yields and the relatively small size of the expected effect have made it difficult to demonstrate a significant crop yield effect in many of the trials conducted. However, as part of a balanced crop nutrient management plan, incorporating both organic and mineral fertilisers, farmers should be able to reduce their mineral N fertiliser use directly by the amount of NH_3-N emission reduction achieved through using the mitigation measure. The amount will vary depending on application method, rate and manure characteristics, but would typically be in the range 5 – 25 kg N ha^{-1} yr^{-1} for agricultural land. Other benefits of reduced emission slurry application techniques are a more uniform application rate across the spread width, compared with surface broadcast application, less contamination of crop leaf surfaces with slurry, lower odour emissions, reduced splash near watercourses, and often a wider window of opportunity for application timings.

Detrimental side-effects of the manure application mitigation methods include a risk of increased N_2O emissions and nitrate leaching at the field scale, but these risks will be minimised if manures are applied at agronomically sensible times and rates, and account is taken of the more efficient application method when calculating volumes applied, i.e. following good practice. In evaluating pollution co-benefits and trade-offs, it is important to consider these on a broader scale than the field scale, and address interactions at farm and landscape scales. By linking between these scales, it is possible to move from a perception focused on trade-offs, to a recognition of the co-benefits of taking action (Box 1).

Box 1: From nitrogen swapping to the co-benefits of improved efficiency.

It has been recognized for several years that low-emission manure spreading may increase emissions of nitrous oxide (N_2O) or leaching of nitrate (NO_3) at the field scale. While some practices will specifically increase risks (e.g., deep injection on deeply cracked soil), to a large extent this trade-off is a result of retaining more N in the soil, as less of it is lost to the air. This highlights the need to develop a wider view of these interactions.

At the landscape level, reduced NH_3 emissions from improved spreading methods will mean that there is less N deposition, so that N_2O emissions and NO_3 leaching decrease elsewhere. Considering these wider interactions, improved field spreading therefore shifts the location of associated N_2O and NO_3 losses from the wider landscape to the field itself, with little net change in total emissions. However, this is not the end of the story.

The next stage comes when it is realised that these changes, which leave more nitrogen in the field, greatly improve the opportunity for good farm management (through nutrient timing and balancing of crop needs) to further reduce total N losses.

This translates in to net savings when the farmer starts to take account of the N benefits from adopting low-emission spreading methods. Based on monitoring improvement in the farm N balance, the farmer can trim N inputs to take account of the NH_3 savings. Overall this translates to a gain in N use efficiency, with smaller overall N losses to the environment and significant cost savings for bought in N inputs.

For the farmer the business case for investing in low emission spreading methods will depend on the economies of scale, with equipment sharing or use of specialist contractors being options to consider in maximizing return.

Other co-benefits associated with livestock housing and manure storage mitigation measures include an associated reduction in odour emissions and, for some measures, a reduction in the emissions of primary particulates (e.g. air scrubber systems for intensive pig and poultry housing). Solid covers to slurry stores will prevent rain ingress, thereby reducing the total amount of material that needs subsequent handling, and minimising overspill during high rainfall events. Dietary measures to reduce N excretion, while maintaining livestock health, fertility and productivity, will result in lower N losses of all forms throughout the manure management chain for a given management system.

Co-benefits of **road transport measures** are often associated with reductions in fuel usage and the emissions associated with their combustion. Traffic management measures can help reduce fuel-use through alleviating congestion and increasing traffic flow. Secondary road transport measures, such as artificial barriers and tree belts, can also help to reduce the overall of pollutants (by up to 15% from photo-catalytic barriers next to the road (‘NOxer barrier’), Eurovia 2013) by increasing turbulence and chemical reactions, respectively, to minimise the effects of dry deposition. In addition to tackling pollutant threats, road barriers can also minimise traffic noise (up to 11db from the NOxer barrier).

For **tree-belt measures** in close proximity of designated sites, it is especially important that any proposals are assessed carefully to avoid detrimental effects, such as changes to the hydrological/groundwater regime, shading or seeding into the designated site, do not occur. Such considerations are less likely to apply to tree belts near emission sources, away from the vicinity of designated sites.

3.2.3. Timescales of potential change – achievement of emission reduction vs. site recovery

Summary

- **Time scales for achieving emission reductions** with agricultural measures are immediate for e.g. manure or fertiliser application measures, given the availability of the tools and techniques. Retro-fitting measures to existing livestock houses and manure storage facilities are often prohibitively expensive, and such measures are generally implemented when existing facilities come to the end of their useful life, which may vary from 10-50 years, with replacement rates depending on the economic situation and market and legislative drivers.
- For UK road transport, emission reductions have mostly resulted from technological advances filtering through the vehicle fleet over periods of 5 to 10 years. Such changes can be accelerated by local scale legislation, as has been shown by the London Congestion Charge, which led to significant improvements in air quality within two years.
- Landscape-scale measures such as low emission buffer zones around designated sites could provide immediate benefits, whereas tree belts would require 10-20 years for the trees to grow and become fully effective, depending on the species used.
- **Timescales for recovery of ecosystems** depend on the receptor, the decline in N input and the amount of N already accumulated. The first signs of improvement are likely within four years (especially for epiphytic species), although substantial recovery may take decades and the system may not return to its pre-impact state, depending on soil turn-over processes. In some cases, the speed and nature of the recovery may be affected by on-site restoration measures.

The time-scales of potential change were analysed in the scenarios, evaluating the time for achieving emission reduction using different remedies (e.g., longer for tree-planting approaches, shorter for the installation of roadside screens/barriers) and relating these to the time-scales of recovery of key habitats. While the limited evidence available is sufficient for a preliminary analysis of this kind, there is, however, an urgent need for more evidence on rates and extent of ecosystem recovery from atmospheric N pollution. The evidence presented here is based mainly on the findings from AQ0823 (REBEND), but also considers the implications of longer-term effects (e.g., accumulated deposition over the past 20 years and longer).

Timescales for achieving emission reductions

Many of the **agricultural mitigation measures**, and particularly those related to manure and fertiliser application, can be implemented immediately and therefore give immediate emission reductions. However, for some of the livestock housing and manure storage measures, retro-fitting of new technologies to existing facilities can be prohibitively expensive and these measures are therefore only generally applicable to new build situations (a potential exception would be review of IED permit adjacent to an SAC, where there is UK precedent for requiring retrofitting acid scrubbers on livestock houses). The anticipated livestock housing lifetime will depend on design and build parameters, and may vary from 10 to 50 years. Assuming a conservative estimate of mean lifetime of 30 years would give an annual replacement rate (and therefore potential mitigation measure uptake rate) of 3.3%. For manure storage, a 20 year lifetime, or 5% replacement rate, may be more applicable. However, the actual replacement rates will be dependent on the economic health of the sector and strongly influenced by market and legislative drivers.

In theory, large pig and poultry farms that have to comply with the IED (accounting for >90% of broilers, >60% of layers and c. 30-40% of pigs in the UK) will already have implemented measures to reduce emissions from housing and on-site manure storage. In practice, there is a lack of robust data as to current uptake of specific mitigation measures on pig and poultry farms. The assumption made in current NH_3 emission projections is that in 2006 there was 0% compliance and that by 2020 there will be 100% compliance, with implementation in housing of best available techniques (BAT) giving, on average, a 30% reduction in emission over baseline. It should be noted that there is a range of techniques recognised as BAT, with a range of performance. It is therefore also possible to specify techniques that exceed the basic BAT requirements (BAT+, BAT++).

Given that N emissions from **road transport** are predominantly governed by advances in technology, reductions in emissions are likely to correspond to the extent and speed in which future technologies are adopted. However, the London Congestion Charge has shown that changes in emissions can be made more rapidly by altering the number of miles driven in the capital. The Congestion Charge has succeeded in reducing the number of vehicles entering the capital and thereby led to significant improvements in air quality being observed within 2 years (reductions in NO_x and PM_{10} of 12 % and CO_2 by ~20% after 2 years; Beevers and Carslaw, 2005).

Use of **landscape scale structural measures** to reduce N exposure to designated sites will have variable implementation times. For example, buffer zones requiring low emission land application of manure and urea based fertilisers could provide immediate benefits. By contrast, strategies based on tree belts (either adjacent to road or farm sources or adjacent to nature areas) can take 10-20 years to become effective, depending on the type of trees used.

The potential time scales for behavioural change will depend on the extent of incentives/disincentives, education and other measures. In principle, with a sufficiently enabling set of measures, behavioural change can be rapid (within 2 years, as illustrated by the example of congestion charging or as in the case of smoking in public places). The limited extent of progress in relation to sustainable transport or dietary choices reflects a combination of deeply held values and insufficiency of the current measures. Developing new cultural norms in such areas may typically take a generation, and will typically be required before the measures needed to foster change become acceptable to most in society.

Timescales for ecological recovery

Timescales for recovery of ecological systems will vary depending on the ecological receptor, the amount by which N deposition declines, the absolute level it declines to, and the amount of accumulated N in the system (see ***Appendix 9*** for a detailed analysis, including time scales for biodiversity recovery, current knowledge on species/ groups of species or habitats). In general, the first improvements in species cover, growth rates and tissue chemistry for N-sensitive mosses, liverworts and lichens are likely to be rapid (within four years, with published evidence of change even within 1 year), although some long-term damage may persist (Figure 1). This recovery depends on N deposition declining to appropriate levels for each species. Nitrate leaching may also reduce within a short timescale if N deposition falls below the level at which annual inputs exceed biological demand from plants and soil. Responses of plant tissue chemistry indicators, plant growth in some habitats, and some improvements in rates of soil processes and stream chemistry and aquatic biodiversity are likely within a timescale of 5 to 20 years. However, substantial recovery of plant species composition and diminution of available soil N pools may take many decades and in some instances may not return to pre-impact state. Passive soil N pools which represent the bulk of stored N in the soil system will not decline, even after several centuries, without intervention. In some situations, the speed and nature of recovery may be assisted by additional restoration measures, which would need to be targeted to particular outcomes.

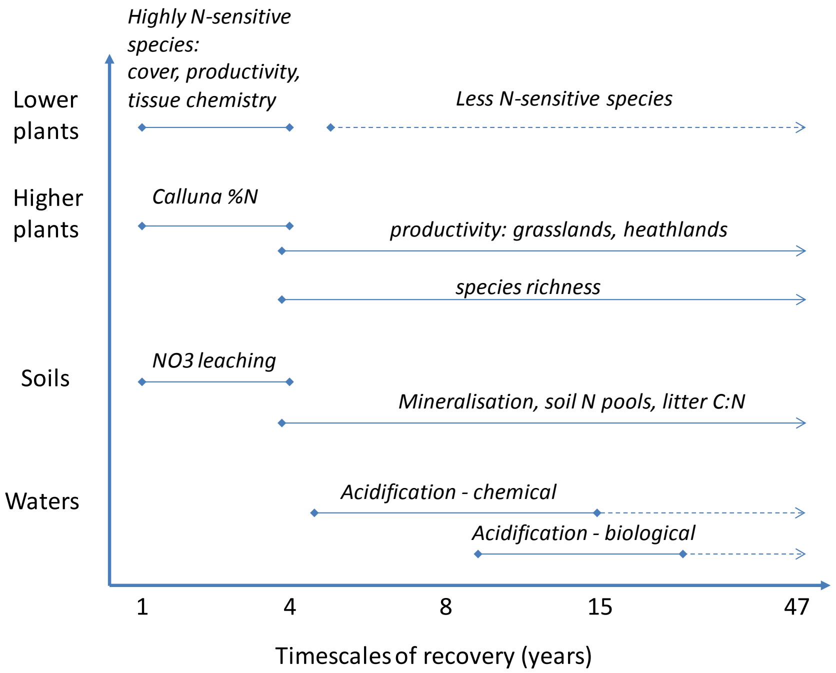

Figure 1. Summary of timescales of recovery for different terrestrial and freshwater receptors.

3.3. Applicability of the remedies and prioritisation of areas/scenarios for action

3.3.1. Practical applicability of measures

Summary

- In the transport, industry and combustion sectors, a wide range of remedies are applicable, with the major barrier related to consumption patterns and behavioural change.
- The main issues in terms of practicality of agricultural mitigation measures are **technical feasibility and site suitability**. For example certain manure application techniques such as slurry injections are not possible on shallow, stony or steeply sloping ground. In such situations alternative low-emission methods may be adopted or manure application avoided (e.g. to limit water pollution).
- **Cost** is another important consideration for most agricultural measures, with larger farms having the advantages of economies of scale and access to the initial capital. Financial barriers for small farms can be overcome by cooperative equipment purchase or the use of contractors, if there is sufficient flexibility in timing of operations.
- Most progress has been made in applying technical mitigation measures to road transport, combustion plants and industry, using regulatory frameworks. Agricultural measures, by contrast, have not been implemented, due to a lack in current policy instruments related at least in part to a lower political willingness to require emission reductions from the agriculture sector as compared with the energy and transport sectors.

The remedies available are often optimised for different circumstances and therefore have limits to the extent of their applicability. For example, certain low-emission combustion processes may only be suited for large combustion plants, while some manure application methods are limited to certain ground conditions. In this section, attention is given to the applicability of agricultural measures, because of the complexity of this sector and the lack of progress to date. By contrast, much more progress has been achieved on ensuring uptake of low emission techniques in vehicles, combustion plants and industry. In these cases, the remaining challenges focus on a) more ambitious high level mitigation – requiring further technological development, b) managing the distribution of sources in relation to receptors and c) managing the drivers of emissions, e.g., transport choices and energy consumption.

Experience shows that the central step in reducing overall NH_3 emissions is to adopt low emission practices for the spreading of manures. In terms of site suitability for manure application, shallow or deep injection of slurry is not possible on shallow or stony soils or on steeply sloping land. This issue was addressed by the TFRN by proposing relaxation of requirements to measures that achieve 30% emission reduction under these circumstances (e.g. trailing hose, trailing shoe; UNECE, 2011). In the case of steeply sloping ground, concerns over run-off and water pollution apply to all manure application methods. Rapid incorporation of manures is only possible prior to crop establishment, and, when growing cereal crops, farmers will only want to use machinery that is compatible with established tramlines, so that they do not have to create additional wheelings in the crop. While this may exclude the use of trailing shoe and injection technologies in this context, trailing hose provides significant opportunity for emission reduction.

For measures targeted at livestock housing and manure storage, the major constraint to uptake is likely to be the cost of retro-fitting a new technology to an existing facility. Where this is not considered feasible on cost grounds, then the measure will be constrained to new installations, greatly reducing the potential annual uptake rate as discussed above, unless the measure is required for specific permitting circumstances.

For most measures, costs will be an important consideration and these will be subject to economies of scale, i.e. measures will typically be more cost-effective on larger farms. Smaller farms are much less likely to have access to the initial capital outlay required to implement some of the measures. For slurry application and manure incorporation, the costs for small farms may be reduced by spreading the costs of the equipment over several farms or through the use of contractors with access to suitable equipment. Such cost saving approaches should be evaluated against the loss of flexibility in timing of operations.

In the EU most livestock is kept on medium or larger farms, which represent a small fraction of the farm holdings. For example, 70% of cattle are kept on farms with more than 50 livestock units, representing only 13% of the farms (UNECE, 2010)[22]. This means that across Europe, a threshold of 50 livestock units for requiring mitigation measures would address most of the cattle while only requiring action on a small fraction of the farms, thereby minimising transaction costs. Similarly, a threshold for requiring low emission manure spreading (e.g. if spreading with mobile spreaders of more than 6 m^3 capacity) would allow the modest contribution of a large number of small farms to be excluded, while focusing on the main sources. Such thresholds could support efficient national application of measures, while specific exceptions might apply in the immediate vicinity of designated sites.

3.3.2. Potential barriers to the uptake of remedies

Summary

- Strong regulatory frameworks, which exist for NO_x emissions from traffic, industry and combustion sources, provide a robust basis for overcoming many of the barriers to the uptake of measures. The main barriers for these sources are the need for further advances in technology and behavioural change to limit resource use and related N emissions. It could be argued that similar frameworks could improve the uptake of measures to reduce NH_3 emissions.
- Voluntary frameworks such as agri-environment options, that are typically associated with financial incentives, tend to get most uptake where farmers don’t have to change practices

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[22] The principle of this relationship applies widely across the EU and for different livestock categories, while the exact values vary according to national agricultural structure. According to UNECE (2010), for the UK, 90% of cattle are on farms with >50 livestock units, representing 53% of the cattle farms.

significantly. The implication is that voluntary frameworks may have lower effectiveness to reduce emissions than expected when farmers avoid selecting measures requiring substantive change.

- In the agricultural sector, the level of engagement with agricultural advisors and the level of education have also been shown to be key for overcoming barriers. There is also anecdotal evidence that prominent local farmers can act as role models for adopting novel practices.

With regard to traffic, industry and combustion-related NO_x emissions, the existence of strong regulatory frameworks provides a robust basis to overcoming many of the barriers to uptake of the remedies. As noted, the major potential barriers include the need for technological advances to further reduce NO_x emissions from traffic sources, together with behavioural changes that limit further increases in vehicle km driven (e.g. facilitated by congestion charges in urban centres and improved public transport).

Given the demonstrated effectiveness of a strong regulatory framework for NO_x emissions in the UK, and for NH_3 emissions in some other countries (e.g. NL, DK, Flanders), it could be argued that the primary barrier to uptake of available remedies for NH_3 mitigation is the lack of strong regulatory frameworks for NH_3 emissions. The potential of different instruments for further developing future regulatory frameworks for ecosystems and NH_3 has been discussed in Section 3.1. above. In the following, some of the barriers are discussed that particularly apply when the possible remedies are considered within the primarily voluntary framework of agri-environment options.

Such voluntary options are typically associated with financial payments to farmers, in return for the provision of environmental services. To ensure that such schemes are attractive to farmers, the level of payment offered should be sufficient to cover the cost of participating in the scheme. Cost of participation will include foregone profits of using the land in another, possibly more production intensive manner, as well as the transactions costs associated with complying with the scheme. An example of the latter is the initial report of relevant aspects of their farm and farming practices that farmers have to submit. However, the relevant authority would not want to pay in excess of this cost as this will increase the costs of implementation of the schemes. Evidence suggests that farmers who would have to change their practices significantly do not tend to take part in such schemes (Hodge and Reader, 2010). Thus, only the more marginal land is entered into the scheme, with intensive producers viewing the forgone profits from switching to a more extensive pattern of farming as too high. Small farm holdings, where every inch of the land is used in production to make the holding viable, also tend to be underrepresented in such schemes. Another reason is that the transactions costs associated with participation relative to incomes on such farms tend to be too high (Hodge and Reader, 2010).

The level of trust in government or agricultural advisors also appears to be key. Barnes et al. (2011) found that although ‘resistors’ resented interference in their operation of farm holdings, they were quite receptive to adopting voluntary pro-environmental measures because of their close relationship with agricultural advisors. The group which posed most problems for policy implementation were the ‘apathists’ who did not engage with advisors at all. Another factor might be level of education with more poorly educated farmers less likely to participate in agri-environment schemes (Wilson, 1997).

There is conflicting evidence over whether age and existence of a successor induces participation in agri-environment schemes. Wilson (1997) suggests that older farmers with no successor are less likely to feel under pressure to maximise return from the holding, whereas Hodge and Reader (2010) link low participation of small holdings in agri-environment schemes to age and absence of a successor.

Although not tested, Wilson (1997) found anecdotal evidence that farmers look to prominent farmers for information about what is advisable to adopt. This suggests that there may be a social norm of the descriptive type operating here, where the norm acts to provide information on the most appropriate action to be taken in a given set of circumstances. Thus, agricultural advisors can help create the norm to protect the environment, while role models within the farming sector can help to ensure that compliance with the norm spreads throughout the sector. Posthumus and Morris (2010) note that although payments under agri-environment schemes can ‘buy’ a change in practices, a change in farmers’ attitudes is required for more long-term benefits.

3.3.3. Prioritisation of potential actions

Summary

- Prioritisation of measures for a designated site needs to take account of the level of complexity of source attribution at the site, and the predicted impact, costs, ease and timeliness of implementation of potential measures.
- For sites allocated to Scenario 1 (diffuse agricultural sources), manure spreading measures are likely high priority, due to the relative importance of landspreading as an emission source and the large potential effectiveness. In decreasing order, slurry storage measures should be prioritised over technical housing measures due to effectiveness and cost differences.
- For sites affected by agricultural point sources (Scenario 2) in close proximity, priorities are more likely to focus on housing or manure storage measures to reduce emissions, complemented by buffer strips and/or tree planting measures.
- For sites affected by non-agricultural point sources (Scenario 3) the priority is likely to focus on adopting Best Available Techniques (or BAT+) for the process in hand, including ensuring that the techniques always operate effectively.
- In the case of sites affected by road traffic sources (Scenario 4), local measures would focus primarily on re-routing or altering traffic flows, combined with buffer areas and/or tree planting measures.
- For sites primarily affected by long-range transported air pollution (Scenario 5), the focus of measures must be on reducing total national and international N emissions, with the most cost effective further measures associated with reducing NH_3 emissions. If substantial reductions in N deposition to remote areas are to be achieved, an increased focus on behavioural change (transport use, food consumption patterns) will be necessary.

There are a number of considerations when deciding on prioritisation of potential actions, including estimated impact (and confidence of the estimate), cost, ease and timeliness of implementation and whether the N deposition at a given site is primarily due to a single point source or a large number of more diffuse sources.

For Scenario 1(lowland agriculture with many diffuse sources), priority should be given to the measures targeting application of livestock manure to land. These measures will have the greatest impact in terms of emission reduction, as this is a major emission source and the potential measures can have a high effectiveness, and tend to be among the most cost-effective. Additionally, targeting the manure application source first will minimise the potential increase in emissions from manure spreading that would arise by later targeting manure storage or livestock housing emission sources. Measures targeted at manure storage would probably be the second priority, particularly the covering of dairy slurry lagoons. Replacement of slurry stores with slurry bags has the potential to be a very effective emission reduction measure, but is a relatively new innovation and a review of the advantages and disadvantages, costs and practicalities is warranted before this is more widely recommended. Housing measures tend to be among the more costly to implement, are often only suitable for newly constructed buildings and are therefore slow to implement, and because of their specificity not necessarily widely applicable. In addition, some of the livestock housing measures are also associated with lower confidence in terms of the robustness of the emission reduction coefficients.

Mitigation measures aimed at reducing NH_3 emissions from fertiliser application can also be considered as a high priority, as this provides one of the cheapest (or most cost beneficial) measures available. In particular, the use of high-emission fertiliser types (such as urea) next to designated sites should be avoided. This has been examined by landscape-scale modelling carried out under Defra project AC0109.

For Scenario 2 (agricultural point sources), priority is more likely to be given to specific housing and/or storage emission mitigation measures in the vicinity of designated sites, as these will generally be the largest point sources causing elevated local N concentrations and deposition, but the best options will need to be determined on a case by case basis. Buffer strips and/or tree planting measures will also be of higher priority and may feature as stand-alone measures or as part of a package of measures to achieve the required effect.

For sites affected by non-agricultural point sources (Scenario 3), the priority is likely to focus on adopting Best Available Techniques for the process(es) being operated. This includes ensuring that the techniques always operate effectively. At the very local scale, buffer strips and/or tree planting schemes may also provide benefits, to re-capture local emissions, disperse and dilute NO_x and NH_3 concentrations and thereby decrease the resulting atmospheric N deposition.

In the case of sites affected by road traffic sources (Scenario 4), the most efficient local measures would focus primarily on re-routing or altering of traffic flows away from the vicinity of designated sites, in combination with buffer areas and/or tree planting measures, in between busy roads and nearby designated sites.

For sites primarily affected by long-range transported air pollution (Scenario 5), the focus of measures must be on reducing total national and international N emissions, with the most cost effective further measures associated with reducing NH_3 emissions. Ambitious technical measures to reduce NO_x emissions from shipping and NH_3 emissions from agriculture would be most likely to make substantial differences to UK-wide reductions in long-range transport. In parallel, if substantial reductions in N deposition to remote areas are to be achieved, an increased focus on behavioural change (transport use, food consumption patterns) will be necessary.

3.3.4. Estimated emission reduction achievable with remedies evaluated in support of NECD negotiations

Summary

- A number of packages of emission reduction measures have been put together for UK agriculture, for quantifying potential emissions under the proposed NECD ceiling targets (current Defra project AQ0947). Estimated total mitigation effects are given for the years 2020, 2025 and 2030 and compared with business-as-usual estimates for the same periods.
- Manure management options are estimated to give the largest emission reductions, compared with livestock housing and manure storage.
- Combining measures across all manure management components (i.e. livestock housing, manure storage and spreading) is more effective than dealing with them in isolation, showing the importance of implementing ‘downstream’ measures to maximise the benefits of ‘upstream’ measures.
- Average costs of additional NH_3 and NO_x control for UK (considering technical measures only) are estimated at €2.7 per kg NO_x-N and €1.2 per kg NH_3-N (based on GAINS modelling).

Given that agriculture now represents the sector with the lowest cost of mitigation opportunities, this section focuses primarily on the emission reductions achievable from this sector. As part of the current Defra project AQ0947 (SNAPS), a number of emission reduction scenarios have been modelled for agriculture using the current inventory of ammonia emissions from UK agriculture. The emission reduction scenarios, or packages of measures, have been put together in a similar way to those developed in the IIASA GAINS modelling on which the proposals for the revised NECD ceiling targets have been based, i.e. low and high efficiency measures for manure application, manure storage and livestock housing. The 15 packages of measures assessed under AQ0947 are given in **Table 4**, with further details of the individual measures within each package given in ***Appendix 3***. In the long-term additional ammonia emissions reductions could also be achieved through measures related to behavioural change (Westhoek et al., 2014), though these effects were not considered in AQ0497, and are therefore not included in Table 4.[23]

The estimated total mitigation effect (kt ammonia) of implementing each of the packages of measures, as described in Table 1, is given in Table 5 for the years 2020, 2025 and 2030. For comparison, the projected business-as-usual emissions from agriculture for the years 2020, 2025 and 2030 are 240.7, 239.9 and 239.9, respectively. Of the individual manure management components (i.e. housing, storage, spreading), available options aimed at manure application give the greatest emission reductions. Available options for housing give relatively modest emission reductions, particularly for the low efficiency measures. This is mostly because of the lack of options currently applicable to the dairy and beef sectors and the length of time required for options to be introduced via new installations, but also because within the pig and poultry sectors a significant uptake is already assumed under business-as-usual through the implementation of the Industrial Emissions Directive.

Combining the manure management options gives greater emission reduction than the sum of those for implementing the housing, storage and spreading options alone, highlighting the importance of implementing 'downstream' measures to maximise the benefit of 'upstream' measures.

Feeding measures (only for dairy cows[24]) and fertiliser measures (targeting urea-based fertiliser applications) can also bring significant emission reductions. Combining all the listed measures in the high efficiency options would give an estimated 25% reduction in emissions as compared with the business-as-usual scenario for 2030. This can be compared with c.40% reduction at the European scale according to the behavioural change options.[25] In practice, a mix of technical and behavioural change aspects may be required if major reductions in NH_3 emissions are to be achieved.

Work is ongoing as part of AQ0947 to provide estimates of cost and cost-benefit for each package of measures listed in Tables 4 and Appendix 3, but results of these are not yet available (May 2014).

The most recent estimates of the GAINS model achieve an emission reduction of 1057 kt NH_3 by 2030 compared with 2005, or 792 kt compared to the 2030 baseline emissions, for the 28 countries of the European Union. For the UK, compared with baseline emissions, reductions of 42 kt NH_3 are estimated to cost an additional 41.8 M EUR. By comparison, costs for NO_x abatement to achieve a further 44 kt NO_x are estimated at 36 M EUR for 2030. The relatively high share of costs of NH_3 compared with NO_x estimated by the GAINS model is a result of cost optimisation, given that substantial investment in NO_x emission reduction has already been made. Based on the total reduction cost, the average cost of additional NH_3 and NO_x control for UK (considering technical measures only) is estimated at 2.7 EUR / kg NO_x-N and 1.2 EUR /kg NH_3-N (based on GAINS).

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[23] Westhoek et al. (2014) show that under a 50% reduction in meat and dairy consumption across the EU ammonia emissions would decrease by 39% ('high prices scenario' with substantially increased arable exports) or 43% ('greening scenario', with substantially increased bio-energy production).

[24] The pig and poultry industry are assumed to have already largely implemented feeding measures, hence there is very little room for improvement. For cattle, low protein feed is relevant for housed animals only, and again only for those which are not predominantly forage-based. This means that the main scope for feed-based measures for cattle is with dairy cows.

[25] See Footnote 18. Based on these estimates, a combination of the most radical European dietary scenario of Westhoek et al. (2014) with the full suite of technical measures listed here would be equivalent to a 55% reduction in NH_3 emissions.

Table 4. Packages of measures assessed for future mitigation scenarios (based on AQ0497 according to categories of the GAINS model).

Package	Details
1. Low mitigation efficiency manure application	Slurry - trailing hose application to grassland and growing crops, 24h incorporation by tine where applicable; FYM/poultry manure - 24h incorporation by tine;
2. High mitigation efficiency manure application	Slurry - shallow injection to grassland, trailing hose to arable crops, 4h incorporation by plough where applicable FYM/poultry manure - 4h incorporation by plough where applicable;
3. Low mitigation efficiency manure storage	Slurry – flexible/floating covers on slurry tanks and lagoons; FYM/poultry manure – no measures
4. High mitigation efficiency manure storage	Slurry – rigid covers on slurry tanks, flexible/floating covers on lagoons; FYM/poultry manure – sheeting covers[26]
5. Storage and spreading measures – low efficiency	Packages 1 and 3 combined
6. Storage and spreading measures – high efficiency	Packages 2 and 4 combined
7. Low mitigation efficiency housing measures	Pigs – partially slatted floor with reduced pit area Laying hens – air drying of manure on belts Other poultry – under-floor litter drying No measures for other livestock types
8. High mitigation efficiency housing measures	Dairy slurry – wash down collecting yards Pigs and poultry – acid scrubbers Dairy FYM and beef – no measures[27]
9. Housing, storage and spreading measures – low efficiency	Packages 1,3 and 7 combined
10. Housing, storage and spreading measures – high efficiency	Packages 2, 4 and 8 combined
11. Feeding measures	Dairy – lower protein diet[28]
12. Fertiliser measures	Use urease inhibitor with urea-based fertilisers[29]
13. All combinations – low efficiency	Packages 1, 3, 7, 11 and 12 combined
14. All combinations – high efficiency	Packages 2, 4, 8, 11 and 12 combined
15. Emerging options	Dairy cattle slurry – grooved floor system for housing Slurry storage – slurry bags

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[26] Additional options include slurry bags for low emission storage (see category 15) as well as keeping poultry litter dry to reduce emissions from storage of poultry manure.

[27] No measures are included in GAINS for reducing NH_3 emissions from cattle housing, as these are naturally ventilated. The main option would be to reduce the housing period (as % N from excreta emitted as NH_3 at grazing is much smaller than from housed livestock). Given the large magnitude of this source, it is logical priority area for investment in developing new mitigation approaches. Options could include: a) alternative floor design and washing systems (see category 15); b) passive chemical scrubbing of NH_3 for naturally ventilated livestock buildings.

[28] The pig and poultry industry are assumed to have already largely implemented feeding measures, hence there is very little room for improvement. For cattle, low protein feed is relevant for housed animals only, and again only for those which are not predominantly forage-based. This means that the main scope for feed-based measures for cattle is with dairy cows.

[29] Other options include urea incorporation, coated urea pellets and substitution of urea with ammonium nitrate.

Table 5. Estimated mitigation achieved (kt NH_3) with each package of measures for three projection years (details in Table 4), based on AQ0497 according to categories of the GAINS model.

Package	**Mitigation achieved (kt NH_3 /yr)**		
	2020	**2025**	**2030**
1. Low mitigation efficiency manure application	8.2	8.2	8.2
2. High mitigation efficiency manure application	18.8	18.8	18.8
3. Low mitigation efficiency manure storage	3.2	3.2	3.2
4. High mitigation efficiency manure storage	6.8	7.1	7.2
5. Storage and spreading measures – low efficiency	11.8	11.8	11.8
6. Storage and spreading measures – high efficiency	27.7	27.9	28.1
7. Low mitigation efficiency housing measures	1.0	1.1	1.2
8. High mitigation efficiency housing measures	5.7	7.3	8.6
9. Housing, storage and spreading measures – low efficiency	12.8	12.9	13.0
10. Housing, storage and spreading measures – high efficiency	34.9	36.9	38.5
11. Feeding measures	9.5	9.5	9.5
12. Fertiliser measures	14.8	14.7	14.7
13. All combinations – low efficiency	36.0	36.1	36.2
14. All combinations – high efficiency	56.9	58.7	60.4
15. Emerging options	3.3	7.1	10.9

There are several areas of uncertainty in the emission reduction estimates provided above, including, activity data projections, emission reduction efficiencies, applicability assumptions, uptake rates and costs. Further work is required to quantify the uncertainties in these parameters, in order to provide a more measured estimate of mitigation potential including best estimate of central tendency together with confidence limits. To date, little attention has been given to comparing the economics of NH_3 (and other N, GHG) reduction based on behavioural change as compared with the use of technical measures. Given the emissions reductions possible by both strategies, this must be a priority for further investigation.

3.4. Evidence required to demonstrate success of remedies

Summary

- Evidence for success can take various forms, and be measured in terms of:
    - Uptake of measures leading to quantified reductions in N emissions with estimates verified by resulting changes in N concentrations and deposition (with the latter requiring atmospheric N monitoring and/or modelling of change over time, and different levels of effort depending on the scale of the assessment, i.e. national vs. site-specific).
    - Local habitat-based biological or biogeochemical indicators to demonstrate recovery, such as floristic change, tissue N content, plant-available N in soils, nitrate concentrations in aquatic habitats. Such evidence for success needs to be considered together with timescales for recovery of the habitats and species.
- A key requirement for demonstrating success at a site level is the establishment of baseline monitoring before any measures are implemented, and a consistent methodology with repeat measurements at the same location to be able to detect change over time.

- At the national scale, the same principles are valid, and evidence from the UKEAP monitoring network, Countryside Survey or the Acid Waters Monitoring Network is available and has been used as evidence for response of species composition and soil processes to N deposition on a wider UK scale.
- For designated sites, Common Standards Monitoring is the only tool currently available to detect change, but is designed for rapid assessment, not to detect changes in species composition due to N deposition.
- In theory, CSM could be supplemented with additional measurements ranging from simple (recording grass:forb ratio) to sophisticated (permanent quadrats, recording abundance of all species). A few permanent quadrats at each site would allow statistical analysis of change across UK designated sites, while multiple quadrats would be needed to monitor change at any individual site. Where available, other transferrable and repeatable surveys at individual sites with historical data might provide a local alternative.
- The concept of the ‘biomonitoring chain’ links key indicators from emission to deposition with species responses to build a robust picture for evidence of success of measures.

Evidence to demonstrate success can take various forms, and needs to be considered in conjunction with the timescales for response of different ecosystem components to changes in N deposition (both of these aspects are reviewed in more detail in Appendix 9).

3.4.1 Uptake of measures, and changes in deposition

Success can be demonstrated in the first instance by measuring the uptake or level of implementation of measures by the agricultural community, by industry or the number and extent of schemes set up by government. This places a key requirement on collection of data on the extent of uptake and effectiveness of the different measures, in order for the consequences to be translated into estimated trends in emissions of NH_3 and NO_x.

Typically, policy analysts may evaluate success based on whether modelled emission estimates for a particular year are less than the legally binding national emission ceilings. On its own, such an approach may miss out on opportunities for increasing the extent of environmental protection for a given investment in pollution mitigation (e.g. that may be achieved by spatial strategies), while it is also necessary to provide independent evidence do demonstrate that the modelled emissions reductions have actually occurred.

Such independent verification is one of the key purposes of long term atmospheric composition monitoring, as implemented in the UK Eutrophication and Acidification Pollution (UKEAP) monitoring network[30] and through the use of atmospheric chemistry and transport models, such as FRAME and EMEP4UK (e.g. Singles et al. 1998, Dore et al. 2012, Vieno et al. 2013). Regional estimates of emissions are mapped (e.g. Dragosits et al., 1998, Hellsten et al. 2008) and provide key input to the atmospheric models, which then deliver simulations of air concentrations and deposition for comparison with the monitoring data. It is this approach that has been used to evaluate whether NO_x concentrations are decreasing in accordance with estimated emission reductions (ROTAP, 2012), and similarly, whether NH_3 emission reductions have been successful (e.g. Bleeker et al., 2009; Horvath et al., 2009).

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[30] http://pollutantdeposition.defra.gov.uk/ukeap

Details of measurement approaches for concentrations and deposition of different N compounds are provided in Appendix 9, and reflect the approaches taken in the UKEAP network. Two complementary strategies can be taken: a) intensive monitoring (e.g. hourly) at a few locations (using expensive equipment) and b) extensive monitoring (e.g. weekly to 8 weekly) at many locations using low cost equipment. The former is particularly suited to improving mechanistic understanding of air chemistry interactions, or wind-direction dependence of concentrations in relation to local sources. By contrast, the latter provides an approach that also allows low cost air concentration monitoring on specific nature conservation sites, including the use of passive samplers, e.g. ALPHA badge-type passive diffusion samplers (Tang et al. 2001).

From site-level ('landscape-scale') up to national scale, it is possible to model the likely changes in deposition as a result of emission control measures being implemented. Site scale assessments using tools such as SCAIL (Theobald et al., 2009) or local scale atmospheric dispersion modelling would involve estimating reductions in emissions from particular sources and modelling the resulting deposition, although this would ideally be backed up by site-based measurements to confirm the model outputs. At a site scale, adjacent to local sources, there is a major interpretive advantage in measuring transects of N concentrations across designated sites including adjacent background monitoring (Sutton et al. 2011c).

3.4.2 Habitat-based measures of success

In addition to measuring emission and deposition/concentration reductions due to measures (Section 3.4.1), it is important to measure local biological or biogeochemical indicators which may demonstrate recovery. This information is presented in more detail in ***Appendix 9***, together with an assessment of the likely timescales over which such evidence would become apparent. Biogeochemical evidence of success includes plant parameters such as reduction in sward height, reduction in growth rates, or declines in the tissue N content of foliage. In soils, it includes a decline in N mineralisation rates or amounts of plant-available N in the soil. The soil total C:N ratio may increase or decrease as a result of N pollution, and is not a consistent indicator of recovery. Total N stocks are dominated by the passive N pool, and will not measurably decline, even after many centuries. Freshwater evidence of success of recovery from eutrophication includes a reduction in nitrate concentrations in lakes and streams, and an increase in pH or Acid Neutralising Capacity (ANC) as evidence of recovery from acidification.

Floristic change has proved a powerful indicator of the effects of N damage, as species change over time, with a loss of N-sensitive species illustrated by numerous studies across a wide range of habitats. While recovery of this indicator and an increase in the abundance or the reappearance of N-sensitive species may take many years, this is likely to be the most tangible and the most accessible monitoring method of site condition for many site managers. In ***Appendix 9***, tables summarised from Emmett et al. (2011) show the N deposition levels at which N-sensitive species have been shown to disappear at a national scale for different habitats, and which might be expected to return or increase in abundance following a reduction in N deposition. Nevertheless, it should be pointed out that relatively little is known about timescales and trajectories of recovery, and there is no guarantee that certain species will re-appear. Re-colonisation by a particular species depends not only on site conditions but on whether the species still occurs locally and can disperse to and establish on a site. Nevertheless, overall changes in the flora are likely. Lower levels of N deposition are associated with a smaller grass / forb cover ratio in grasslands, and greater species-richness in several habitats. Changes in these metrics may indicate recovery from N pollution, but could also be due to other factors including site management. A more specific indicator that conditions are becoming less eutrophic is a decrease in the mean 'Ellenberg N' score for the species present, which can be obtained from the PlantATT system[31] (Hill et al., 2004).

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[31] Report: http://nora.nerc.ac.uk/9535/1/PLANTATT.pdf; spreadsheets: https://www.brc.ac.uk/resources.htm

3.4.3 Overall requirements for demonstrating success

In order to demonstrate success of remedies at individual sites, it is essential to establish monitoring of the baseline prior to implementation of any measures. For monitoring of pressures (emissions, N deposition), this requires monitoring for at least a year (and preferably for several years) both before and after implementation of remedies. For monitoring of ecosystem response, this requires a consistent methodology, repeated at regular intervals over time, and preferably at the same locations, e.g. by the installation of permanently marked vegetation quadrats at key locations on conservation sites.

In terms of demonstrating success at national scale, the same principles apply, that there is a need for monitoring using a consistent methodology with repeat measurements over time at the same locations. At national scale this evidence can come from the Countryside Survey (e.g. Emmett et al, 2010), or from freshwater monitoring programmes such as the Acid Waters Monitoring Network (Monteith and Shilland, 2007). In fact, partial soil recovery from acidification effects has already been demonstrated in Countryside Survey data. The Countryside Survey approach will reveal any recovery in the broader UK landscape but does not cover designated sites. At designated sites, the only current tool with the potential to demonstrate recovery from changes in N deposition is Common Standards Monitoring (CSM) and subsequent reporting to EU under Article 17. However, the current CSM methodology is designed for rapid assessment, rather than for the detection of gradual trends in species composition or to attribute the causes of these changes, whether they are due to N deposition, climate change, site management or new emerging threats (Williams 2006). This is because CSM assessment typically records pass/fail against specified thresholds rather than recording values of e.g. cover of indicator species. The CSM positive and negative indicator species are not necessarily appropriate for monitoring changes due to N deposition as they were not selected solely for this purpose, and the CSM guidance suggests monitoring locations should be re-locatable, but in practice it is not clear how frequently this is implemented. In theory, CSM could be supplemented by additional measurements, ranging in sophistication and complexity. The simplest might be incorporate recording of grass:forb ratio[32] at specified monitoring locations on-site. More powerful methods to detect change would involve setting up permanent monitoring quadrats to detect changes in the indicators discussed above. At sites where there is a particular interest in monitoring N impacts it would be necessary to set up multiple permanent quadrats. However, if the purpose is solely to monitor country-wide changes over time, only a few permanent quadrats might be needed per site, with the statistical power coming from analysing changes across sites (see ***Appendix 9***). A further alternative is to identify sites or habitats with historical and re-locatable survey data and use this as a baseline for repeat surveys in future. As with any indicator, there is a basic need for high quality repeatable data over time.

In building up a robust body of evidence to demonstrate success of remedies it is useful to consider the concept of the ‘biomonitoring chain’ (Ch 16 in Leith et al., 2005; Sutton et al., 2011b; Hall et al. 2012). This recognises that the indicators most closely related to features of interest are better to indicate effect, but may be influenced by factors other than N emissions and deposition. Conversely, the indicators most closely linked to source attribution are not necessarily linked to biological change. The concept of the biomonitoring chain therefore links key indicators across the series from emission to deposition to species-response in order to build a robust package of observations that can demonstrate the success of measures to reduce N threats.

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[32] Ideally separately record the percentage cover of 3 categories: graminoids, forbs and remaining species. This allows calculation of several different grass:forb metrics.

3.5. Identification of evidence gaps

Summary

Evidence gaps can be grouped into different aspects for the purpose of identifying potential remedies for atmospheric N pollution at designated sites, on both data and knowledge:

- **National datasets**: More detailed approaches/data are needed on a number of issues for national and site-based assessments: a) the extent of uptake of mitigation measures (and spatial distribution), b) the location and extent of designated features within sites (only available locally, no national datasets), c) the spatial resolution of UK national deposition data informing critical loads assessment (currently 5 km, which does not highlight ‘hotspots’ adequately), d) uncertainties and limitations of national critical loads and exceedance data and e) a more detailed source-attribution dataset allowing the proportion of long/medium/short range N input at each site for each source type to be modelled separately (also bringing dataset up to date from current 2005 version). Only in the case of c) and d) is work in place to address these gaps.
- **National tools**: The outcomes of the RAPIDS project (and the subsequent IPENS projects) could be made available in the form of *decision support tool*, to enable conservation and regulatory agencies to assess all sites under their care for the main atmospheric N threats and suitable measures to target N pollution at a site level. Such a tool would complement existing web-based tools such as APIS and SCAIL.
- **Critical loads and critical level evidence**: Critical level data are currently very coarse tools, and values have not been assigned to specific habitat types or features at a national scale, while there are still designated features with no critical load value assigned in the UK database.
- **Recovery of habitats and species from N effects**: There are few experimental studies on long-term effects of N deposition. Similarly, there are relatively few studies that have quantified rates of recovery. Priority actions required include: a) systematic re-assessment/re-survey of historical N manipulation, b) further work on emerging evidence of links between ozone (O_3), NH_3 concentrations and N deposition and c) further evidence on long-term recovery of aquatic systems through long-term monitoring.
- **Demonstrating the effectiveness of measures**: Further work is required in particular on field demonstration of: cost-effective measures for cattle housing and guidance on planning locally targeted landscape remedies for both farms and roads (inc. atmospheric buffer zones, tree belt designs and vegetation screens).

This section includes both gaps in knowledge and gaps in currently available datasets, with current/recent developments mentioned where improvements/additional knowledge is being prepared, but not yet available.

3.5.1. Evidence gaps in national datasets and tools

There remain significant process uncertainties in the **relationships between NO_x and NH_3 emissions and deposition**, especially when analysed over time in the context of a changing pollution climate. Continued collection of underpinning evidence on concentration –flux relationships is therefore vital and with substantial remaining uncertainties in regional scale atmospheric chemical transport and deposition models. An assessment of spatial variation in the level of uncertainty surrounding estimates of emissions and deposition would be invaluable in spatially-explicit assessments of N damage to ecosystems.

As national spatial models of NO_x and NH_3 emission are refined from 5 km to 1 km resolution and to take on board information on mitigation practices, it becomes ever clearer that **further data inputs are required to improve the models**. Work is ongoing to integrate country based IED databases of large pig and poultry farms into the AENEID agricultural emission model, but major testing still needs to be done including substantial stakeholder liaison to ensure that data confidentiality agreements are maintained. The **spatial consequences of mitigation strategies** also need to be further underpinned. In particular, there needs to be a **more coordinated approach to gathering information (especially spatially) on the uptake of agricultural remedies**, both including emission mitigation technology and the adoption of landscape level mitigation strategies. This information is vital if the achievements of existing actions are to be recognised in national assessments.

Currently, European and UK scale assessments of N deposition effects are based on the assumption that all forms of N deposition have the same effects. There is clear evidence from the Whim Bog long term experiment that this is not the case, with **differential effects between NO_3 wet deposition, NH_4 wet deposition and NH_3 dry deposition** (Sheppard et al., 2011). These differentials are of major policy consequence, and will affect the extent of ecosystem recovery that can be expected (especially as the fraction of NH_3 increases over time with reducing S and NO_x emissions).

It is currently not possible to use the source attribution dataset to **distinguish between short/medium and long-distance origin of emission source categories**, apart from the estimated N input as wet deposition at each site (which is likely to be due to medium/long range sources). For a site-based approach attempting to determine the influence of local sources on the atmospheric N input, the proportion of N deposition in a model grid square that is due to local emission sources, i.e. from within the same grid square, is a key piece of information that is not straightforward to calculate without separate model runs being carried out for each individual grid square, for all source attribution categories. However, an approximation of the contribution from short (~0-10 km), medium (~10-100 km) or long (> 100 km) range sources could be calculated by producing additional output from the FRAME model for a larger number of individual gases and particulates in combination with dry/wet deposition. Currently, N deposition is split into the following categories in the FRAME and CBED models:

- wet N total
- dry N total
- NH_x total
- NO_x total

Splitting the FRAME output data into more detailed chemical species (than done currently) could provide an approximation of how much of each ‘source attribution type’ (e.g. livestock, fertiliser, shipping, etc) is from short, medium or longer distance sources, as follows:

- Wet NH_3 deposition (short range)
- Wet NH_4^+ deposition (medium/long range)
- Dry NH_3 deposition (short range)
- Dry NH_4^+ deposition (medium/long range)
- Wet nitric acid deposition (medium range)
- Wet nitrate deposition (long range)
- Dry NO_2 deposition (short range)
- Dry nitric acid deposition (medium range)
- Dry nitrate aerosol deposition (long range)

This would then allow the allocation of proportions of N deposited for each source attribution (emission) category into short/medium/long range origins and could be done by introducing a modification to the FRAME code to output these components separately and is expected to be reasonably straightforward, however the format would be incompatible with current plotting and post-processing routines. The same approach would be possible in CBED, but only for dry deposition. Splitting wet deposition into further components in CBED is not possible, due to the bulk collection of precipitation samples for chemical analysis.

A further major evidence gap is that **deposition data** used for source attribution and calculating exceedances (from the CBED model) are mapped at a **5 km grid resolution**. This spatial resolution may not highlight "hot spots" of deposition from point sources (e.g. large pig or poultry farms). The same applies for NH_3 concentration and critical level exceedance calculations, however a solution for this is currently being implemented in the Defra NFC contract, with 1 km concentration estimates being calculated operationally for the first time (assessment to be carried out annually)[33]. This has been possible following careful testing of the 1 km grid version of the FRAME model, and a new calibration that uses national monitoring network data. In the first instance, these new high resolution concentration data will only be used to calculate national statistics, rather than publicly released at the 1 km grid resolution, due to confidentiality agreements regarding the high-resolution input emission data that require discussion and agreement with the DA agricultural statistics teams. However, it is anticipated that data could be made available to conservation agencies for internal work, under a data agreement.

A major evidence gap for more reliable assessment of N threats to designated sites is the lack of a national dataset with detailed **information on the spatial location and extent of current designated features within designated sites**. While such detailed maps of presence/absence of designated habitats or species partly exists at the local level, e.g. on paper maps, at individual sites or regional conservation offices, these have not been translated into a national dataset that can be used in the assessment of Critical Loads and Critical Level exceedance. It could also be interesting to assess N threats for future aspirational distribution of features of sites restored to an optimal condition, however no national datasets currently exist for this assessment.

Therefore the national-scale **Site-Relevant Critical Loads (SRCL) exceedance analysis** has to be carried out with the assumption that all features occur across the entire site. When summarising the results to site and country levels, the potential maximum exceeded area for any feature is used, based on the assumption that the feature may occur everywhere across the entire site.

This is less of a problem for smaller sites of (e.g. a radius of ~1 km), however it constitutes a serious issue for assessing very large sites such as the North Pennines or the New Forest, or elongated sites such as the limestone coast of SW Wales or various rivers. For sites stretching over many grid squares of the 5 km national scale deposition and NH_3 concentration datasets (NO_x concentrations at 1 km), sensitive features may only occur in some restricted areas, however the lack of information on feature location means it is very difficult to quantify the level of threat with reasonable certainty, given the spatial variability of N deposition across larger sites. For site-specific (rather than national-scale) assessments, where available, site-specific information on habitat distributions, site management, local pollution sources, and local-scale atmospheric dispersion models should be used to inform the assessment process. The same issue applies to NH_3 and NO_x concentrations and critical level exceedance calculations.

Finally, the outcomes of the RAPIDS project itself **point to the benefits of encapsulating key information obtained in a web based decision support tool**. Such a tool could provide information on decision support trees, scenarios and lists of relevant measures for each scenario. It would complement existing web based tools such as APIS and SCAIL, delivering a framework to support casework analysis by UK conservation and pollution agencies.

3.5.2. Evidence gaps in critical load and critical level data

Uncertainties and limitations in the national critical loads, SRCL and exceedance data include lack of critical loads data for some designated features sensitive to eutrophication (Bobbink & Hettelingh, 2011), where current knowledge is not available for some habitat types (see ***Appendix 7*** for further details). The SRCL database will be updated during 2014 to include an additional set of critical load values based on the recommended values being used for Article 17 Reporting for the Habitats

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[33] Nevertheless, it should be noted that there is no plan currently in place to produce move from 5 km to 1 km nitrogen deposition estimates for use in the UK assessment of critical loads exceedance.

Directive. The summary exceedance statistics and maps presented in Appendix 7 will be updated with the new SRCL and with more recent deposition data (e.g. 2010-12).

Critical levels for NH_3 are currently very coarse tools, as they are only available for two ‘vegetation types’ (CLRTAP, 2014):

- lichens/bryophytes (including ecosystems where lichens and bryophytes are a key part of the ecosystem integrity) and
- higher plants

At present work is being carried out under APIS to assign critical levels to habitat features at designated sites at the national scale, for the SRCL database, for SACs (UK-wide) and SSSIs (England only). These data will be available for assessing NH_3 Critical Level exceedances across the sites later in 2014. More data from primary field manipulations and monitoring evidence for other ecosystems would be needed as a foundation for any future updating of the NH_3 and NO_x critical levels.

3.5.3. Evidence gaps in recovery of habitats and species from N effects

There is an extensive literature on impacts of N deposition on biological and biogeochemical receptors covering a wide range of habitat types and based on experimental and gradient survey approaches. Nevertheless, there are still relatively few experimental studies that have addressed the long-term consequences (over more than 5 to 10 years) of nitrogen wet/dry deposition or elevated NH_3 concentrations. Similarly, there are relatively few studies looking at recovery from N effects. This remains a major knowledge gap in the assessment of both the potential for and the timescales of recovery from N effects. Two key actions would help address this in the short term: a systematic re-survey of historical N addition experiments, targeted on selected indicators, covering a range of habitats, recovery durations and length of accumulated treatment N additions; and a systematic data collation and analysis of this data together with previous results from published experiments.

Evidence is starting to emerge from the EU ECLAIRE project (results not yet published) that there are significant interactions between N deposition and O_3 pollution. This is leading to a crystallisation of the **hypothesis that O_3 pollution increases ecosystem vulnerability to N deposition** (linked with increases in other N pollution forms), while **NH_3 pollution may increase vulnerability to O_3 effects**. This is a major emerging research challenge, given the increasing O_3 background with little current reduction in NH_3 emissions.

There is a need for further research into the evidence for the harmful effects of N deposition on aquatic organisms, particularly nutrient enrichment, across the wide critical loads ranges currently in place. Further uncertainties relate to the role of anaerobic bacteria in removing N from waterlogged soils. These effects need to be assessed in conjunction with climate change impacts and disentangled where possible. Similarly, the **recovery of aquatic ecosystems from the nutrient-enrichment effects of N deposition** needs to be examined through long-term monitoring programmes, as current evidence is limited.

In wetland and aquatic systems, there is the potential for other sources of N such as groundwater or runoff to impact sensitive sites. The **lack of consideration of external sources of N in addition to atmospheric deposition** is a knowledge gap both within the overall critical loads methodology (although it is mentioned briefly in Bobbink and Hettelingh (2011), and in site assessments in the UK. For example, a wetland site receiving a substantial annual load of N from groundwater would in theory only be able to tolerate a much lower load from atmospheric deposition before adverse effects become apparent. Sites potentially below the critical load for atmospheric N deposition may therefore still be impacted by the combined load from atmospheric deposition and other sources. Further work is required in the UK to establish in which habitats this is likely to be an issue, and how to subsequently assess inputs from atmospheric deposition in relation to the overall N input budget for the site.

3.5.4. Evidence gaps in demonstrating effectiveness of measures

With regard to the mitigation measures, there are still significant gaps requiring further work to **demonstrate the effectiveness at field scales**. Key priorities include the demonstration of cost-effective methods for reducing NH_3 emissions from cattle housing, relationships between width and structure of tree belts adjacent to both farms and roads in reducing concentrations and N deposition – at the field scale. There remains a gap in the need to further develop **guidance on planning locally targeted landscape measures**, including atmospheric buffer zones, which could be facilitated by web based decision support tools and on line model tool to demonstrate in information system.

For road transport measures, specifically, more information on the effectiveness of vegetation screens is required. While there have been studies into the effectiveness of green infrastructure in urban environments (e.g. Pugh, 2012), there is limited information on their effect in rural settings.

3.6. Draft framework for producing site action plans

3.6.1. Draft framework development

Summary

An 8-step draft framework has been developed under RAPIDS for assessing all SACs (and A/SSSIs), guiding the user through:

- Identifying major atmospheric N pollution sources or ‘scenarios’ for each site (using national and local scale information)
- Determining whether there are local sources where mitigation measures could provide cost-effective solutions for a site vs. wider regional/national/international N input that requires larger scale solutions to reduce atmospheric N input
- For sites where local sources have been identified, selecting a subset of suitable measures from suites of potential measures for the scenarios allocated to the site, based on local conditions,
- Checking for local availability of spatially targeted instruments (e.g. agri-environment scheme target areas), and finally
- Detailed assessment of measures for potential implementation on the ground or, especially in the case of dominating long-range N input, referral of issues to national level for high-level actions and further regulation/policy development.

The draft framework has been piloted with available data for UK SACs and A/SSSIs, and illustrated for a number of case studies. It clearly indicates that there is no single ‘one size fits all’ solution for all designated sites, and spatial considerations of relevant sources contributing to N inputs at sites are needed for smart solutions that provide cost-effective mitigation.

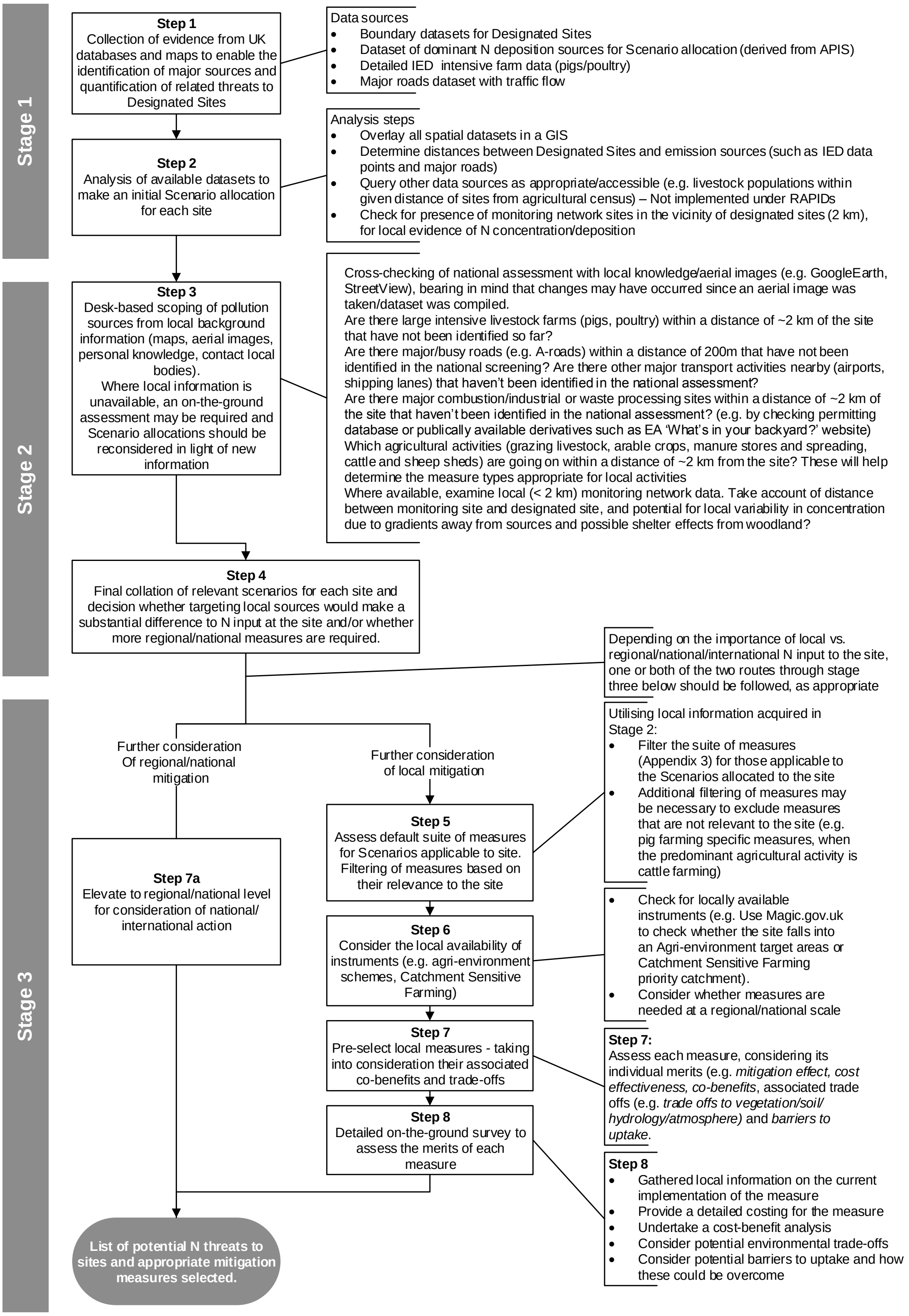
The information gathered as part of the previous tasks has been used to develop a draft framework for guiding action plans for individual designated sites (A/SSSIs and SACs), as summarised in Figure 2 (see Appendix 10 for detailed guidance notes). The proposed 8-step approach guides the user through the identification of major source sectors (Scenarios) for each site, starting from a ‘top-down’ national scale assessment (Steps 1-2), which is then supplemented with local/landscape scale information (Steps 3-4).

Once the main relevant Scenario(s) have been allocated to each site and the importance of local sources vs. wider regional/ national/ international input has been considered, an assessment of the suitability of locally targeted measures can be made for the site. If local targeting of measures is deemed to be suitable for a site, the appropriate suite of measures/remedies (see Section 3.1.3 and Appendix 3) can be assessed and filtered for suitability to the site, based on local conditions. This may include information on local road and point sources, current farm practice, the location of designated features (and/or particularly sensitive sub-features), topography, meteorological conditions etc (Step 5). The selected subset of measures can then be checked against local availability of spatially targeted instruments (Step 6, e.g. agri-environment scheme target areas or CSF catchments), before proceeding to detailed assessments of measures for potential implementation of local scale measures (Steps 7-8).

If a site’s atmospheric N input is mainly due to regional/ national/ international N input, the issues and potential solutions need to be communicated to the national/international level for high-level actions (Step 7a) and further development of policy. The latter would be particularly relevant if long-range or trans-boundary emissions are the dominant contributor to N deposition at a site. If such a framework for producing site action plans were to be adopted, the plans and any actions would need to be reviewed periodically, and especially if large local or regional developments affecting atmospheric N concentrations and deposition are being proposed or carried out. If the framework were to be adopted with the implementation of detailed measures, the success and viability of the measure would need to be evaluated, in addition to monitoring the site to assess its recovery.

The information needed for the source allocation process originates from a variety of data sources briefly introduced in Section 3.1.2, with further details in **Figure 2** below and **Appendix 2** (Source Attribution data sources)). The top-down approach of assigning initial Scenarios (Steps 1-2) to all UK SACs and A/SSSIs has been piloted with available data. Summary output (**Figure 3**) shows the relevant scenarios for SACs as pie-charts for each of the 615 sites. This clearly indicates that there is no single ‘one size fits all’ solution for all designated sites, and spatial considerations of relevant sources contributing to N inputs at sites are needed for smart solutions that provide cost-effective mitigation with limited resources. Figure 3 also illustrates the difficulties of distinguishing Scenario allocations regarding local vs. medium-/long-range origins of the N being deposited at the designated sites, with the current source attribution datasets (as already described as a major gap in Section 3.5.1. above). For example, many sites in the remote northwest Highlands of Scotland are assigned to both Scenario 3 (non-agricultural (point) sources) and Scenario 5 (remote (upland) sites affected by long-range transport). For these sites that are allocated both scenarios due to a category overlap, this is mainly because the N deposition arriving through long-range (wet) deposition originates from sources categorised under Scenario 3 (e.g. large power plants, shipping emissions etc).

Further details are presented in ***Appendix 5*** (Scenario Allocation Pilot), including a similar analysis for A/SSSIs and overview maps showing the numbers of scenarios relevant at each SAC and A/SSSI.



Step 1
Collection of evidence from UK databases and maps to enable the identification of major sources and quantification of related threats to Designated Sites

Data sources
- Boundary datasets for Designated Sites
- Dataset of dominant N deposition sources for Scenario allocation (derived from APIS)
- Detailed IED intensive farm data (pigs/poultry)
- Major roads dataset with traffic flow

Step 2
Analysis of available datasets to make an initial Scenario allocation for each site

Analysis steps
- Overlay all spatial datasets in a GIS
- Determine distances between Designated Sites and emission sources (such as IED data points and major roads)
- Query other data sources as appropriate/accessible (e.g. livestock populations within given distance of sites from agricultural census) – Not implemented under RAPIDs
- Check for presence of monitoring network sites in the vicinity of designated sites (2 km), for local evidence of N concentration/deposition

Step 3
Desk-based scoping of pollution sources from local background information (maps, aerial images, personal knowledge, contact local bodies).
Where local information is unavailable, an on-the-ground assessment may be required and Scenario allocations should be reconsidered in light of new information

Cross-checking of national assessment with local knowledge/aerial images (e.g. GoogleEarth, StreetView), bearing in mind that changes may have occurred since an aerial image was taken/dataset was compiled.
Are there large intensive livestock farms (pigs, poultry) within a distance of ~2 km of the site that have not been identified so far?
Are there major/busy roads (e.g. A-roads) within a distance of 200m that have not been identified in the national screening? Are there other major transport activities nearby (airports, shipping lanes) that haven’t been identified in the national assessment?
Are there major combustion/industrial or waste processing sites within a distance of ~2 km of the site that haven’t been identified in the national assessment? (e.g. by checking permitting database or publically available derivatives such as EA ‘What’s in your backyard?’ website)
Which agricultural activities (grazing livestock, arable crops, manure stores and spreading, cattle and sheep sheds) are going on within a distance of ~2 km from the site? These will help determine the measure types appropriate for local activities
Where available, examine local (< 2 km) monitoring network data. Take account of distance between monitoring site and designated site, and potential for local variability in concentration due to gradients away from sources and possible shelter effects from woodland?

Step 4
Final collation of relevant scenarios for each site and decision whether targeting local sources would make a substantial difference to N input at the site and/or whether more regional/national measures are required.

Depending on the importance of local vs. regional/national/international N input to the site, one or both of the two routes through stage three below should be followed, as appropriate

Step 7a
Elevate to regional/national level for consideration of national/ international action

Step 5
Assess default suite of measures for Scenarios applicable to site. Filtering of measures based on their relevance to the site

Utilising local information acquired in Stage 2:
- Filter the suite of measures (Appendix 3) for those applicable to the Scenarios allocated to the site
- Additional filtering of measures may be necessary to exclude measures that are not relevant to the site (e.g. pig farming specific measures, when the predominant agricultural activity is cattle farming)

Step 6
Consider the local availability of instruments (e.g. agri-environment schemes, Catchment Sensitive Farming)

- Check for locally available instruments (e.g. Use Magic.gov.uk to check whether the site falls into an Agri-environment target areas or Catchment Sensitive Farming priority catchment).
- Consider whether measures are needed at a regional/national scale

Step 7
Pre-select local measures - taking into consideration their associated co-benefits and trade-offs

Step 7:
Assess each measure, considering its individual merits (e.g. *mitigation effect, cost effectiveness, co-benefits*, associated trade offs (e.g. *trade offs to vegetation/soil/ hydrology/atmosphere)* and *barriers to uptake.*

Step 8
Detailed on-the-ground survey to assess the merits of each measure

Step 8
- Gathered local information on the current implementation of the measure
- Provide a detailed costing for the measure
- Undertake a cost-benefit analysis
- Consider potential environmental trade-offs
- Consider potential barriers to uptake and how these could be overcome

List of potential N threats to sites and appropriate mitigation measures selected.

Figure 2 – Summary of draft framework for establishing site action plans

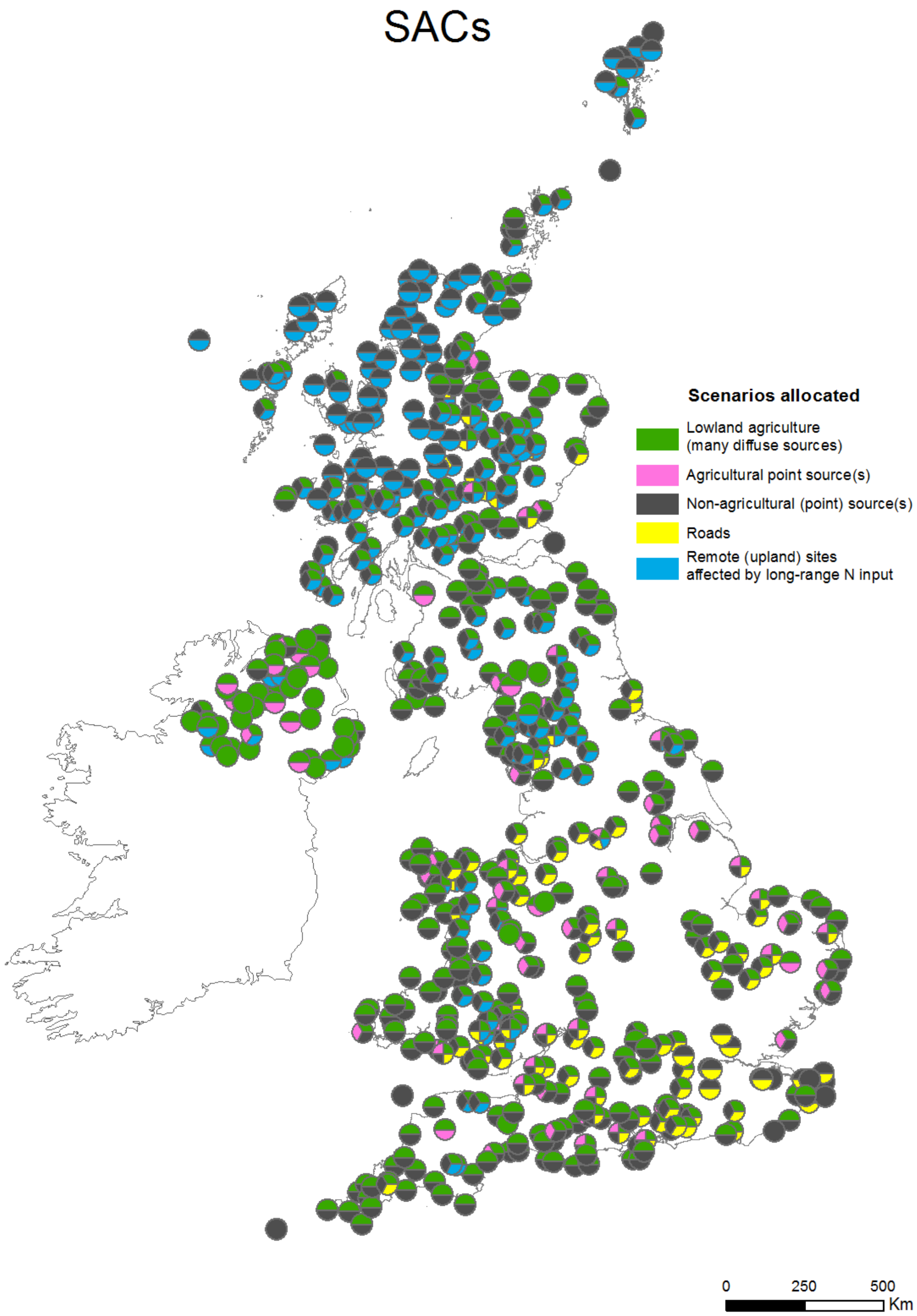


Figure 3 – Estimated Scenario allocation for all UK SACs (615 sites) from national scale source attribution data (5 km grid), also drawing on proximity assessment of sites to IED pig & poultry point data (2 km radius) and major roads (200 m radius). The category ‘non-agricultural point source’ shown in this map does not include a local distance criterion.

3.6.2. Information/data needs for different levels of details

Summary

The information required to enable the implementation of the framework includes:

- National deposition and source attribution datasets (currently at a 5 km grid resolution)
- Vicinity of sites to ‘hotspot’ point sources (IED farms) and line sources (major roads)
- Local/landscape scale information on agricultural practice/operations taking place in the vicinity of the site, topography, prevailing winds, local constraints on measures
- Data on measures (inc. effectiveness, applicability, costs, co-benefits and trade-offs) and instruments (where available)
- Local screening tools (such as SCAIL) for quantitative assessment on likely contributions from IED farms or combustion sources, if applicable
- Atmospheric concentration or wet deposition measurements in close proximity to the site, if available (such as UK national monitoring network sites)

For identifying the main characteristics of the contributing pollution sources, it is likely that data with a mix of spatial resolution will be needed. Depending on the nature of the assessment and the complexity and size of the site, this may range from 5 km grid resolution national mapped datasets combined with point data for IED sources and line source for data major/busy roads for initial assessments to a detailed assessment of N emission sources and dispersion/deposition in the local area.

To be able to implement the most cost-effective measures with the least side effects, local source types need to be assessed. These include major roads, industrial point sources and agricultural practice/operations taking place in the vicinity. In the case of agricultural practices, the occurrence of point and intermittent sources such as animal houses and manure storage, manure and fertiliser applications up to 2km distant should be considered. The assessment should take account of the relative spatial location of sources and the designated site (inc. prevailing winds and topography), as well as local suitability for application of candidate measures.

Local screening tools such as SCAIL can provide fast quantitative assessments of likely contributions from local IED farms and combustion sources (and other smaller sources) if high-resolution assessments are required. However, local diffuse agricultural sources are more difficult to quantify without expert knowledge and/or local scale model estimates at better than 100 m resolution, due to the high spatial variability of ammonia.

Supporting data on UK-scale annual deposition for critical loads exceedance assessment would typically be based on at least 3-year average estimates (available annually, in APIS), while source attribution modelling output would be based on periodic updates (previous version based on 2005 data –implemented in APIS). A new analysis is currently under discussion with the APIS Steering Group.

For quantitative assessments utilising measurement data on atmospheric concentrations or deposition at the designated site (or in close proximity, < 1 km), datasets over multiple years are preferred (at a minimum, 1 year is needed to be informative[34]). For a detailed ecosystem impacts assessment of N deposition, weekly or monthly time resolved monitoring is typically sufficient – while continuous hourly data on air concentrations can optionally be useful to better understand pollution exposure characteristics.

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[34] Ideally, multi-year data would be preferable, as single year data can potentially be misleading if weather patterns were unusual, e.g. through significant jet stream disruption, resulting in a change to the direction and/or speed of prevailing winds.

3.6.3. Illustration of the approach through case studies

Summary

- Seven case study sites were selected, in discussion with the Steering Group, to illustrate the approach suggested for the draft framework, using the pilot source attribution assessment of UK designated sites. These case studies were chosen to represent the range of scenarios and sites across the UK, as well as the size range, from small designated sites of < 1 km^2 to whole mountain ranges.
- Summary information on the case studies is presented here, with more detail on Scenario 1 (Lowland agriculture – many diffuse sources). Details for all case study sites are provided in a separate document (***Appendix 6***).
- The case studies highlight that, while the initial national scale source attribution assessment gives an overview of the likely key sources of N deposition in the wider area, more detailed information is needed to establish the actual local sources and for identifying the most effective local measures.

Seven case study sites were selected, in discussion with the project Steering Group, to illustrate the approach suggested for the draft framework, following the pilot source attribution assessment of UK designated sites (see Section 3.6.1 above, and ***Appendix 5*** – Scenario Allocation Pilot, for details). The case studies were chosen to represent the range of scenarios and sites across the UK, as well as the size range, from small sites of ~ 1 km^2 to whole mountain ranges.

Table 6 gives a short overview of the main N threats at the seven (un-named) case study sites, showing the national-scale source attribution assigned to each of them, together with distances to the nearest major road and IED intensive livestock farm. Colour coding is used to show scenarios that apply at the site (in red), and those that do not apply (in green), from the initial scenario allocation. For two sites, there is ambiguity in the scenario allocations for roads (colour coded in grey). In the first case, the % source allocation threshold for the roads scenario is exceeded, but major roads (i.e. motorways, primary and A-roads) are not within 200 m of the site boundary. In the second case, a major road intersects the site, but the % scenario allocation threshold for roads is not exceeded at the 5 km grid resolution of the source attribution database (see detailed section for Scenario E below for a discussion).

A single case is discussed in more detail below for Scenario 1 (Lowland agriculture – many diffuse sources). All case studies are illustrated in detail in ***Appendix 6***, each with an aerial image, sample description of surrounding emission sources, and sample data flow diagrams for the Scenario allocation and selection of measures. The flow diagrams provide walk-through examples of the RAPIDS framework for site action plans.

In summary, the case studies highlight that the initial national scale source attribution assessment at a 5 km grid resolution gives a high-level overview of the likely key sources of N deposition in the wider area. However, they also show that more detailed information is needed to establish the actual local sources and for identifying the most effective local measures.

Case Study A - 1 – Lowland agriculture (many diffuse sources)

Site area: ~ 0.3 km^2

Habitat types: woodland features of UK and European importance

Landscape context: intensive lowland agricultural landscape in England

Main N sources identified: large cattle farms and the associated NH_3 sources of landspreading of manures, fertiliser application and livestock grazing right up to the site boundary, and several cattle sheds within 0.5-1 km of the site boundary, both to the W and NE of the site.

Source attribution calculations: Diffuse agricultural NH_3 emissions are the major source of N deposition at this small site, with the contribution to the surrounding 5 km grid square from diffuse agriculture at ~ 70% of total N deposition (**Table 6**). The nearest major road is > 1 km away, and the nearest large poultry farm is at nearly 4 km distance from the site, with wet deposition contributing ~15% of the total atmospheric N input to the site. The total annual N deposition estimated for woodland features in the 5 km grid square containing the site is ~57 kg N ha^{-1}, which is well in excess of the critical load. Given the large spatial variability of N at the landscape scale, this value is likely to be an underestimate in close proximity to sources, especially at near the site boundary. The estimated NH_3 concentration from APIS is 4.5 μg m^{-3}, while nearby NH_3 monitoring (<30 m from site boundary) has a long term mean of 3.6 μg m^{-3} NH_3, with both measured and modelled concentrations in excess of the mean critical level for higher plants of 3 μg m^{-3}. By comparison, NO_x concentrations (as given by APIS) are 8.7 μg m^{-3} NO_2, which is much less than the critical level of 30 μg m^{-3}.

Given the dominance of cattle farming and associated grassland and fodder crop production, the main candidate measures for reducing local NH_3 emissions and associated concentrations and dry deposition are those targeted at *efficient manure management* (example in **Figure 5**). Such measures include *minimising emissions from cattle housing, manure storage and application of slurries and manures to land*, together with *general nutrient efficiency measures* such as accounting for N in manures when calculating mineral fertiliser application rates.

In addition, *buffer zones* with reduced or no application of manure or urea fertiliser in the immediate vicinity of the site and/or tree belts around animal houses and manure stores to re-capture/disperse NH_3 emitted would also reduce elevated NH_3 concentrations or deposition to the site. Given the location of the site among a multitude of diffuse agricultural sources causing elevated NH_3 concentrations for the wider surroundings, it may be worth considering *conversion of agricultural fields* surrounding the site to e.g. mixed native woodland as a shelter belt, to take the brunt of the leading edge of incoming atmospheric N.

Potential co-benefits and side-effects of measures: Many of the above listed measures would also deliver considerable reductions to nitrate leaching risks at the site, among other co-benefits. However, the tree belt options close to the site boundary would need to be evaluated thoroughly to eliminate potential detrimental change to the designated features, e.g. species composition and potential effects on the hydrological state of the site would have to be carefully evaluated.

Potential Outcome: Discussions with site managers, agricultural advisors and agri-environment scheme managers considering local farm management practices, site characteristics and prevailing wind conditions, could think about whether farmers would sign up to a Higher Level Stewardship (HLS) scheme. This could include low-emission manure/fertiliser landspreading options (with agreed maximum application rates) in an area of 500 m surrounding the site, with the zone extended to ~ 1 km upwind, i.e. to the southwest of the site. Other measures that could be considered are covering slurry lagoons (using the CSF[35] Capital Grant Scheme) and placing manure stored in field heaps no closer than 500 m from the site boundary. Farmers could also apply for woodland grant schemes to plant and maintain both farm- and site-focused tree shelter belts, the latter in collaboration with site managers to prevent potential side-effects.

The benefits of these measures in terms of decreased N deposition and NH_3 concentrations at the site can only be quantified through a detailed assessment that includes quantification of emissions saved with each individual measure and/or combination of measures. The outcome will depend on ambition, current systems and practices in operation, including prior implementation of measures, land areas affected and relative position of the potential emission source to the designated site, etc. Following an assessment of emission savings that could be achieved, a full quantification of N deposition savings

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[35] The potential for implementing atmospheric ammonia measures via CSF capital grants is to be investigated for a number of case studies in CSF areas under IPENS, due to report in summer 2014

would require detailed atmospheric modelling at the landscape scale, as reductions in emissions cannot be directly generalised into savings in deposition.

Table 6 - Summary information on case studies (A-E): number of scenario(s) allocated to each case study, **total N deposition** (maximum for site, using FRAME 2005, consistent with source attribution data) and source attribution, using national scale 5 km grid data**.** The **deposition type** refers vegetation-specific N deposition estimates, with ‘woodland’ values appropriate for any woodland habitats present at the designated site, and ‘semi-natural’ for other (low-growing) semi-natural vegetation, such as grassland, heathland etc. When adding up **percentage scenario contributions**, wet deposition should not be added to the other categories (roads, agriculture and non-agricultural) as these contain wet deposition contributions already. Scenario totals will not add up to 100%, due to rounding and other small source categories, which are not included in the scenario definitions (e.g. dry deposition from imported emissions and offshore installations). The **colour coding** shows allocated scenarios in green, scenarios below the threshold in red, and ambiguous allocations in grey (e.g. % source attribution for roads is below the threshold, but a major road intersects the site).

Case study	Deposition Type #	Scenarios allocated (number, IDs)	Total max. N for site (kg N ha^{-1} y^{r-1})	Scenario allocations in **green**				Nearest feature (m)	
				Total wet N deposition (% of total N deposition)	Source Attribution (% of total N deposition)			Close proximity of sources in **bold**	
				Long Range N deposition (Sc5)	Roads (Sc4)	Non-Agricultural sources (Sc3)	Agriculture (fertiliser & livestock) (Sc1,2)	Major Road (Sc4)	IED Intensive farm (Sc2)
A	Woodland	1 (**Sc1**)	57	13	8	17	**69**	> 200	> 2,000
	Semi-natural		31	21	5	16	**72**		
B	Woodland	2 (**Sc2**,1)	50	16	3	10	**80**	> 200	**530**
	Semi-natural		29	23	2	11	**78**		
C	Woodland	2 (**Sc3,4**)	39	17	29	**50**	11	> 200	> 2,000
	Semi-natural		20	31	22	**49**	13		
D	Woodland	2 (**Sc4**,3)	49	19	**22**	**53**	15	**0 (Intersects site)**	> 2,000
	Semi-natural		24	36	**15**	**52**	17		
E1	Woodland	2 (**Sc5**, 3)	34	**74**	8	**39**	18	> 200	> 2,000
	Semi-natural		21	**88**	7	**37**	20		
E2	Woodland	4 (**Sc5**,1,3,4)	57	**57**	**11**	**32**	**30**	**0 (Intersects site)**	> 2,000
	Semi-natural		33	**73**	8	**28**	**33**		
E3	Woodland	3 (**Sc5**,1,3)	36	**73**	8	**30**	**34**	**0 (Intersects site)**	> 2,000
	Semi-natural		27	**87**	6	**28**	**33**		

- N.B. Differences between % source allocation to the scenarios (columns 5-8) are due to a combination of reasons, including differences in deposition velocity between NO_x and NH_3 to different vegetation types, with small differences also due to the calibration approach for the deposition data. The larger differences in the contribution of wet deposition to total deposition to woodland and other semi-natural vegetation types are due to woodland receiving larger amounts of dry deposition, with similar wet deposition input to both vegetation types, hence the relative differences.

Currently there is a shortage of existing delivery mechanisms in the UK specifically targeted at reducing nitrogen deposition from ammonia emissions. Nevertheless, increased focus on NH_3 options in HLS can be expected following the current review. Similarly, measures available under the CSF Capital Grant Scheme and woodland grant schemes can provide co-benefits, if spatially optimised, and could be the basis for introducing specific targeted and spatially optimised atmospheric N mitigation options (key measures listed in ***Appendix 3***).

3.6.4. Main uncertainties in the evidence

Summary

The framework incorporates a combination of national and local scale data sources, which are all associated with their own uncertainties.

- Key uncertainties identified for source attribution lie in the n**ational scale model data**, both due to the relatively coarse resolution of model input and output data for use at the scale of individual designated sites
- The national scale data are the best source for providing rapid initial best estimates for source attribution, but need to be supplemented with local evidence of source characteristics and location, for practical solutions. Atmospheric monitoring data also can be used to support in the collection of evidence.
- If amounts of N deposition are required in more detail for site action plans, additional local scale modelling may be required to improve on the national scale estimates.

The information framework developed here (Figure 2) depends on a combination of national scale and local scale data sources – each with their own uncertainties. While the process of establishing and reviewing case studies must therefore consider multiple uncertainties, it is nevertheless possible to highlight the following key uncertainties:

- **National model datasets** at 5 km and 1 km resolution include both absolute and spatial uncertainties according the modelling procedure used. They provide best estimates for any site in the UK, but should ideally be supplemented by **local evidence** on the source location and more detailed source characteristics. For example, agricultural emission maps are calculated using average agricultural practice information across the UK from sample survey data, as detailed information on the distribution of management systems is not available on a farm-by-farm basis. It is not currently possible to quantify the confidence in the UK exceedance statistics into high/medium/low, however work has recently started on this under a JNCC contract (Oct. 2014, led by L. Jones, CEH Bangor).
- Air pollution **monitoring data** can be used to support modelled estimates of air concentrations and wet deposition at a site scale, but the existence of local spatial gradients must be recognised, both in the adjacent km near a site and even within a site at the range of 10-100 m, especially when near ground based sources of NO_x and NH_3 (roads, fields, farms etc.).
- In developing a site plan of appropriate measures, the relative contribution of different source types (source scenarios) is just as important as the amount of N deposition, as this directs the priorities for action. Identifying these contributions contains uncertainties associated with national dataset availability (e.g. distance to source of quantified magnitude) and may require additional local modelling to improve estimates, especially where supporting evidence points to the existence of additional nearby sources.
- In conducting more comprehensive uncertainty analysis, note may be taken of procedures developed elsewhere for greenhouse gas and biodiversity assessment by IPCC[36] and LWEC[37].

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[36] http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

[37] http://www.lwec.org.uk/resources/report-cards/biodiversity

4. Main implications of the findings and their reliability

The present analysis shows that there are major threats associated with atmospheric N deposition to designated nature conservation sites in the UK. It is estimated that 65% of the sensitive habitats of the UK are subject to unsustainable levels of nitrogen deposition (i.e. in excess of critical loads, 2010-12 data). At the same time, substantial exceedance of the $1 \mu g\ m^{-3}$ NH_3 critical levels is estimated, at 67% for 2010, with similar values expected for 2020. These levels of exceedance mean that the UK and devolved administrations will struggle to meet national and European biodiversity commitments.

Nevertheless, this report has shown that there are many remedies available to reduce N emissions, and thereby for achieving reductions in N deposition (and associated NH_3 and NO_x concentrations) to designated sites. At the same time, measures based on landscape structure are available that can be used to optimise the location of emissions, to improve dispersal and to encourage re-deposition to less sensitive receptors, thereby providing a contribution to further reduce the N threat to designated sites.

The report has shown how that there is no single solution that fits all cases. To address this, the report has shown how measures can be targeted by considering the local situation, especially in relation to the major sources contributing to the N deposition at each site. In practice, the following key statements can be made in relation to the priority opportunities for each source scenario:

1 **Lowland agriculture (many diffuse sources):** This is a priority area for reducing N emissions and deposition, given that little abatement has so far been achieved, with many ‘low hanging fruit’ still available. According to estimates from GAINS (Winiwarter and Klimont, 2011), mitigation of agricultural NH_3 emissions is on average half the cost of further mitigation of NO_x emissions. Key low-cost opportunities include low emission manure spreading and urea application, covering manure stores and farm nitrogen budgeting (guidance is provided by Bittman et al., 2014). In the absence of a regulatory framework (as implemented in some other countries), there are currently limited available delivery mechanisms in the UK. However, options include increasing emphasis of NH_3 in the HLS under CAP, and of landscape structure approaches.

2 **Agricultural point sources**: As with other agricultural NH_3 sources, this is a priority area for action. In the case of most poultry farming in the UK and a substantial fraction of pig farming, the IED directive requires that Best Available Techniques (BAT) be used, with the European reference documentation (BREF) on this sector currently being updated[38]. Given the nature of these activities as point sources, measures focus on livestock housing and manure storage, though manure spreading measures are also relevant where this occurs on site. Similarly, landscape measures including buffer zones and tree belts are highly relevant. In the case of planning for new sites, local protection of a Natura 2000 site may be achieved simply by siting the new development further from the designated site, for which screening support is provided by the SCAIL model. It should be noted that the delivery mechanism to protect Natura 2000 sites from larger point source cattle farms is currently poorly developed. Given the magnitude of emission from this sector and the need to develop improved cost-effective mitigation techniques (e.g. for naturally ventilated cattle houses), this is a logical priority for further development.

3 **Non agricultural (point) sources**: This scenario contains a wide diversity of source sectors, ranging from large combustion plants associated with the electricity supply industry to a diverse range of industrial processes and shipping. The main N pollutant emitted is NO_x, though some processes can also emit NH_3 (also as ammonia slip as part of NO_x pollution reduction processes). Most processes in this group fall under either or both the Industrial Emissions directive and the Large Combustion Plant directive, providing stringent requirements for emissions levels. Where a particular plan apparently complies with BAT but is still estimated to contribute to a significant adverse effect on a Natura 2000 site, then the permit review in relation to provisions of the Habitats Directive may require that more stringent pollution mitigation actions are installed (i.e. BAT+ or BAT++).

4 **Roads**: Emission standards for N from vehicles (mainly focused on NO_x) are controlled at a European level. This means that remedies for specific Natura 2000 sites focus on traffic and /or landscape management. As part of such analysis it is important to recognise that very close to major roads (<10

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[38] Latest draft (August 2013) http://eippcb.jrc.ec.europa.eu/reference/BREF/IRPP_D2_082013online.pdf

m) up to half of the local enhancement in N deposition may result from NH_3 emitted from catalytic converters, due to the larger deposition velocity of NH_3, as compared with NO_x. Ongoing improvements in engine design are understood to be reducing the NH_3 emissions, but further underpinning evidence on the future situation would be useful. Remedies in relation to traffic management include re-routing of traffic or traffic charging schemes. Similarly, landscape structure elements such as tree belts may help disperse NO_x to lower concentrations in the vicinity of a Natura 2000 area. It should be noted that the maximum NO_x levels are much smaller than from point sources (Scenarios 2 and 3) as traffic typically represents a line source of N emission (i.e. is better dispersed than a point source).

5 **Long-range N transport**: For many Natura 2000 sites that are remote from local N sources, the main source of N deposition arises from long-range transported pollution. This situation is especially characteristic of upland locations where the main N deposition input is typically as wet N deposition. In this scenario, local landscape measures are typically ineffective (as they focus on dispersing or recapturing the gaseous and aerosol fractions), so that the only approach is to reduce regional scale N emissions. Given the position of the UK on the west of Europe and the nature of prevailing winds, much of the N deposition in the UK is a result of UK emissions. Therefore, while international agreements are necessary to reduce the amounts of imported N pollution, and the export of UK pollution to other countries, the UK will be the largest beneficiary of its own national actions to reduce N emissions. Key frameworks here are the Gothenburg Protocol and the National Emissions Ceilings directive. While the UK has committed a further 30% reduction in NO_x emissions across Europe from 2010 to 2020, only a 2% reduction in NH_3 emissions was committed. This means that the current negotiations under the National Emissions Ceilings directive will be especially important if substantial reductions in NH_3 emissions are to be achieved.

5. Possible future work

Possible future work can be grouped into different priorities, based on the evidence analysed and summarised under the RAPIDS project:

A major priority should be the development of a **new source attribution dataset** that a) brings the dataset up to date (current version for year 2005) and b) reports the different chemical N species in more detailed categories. The latter, in particular, would be essential to enable proportions of local/ medium/ long distance atmospheric transport for each source type to be distinguished.

Further work is required on **field demonstration/experimental evidence** of cost-effective measures for **guidance on planning locally targeted landscape remedies for both farms and roads** more generally. This includes atmospheric buffer zones, tree belt designs and vegetation screens. Case study measurements at sites with long-term data availability and sufficient monitoring in place, to compare ‘before’ and ‘after’ the implementation of measures, are required to quantify the effects of measures, both with measurements and modelling tools.

Additional experimental studies on **long-term effects of N deposition** and **quantification of the rates of recovery** are needed, as the current evidence is very sparse. Suggested priority areas for further research include: a) systematic re-assessment/re-survey of historical N manipulation experiments, b) more detailed investigation of emerging evidence of links between ozone (O_3), NH_3 concentrations and N deposition and c) collation of further evidence on long-term recovery of systems through long-term monitoring.

The outcomes of the RAPIDS project (and the subsequent IPENS projects) could be made available to conservation and regulatory agencies in the form of a **decision support tool**, to enable the assessment of all sites under their care for the main atmospheric N threats and identification of suitable measures to target N pollution at a site level. Such a tool would complement existing web-based tools such as APIS and SCAIL.

In terms of **national datasets,** more detailed approaches/data are needed for national and site-based assessments, on a) the extent of **uptake of mitigation measures** (and spatial distribution) and b) spatial

resolution of UK national deposition data informing critical loads assessment. The current spatial resolution is 5 km grid square data, which does not highlight ‘hotspots’ adequately.

Finally, there are still **designated UK features with no critical loads values** assigned in the UK database. Further work could investigate best estimates to be applied to these features, as they cannot be assessed for exceedance of critical loads at present.

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