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APPROACHES TO MODELLING LOCAL NITROGEN DEPOSITION AND CONCENTRATIONS IN THE CONTEXT OF NATURA 2000 (THEME 4)

6.1 Background document

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Abstract:

- Transport-chemistry models are useful and well used tools in the environmental assessment of impacts of atmospheric N on Natura 2000 sites.
- Impacts arise from two groups of reactive nitrogen compounds: reduced nitrogen compounds (NH_3 and its reaction product NH_4+) and oxidised nitrogen compounds (NO, NO_2 and their reaction products). Often the contributions from these two groups are of the same magnitude, but close to intensive livestock farms, the contribution from NH_3 may dominate.
- Oxidised nitrogen compounds contribute to the long-range transport component of nitrogen deposition, but may for most practical purposes be disregarded in local scale assessments. Local scale assessments, therefore, concentrate on the assessment of NH_3 deposition from local agricultural sources.

6.1.1 Introduction

The impact of atmospheric nitrogen (N) on nature areas is both a local scale and a transboundary problem. These impacts can be the result of both deposition (wet and dry) and elevated ambient concentrations of reactive nitrogen (N_r) compounds. In some regions the contribution from (mainly) wet deposition of long-range transported aerosol-bound N_r compounds exceeds the critical loads of sensitive ecosystems. Close to intense agricultural areas the contribution from dry deposition of locally emitted ammonia (NH_3) may, however, equal or even exceed the nitrogen contribution from long-range transport.

Two types of assessment studies are carried out with respect to evaluating the impacts on Natura 2000 areas; the assessment of critical load and critical level exceedances, respectively. The model approaches for the two types of studies are similar, although the critical levels approach focuses on ammonia concentrations, whereas the critical load approach focuses on deposition (arising from dry and wet deposition of both reduced and oxidized N_r compounds in gas and particle phase). The assessment of atmospheric N_r deposition, therefore, needs to account for both local and long-range transport contributions to the nitrogen input to the nature area in question (Hertel *et al.*, 2006a), whereas critical levels may be limited to considering only contributions from local sources of NH_3 or in some situations elevated nitrogen dioxide concentrations from local sources such as major roads (e.g. Cape *et al.,* 2004)..

It should be noted that Natura 2000 areas vary considerably in size throughout Europe – with cross-sectons of a few hundreds of meters to many kilometres. Naturally, this has strong implications for which tools are applicable in the assessment of impacts of atmospheric N. An overview of the chemistry-transport modelling of NH_3 on local and regional scale has recently been presented by (Loubet *et al*., 2008) and (Van Pul *et al*., 2009). The focus in the current chapter is on describing the model approaches used in the assessment of local atmospheric N_r deposition. We limit our selves to describing the contribution from local sources within a distance of 20 km of a Natura 200 site.

Processes on the local scale

In the following section we will look at the physical and chemical processes that play a major role in the impacts of N on Natura 2000 areas, and therefore need to be included in assessment studies at the local scale (<20 km).

Transport and chemical transformation

Buildings and other obstacles may have significant influence on the initial downwind dispersion of NH_3 emitted by livestock houses. The landscape may also impose certain flow conditions that have to be accounted for and nearby vegetation may influence the generation of turbulence, thereby affecting the rate of dispersion.

Only fast chemical transformations can take place on a time scale of minutes to a few hours. Concerning N_r compounds, fast reactions of this kind applies to the conversion of NO to NO_2 through the reaction with ozone and the photo dissociation of NO_2 reforming NO. Further conversion of atmospheric NO_2 to HNO_3 through the reaction with hydroxyl radicals (OH) has a rate in the atmosphere of about 5 per cent per hour, which means that this reaction is negligible on the time scale of local dispersion. NH_3 reacts with acid gases and aerosols in the atmosphere to form aerosol-phase ammonium (NH_4^+); a reaction that used to be relatively fast. In the 1980s and 1990s the average conversion rates in Europe were estimated to be in the order of 30 per cent per hour, but due to the large reductions in European sulphur emissions leading to significant decrease in sulphate concentrations, the conversion rate is now believed to be of the order of 5 per cent per hour (Van Jaarsveld, 2004). This means that NH_3 now has an atmospheric lifetime of the order of a day, where it used to be of the order of 4 to 6 h. Thus, NH_3 to NH_4^+ conversion may, for most practical purposes, also be disregarded in local-scale modelling.

Wet and dry deposition

Precipitation events take place during a very short period of time. The residence time of local pollutants within the 20 km distance from the source is on the order of minutes to a couple of hours. This means that within this domain wet deposition of locally emitted pollution is generally negligible and it may for most purposes be disregarded in local scale modelling of nitrogen deposition (Hertel *et al*., 2006a). The contribution to the background deposition is, on the other hand, very significant.

It is common to assume a zero concentration at the ground in the computation of the dry deposition flux. This may, however, not apply over vegetation where the flux of NH_3 and NO_2 may be bi-directional (Schjørring *et al*., 1998a; Schjørring *et al*., 1998b). This bi-directional flux depends on the concentration in the air as well as in the plants, which changes during the season and is also dependent on management such as grass cutting or use of fertilizer. An important pathway for dry deposition of NH_3 is the uptake through stomata of plants, but it may also be absorbed through dew on the plants or through the thin water film on the leaf epidermis (Nemitz *et al*., 2004). Experimental studies have shown that co-deposition of NH_3 and SO_2 takes place, and that the ratio between atmospheric concentrations of these two compounds together with the humidity and temperature are important factors for the deposition of NH_3 (Neirynck *et al*., 2005). NO_2 may also be taken up by plants through the stomata. Although this deposition is not very fast (to a forest the dry deposition velocity is on the order of 2 to 4 mm/s), it may in some areas be of importance for overall N_r deposition (Wesely and Hicks, 2000). HNO_3 sticks to almost any surface and is therefore, quickly deposited. In addition, the dry deposition of peroxyacetyl nitrate (PAN), N_2O_5, and HONO may be of some importance for overall N_r deposition (Wesely and Hicks, 2000). As previously discussed, the formation of these NO_y compounds is too slow for local emissions to play a role in the atmospheric deposition of N_r.

Current state-of-the-art in modelling

Above we have discussed the processes that need to be accounted for in modelling of local-scale nitrogen deposition. Table 6.1 summarises the state of the art in process descriptions of currently applied models. For comparison modelling of long-range transport is also included in the table.

Table 6.1: State-of-the-art in LRT & local-scale modelling of N_r deposition (Hertel *et al*., 2006a).

Process	Long-range transport (LRT)	Local scale
Emissions	European 17 km x 17 km inventory. For parts of the domain detailed seasonal variation is included.	Single farm level with dynamic seasonal variation divided into contributions from livestock housing and manure application
Transport	Eulerian 2-way nested grid models with 17 km x 17 km or even 5 km x 5 km resolution in the inner nest.	In process studies, CFD models provide detailed information, e.g. flow around building obstacles.
Aerosol description	Dynamic aerosol-phase chemistry.	1st order transformation between gas phase NH_3 & aerosol phase NH_4^+.
Gas phase chemistry	Explicit chemical mechanisms including the most important species.	First-order transformations.
Wet deposition	Full wet phase chemistry in cloud and rain droplets and subsequent scavenging of rain droplets.	Not included.
Dry deposition	Resistance method incl. detailed seasonal variation & actual meteorology. Bi-directional flux parameterisation for NH_3.	Resistance method incl. detailed seasonal variation & actual meteorology. Bi-directional flux parameterisation for NH_3.

6.1.2 Methodologies and tools

The following section outlines the main features of model tools and systems applied in the literature. A review of literature reveals assessment studies from only a few European countries including United Kingdom, the Netherlands, France, Poland and Denmark. Concerning approaches in the calculations of atmospheric N_r impacts to nature areas, one can distinguish between the methods and tools that have been developed for:

- Screening purposes – to provide a crude and quick assessment of the potential environmental impact of atmospheric N_r impacts;
- Routine assessments e.g. by local authorities using methods based on nomograms and tables generated from model calculations of source-receptor relationships;
- High resolution assessments using all available information and applying detailed modelling systems.

Screening methods are based on simple parameters like size of farm and distance between sources and nature areas, and it provides crude, worst-case deposition estimates. Nomograms and tables are also somewhat crude tools for estimating the loads but, in compliance with the local legislation, in some countries they are applied by local authorities and consultants to assess impacts from single farms; this is the case e.g. for Denmark. Focus in this paper is, however, mainly on the more detailed modelling systems such as those listed in Table 6.2.

Table 6.2 contains references to three types of models applied in assessment of atmospheric nitrogen deposition:

- The Gaussian plume models are used in local scale modelling (limited to a distance of about 20km from the source) and assume a Gaussian distribution of the pollution concentration in both the vertical and horizontal direction. The simplest versions apply source depletion for describing dry deposition; whereas surface depletion provides a more correction description. First order chemistry is often applied.
- The Lagrangian type models may be applied for describing local to long-range transport. The model concept is based on following a single air parcel at a time along a transport route (a so-called trajectory). The difficulty of this type of model is the description of mixing of air masses and the uncertainties in determining the transport routes. Full chemistry and dry and wet deposition processes are usually implemented.
- Eulerian type models are based on fixed sets of grid cells and describing exchange of pollutants between these cells. In order to describe concentrations and depositions well a high resolution is necessary, but this costs substantial computer time. Horizontal advection may generally be well resolved whereas vertical mixing is less well described. Just as in the case of the Lagrangian models, full chemistry as well as dry and wet deposition processes are usually implemented.

The local legislation may be a powerful tool in reducing local atmospheric nitrogen loading of nature areas. These regulations may include use of buffer zone around sensitive nature areas, restrictions on number of animal units per farm etc. Trees have been discussed as a tool in landscape planning to reduce the impact of atmospheric NH_3 deposition, and local scale models have been used to evaluate the impact (Sutton *et al*., this volume). The efficiency of measures on a local scale depend largely on how much nitrogen is coming from local sources and how much from sources further away (often called background deposition). In the Netherlands, for instance, in general the background deposition to nature areas is dominant over the contribution by local sources. This makes the efficiency of local measures limited (van Pul *et al*, 2004).

Table 6.2: Models applied in local scale modelling of nitrogen deposition.

Name	Type of model	Process description	Refs
AERMOD	Gaussian plume model.	Uses hourly meteorological data to derive stability & dispersion parameters. Ground & elevated sources in simple & complex terrain. Dry deposition using source depletion & applying resistance algorithm. Wet deposition. using simple wash out ratios for gases & particulate matter (PM).	(US-EPA, 2004)
ADMS	Gaussian plume model.	Uses hourly meteorological data to derive stability & dispersion parameters. Ground and elevated sources in simple & complex terrain. Dry deposition using source depletion & resistance algorithm. Wet deposition using simple wash out ratios for gases & PM. Dry & wet deposition algorithms recently updated.	(Carruthers *et al.*, 1994)
FRAME	Lagrangian transport model.	Horizontal resolution of 5 x 5 km & 33 vertical layers. Boundary conditions from FRAME-Europe on 150 km x 150 km. Calibrated to interpolated measured deposition on cell basis over three most recent years. Dry deposition applying resistance method & 5 land use classes. Wet deposition applying scavenging ratios from EMEP model & a directional orographic model for enhanced precipitation generated by terrain.	(Griffith, 2007)
CMAQ	Eulerian chemistry-transport model	Uses MM5 meteorological data, but other data may be applied. Carbon-Bond V (CB05) chemistry mechanisms incl. aerosol module from RPM. A variable resolution multi-layer model incl. sub-grid scale treatment of large point source plumes (PinG). Hourly dry deposition using resistance methods from RADM incl. seasonal variation & 11 land use types. Wet deposition using scavenging coefficients.	(Binkowski and Roselle, 2003)
LADD	Lagrangian multi-layer model	Uses the trajectory approach from FRAME. Horizontal resolution 50m x 50m & very high vertical resolution (lowest points defined at 0.25m; 0.5m; 1.0m & 2.0m above ground level. Computes dry deposition. of NH_3 applying resistance method. Wet deposition. not accounted for.	(Dragosits *et al.*, 2002; Sutton *et al.*, 1998)
DEHM	Eulerian chemistry-transport model	Uses MM5 meteorological data, but other data may be applied. Explicit chemistry mechanisms with 80 species & 200 reactions. Covers Northern Hemisphere on 150 x 150 km, nested grid 50 x 50 km for Europe, & 5 x 5 km for Denmark & close vicinity. Hourly dry deposition applying resistance method from EMEP model. Wet deposition applying in-cloud & below-cloud scavenging coefficients.	(Christensen, 1997; Frohn *et al.*, 2002a; Frohn *et al.*, 2002b)
OPS	Gaussian plume model on local scale & Lagrangian transport further away from source.	Uses statistical climatology derived from hourly meteorological data. Computations performed for climatological classes & hourly concentration & deposition derived from frequency. Chemistry using 1st order conversion. Dry deposition based on resistance method. Wet deposition as wash out & rain out using coefficients; rain out after plume penetrates cloud; thus at some distance from source.	(Colles *et al.*, 2004; Pul *et al.*, 2004; Van Jaarsveld, 2004)
OML-DEPOSITION	Gaussian plume model.	Uses hourly meteorological data to derive stability & dispersion parameters. Handles point & area sources in simple terrain applying variable horizontal resolution. (usually 400 x 400 m or 100 x 100 m). Dry deposition using surface depletion & resistance algorithm. No wet deposition or bi-directional flux.	(Hertel *et al.*, 2006b; Olesen *et al.*, 1992; Sommer *et al.*, 2009)

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6.2 Working group report

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6.2.1 Conclusions and recommendations of group discussions

- It was noted that modelling assessment approaches differ widely from country to country, both in terms of the type of models used and the level of detail considered. In particular, two types of assessment can be used (source-based or receptor-based) and the workshop recommended the type used should be clearly specified in all assessments.
- The workshop concluded that the uncertainty in concentration predictions by models is much smaller than the uncertainty in the deposition predictions. This has the practical implication that, from the perspective of the atmospheric modelling, assessments based on air concentrations will have less uncertainty than those based on atmospheric deposition.
- The workshop noted that the emissions from fertiliser (including both inorganic mineral fertilizers and organic manures) when applied to land is not usually modelled in current assessments. This is a major gap in current practice, given the substantial contribution to nitrogen deposition at many Natura 2000 sites from the nearby land application of fertilizers to agricultural land.
- The workshop concluded that estimation of dry deposition of nitrogen compounds remains highly uncertain. In particular, uncertainty analysis for dry deposition is needed but remains a difficult task.
- The workshop recommended that validation datasets for both concentration and deposition need to be developed and compiled in a form that can be made readily available for the purpose of model verification.
- The workshop recommended that further development and testing of nitrogen dry deposition parameterisations are needed as a means to reduce uncertainties in assessing total nitrogen inputs to Natura 2000 sites. In particular, further assessment of ammonia canopy compensation points is needed for different habitat types. Overall, much more field deposition data is needed for model verification.
- The workshop recommended that the emissions of ammonia to the atmosphere following fertiliser application (including both organic manures and mineral fertilizer) should be included in future environmental assessments of the impact of current and future activities on Natura 2000 sites.
- It was recommended that a harmonised approach to uncertainty analysis for the models needs to be developed to aid the regulatory assessment of nitrogen emission, dispersion and deposition to sensitive habitats.

6.2.2 Introduction to structure of discussions

Prior to the meeting, the members of the group agreed on a list of key questions that were to be discussed during the meeting. The key questions were:

- How comparable are modelling approaches of different European countries?
- What are the current uncertainties in the modelled estimates of concentrations and deposition?
- What model developments or data requirements are needed to reduce these uncertainties?
- How can model uncertainties be taken into account?
- How should model outputs be used/presented in impact assessments?

It also concluded that there are many different models of varying complexity to predict concentrations and deposition rates and that the most suitable type of model should be chosen to carry out a specific task.

For example, an overview of a current project to develop a screening model to assess concentrations of NO_x and SO_2 and deposition of nitrogen and sulphur resulting from emissions from combustion plants (20-50 MW) was given. Following a scoping study of different modelling options, the chosen option was the USEPA/AERMIC AERMOD Model linked to a web interface to allow online execution.

6.2.3 Key Question 1: How comparable are modelling approaches of different European countries?

The presentations highlighted the similarities and differences of the approaches used in the Netherlands and Denmark. In addition to these two countries, information was provided from the UK representatives on the assessment approach used there. Appendix 6.1 gives a more detailed overview of the process in these three countries.

An interesting point was made during the subsequent discussions, which was that assessments can be approached in two ways, depending on their objectives. One approach is to consider the impact of all relevant sources on one specified natural area (receptor-based) and the other is to consider the impact of a specified source on all relevant natural areas (source-based). The modelling methods may be different for the two different approaches. The following discussion focussed on the source-based approach only.

Although information was only available for three European Member States, there are considerable differences between the approaches. In the UK, different distances (2-10 km) are used to decide whether a source is likely to have an impact (screening distance) depending on the classification of the nature site. In Denmark, a screening distance of one km is used in all cases, whilst in the Netherlands screening distances are not applied. Different dispersion models are used in the different Member States. In the UK there is no prescribed regulatory model and assessments are usually carried out using either the ADMS or AERMOD models. In Denmark and the Netherlands national regulatory models (OML-Dep and AAgro-Stacks respectively) are used. The use of different models in different Member States potentially could lead to inconsistencies across Europe. Results were presented from an intercomparison of short-range dispersion models (LADD, ADMS 4, AERMOD and OPS-st), using four hypothetical emission scenarios (of different source types), that showed that, at least for concentrations, the predictions of the different regulatory models are similar (Theobald *et al*., 2010). The discussions also highlighted that different types of meteorological data is used for the assessments. For example, in the UK, five years of continuous data is normally used, whereas in Denmark, the tables based on OML-Dep model output were developed using data from

2005 and in the Netherlands hourly meteorological data from the year in question are used. One surprising difference between the approaches is that assessments in Denmark do not use ammonia concentration predictions or take into account background nitrogen deposition. The assessment only calculates the farm's additional deposition to a natural area. One surprising similarity between the different approaches is that none of the Member States model the ammonia concentrations or nitrogen deposition resulting from the application of organic or mineral fertilisers. This is because it is difficult to get information on the exact timing and location of the applications. However, since these emissions may make a significant contribution to Member States' ammonia emissions, the group agreed that these emissions should be taken into account in assessments. The development of protocol to calculate these emissions should be a priority for future discussions.

6.2.4 Key Question 2: What are the current uncertainties in the modelled estimates of concentrations and deposition?

Uncertainty of deposition predictions is significantly larger than that of concentration predictions. This is because: a) deposition rates are usually calculated from modelled concentrations; b) deposition processes are less well understood/more complex than atmospheric dispersion processes, c) consequently deposition is modelled/parameterized in very different ways and d) deposition predictions are more difficult to validate than concentration predictions. The model validation data presented showed that ammonia concentrations predicted by regulatory models agree fairly well with measured concentrations. Although detailed uncertainty analyses have not been carried out for the models, the validation studies provide an estimate of average prediction uncertainty of approximately ± 20 per cent for concentrations (e.g., absolute fractional bias < 0.2), when using measured emission data and on-site meteorological data. This is of a similar order of magnitude to the uncertainty in national emission rates of ammonia in the UK (Misselbrook *et al.*, 2000). Model uncertainty can be significantly greater than this, however, if emission factors are used instead of measured emissions or on-site meteorological data is not used, which is often the case for assessments. Specifying uncertainty estimates for nitrogen deposition is much more difficult due to lack of validation studies. For the Danish assessment approach an uncertainty estimate of +/- 35-70% was reported. Based on expert judgement the group agreed that uncertainties in deposition estimates of regulatory models lay in the range of ± 50-100 per cent. This uncertainty can be reduced if more detailed information on deposition characteristics (surface roughness, vegetation type) of the area is known. At present it is not possible to provide a more accurate estimate of uncertainty and the group concluded that more model uncertainty analyses are needed. Moreover a common approach in uncertainty assessment would be useful for model comparison across Member States.

6.2.5 Key Question 3: What model developments or data requirements are needed to reduce these uncertainties?

Since the uncertainty in modelled annual concentration predictions is of a similar order of magnitude as the emission data, model improvements are unlikely to reduce the prediction uncertainty significantly. If there is a need to model predictions at a higher temporal resolution (e.g. daily or hourly) then the temporal resolution of emission data will need to be increased where necessary. With regards to the uncertainty in deposition predictions there is still a lot that can be done. For some ecosystems the bi-directional exchange of ammonia with the atmosphere has a large influence on the net deposition rate and on ammonia concentrations further downwind and therefore models should include a canopy compensation point to model this. In order to validate the dry deposition parameterisation of models, it is necessary to have measurements of dry deposition rates. Very few data is currently available for this purpose and those that are available have been used in the formulation/calibration of model routines. Therefore, more measurements of dry deposition over a range of ecosystems are necessary to validate the models.

6.2.6 Key question 4: How can model uncertainties be taken into account?

When using model predictions for regulatory assessments, the values used must be accompanied with an estimate of model uncertainty, even if (as the previous discussion highlighted) this estimate is only based on expert judgement. An example would be an ammonia concentration prediction of four µg m^{-3} with an uncertainty estimate of +/- 20 per cent. This could be presented in an assessment as either:

4 ± 0.8 µg m^{-3} or

3.2 - 4.8 µg m^{-3}

The option to use is at the discretion of the assessor. If the uncertainty assessment is based on a published study then the reference should also be given.

6.2.7 Key Question 5: How should model outputs be used/presented in impact assessments?

Ideally (receptor-based) regulatory assessments should provide an estimate of concentration and deposition predictions for each source (within a screening distance) at locations of interest within the natural area. For each location the assessment should provide the following information (with uncertainties):

- Concentration contribution from each local source (NH_3 and NO_x)
- Dry deposition of reduced and oxidised nitrogen from each local source
- Background wet and dry deposition (split into reduced and oxidised)

Background data should come from national modelling/monitoring activities.

Provision of these data will enable an estimate of the concentrations (NH_3 and NO_x) and nitrogen deposition rates at the locations of interest, as well as the contribution from each source within the screening distance. These estimates can then be compared with critical levels and loads to assess impacts on the natural area.

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Appendix 6.1: Description of the modelling assessment process for different countries

Denmark - ***L. M. Frohn and O. Hertel, National Environmental Research Institute, Aarhus University, Denmark***

The Danish regulatory system is required by authorities to be as simple, transparent and robust as possible in order to secure a uniform scientific base for decision making within the municipality administration. National demands for approval of new husbandry activities (or expansion of existing activities) depend on the distance to nature areas included in the Danish VMPIII (Action Plan for the Aquatic Environment) agreement (like e.g. Natura 2000 areas). If any point source related to an application is located within 1000 meters (buffer zone 2) from a VMPIII area, then the additional nitrogen deposition to the nature area arising from the expansion applied for, must be estimated. If any point source is located within 300 meters (buffer zone 1) from a VMPIII area, the application is rejected. Within buffer zone II, the cut-off criteria for the additional nitrogen deposition are differentiated depending on the number of other farms with more than 75 animal units, located within a distance of 1000 m from the farm house of the applicant in order to account for the accumulated effect. The differentiation is set to:

- 0.3 kg N pr. hectar per anno (more than two farms)
- 0.5 kg N pr. hectar per anno (two farms)
- 0.7 kg N pr. hectar per anno (one or no farms)

The emissions of ammonia from application of manure, fertilizer as well as releases from crops are not taken into account in the system, since the calculation only deals with the ammonia loss from stables and storages in the husbandry production.

The atmospheric ammonia deposition is based on a set of “standard tables” corresponding to different combinations of intermediate land surface types (between the farm and the nature area) and nature area surface types. The standard tables give the atmospheric ammonia deposition with distance from the source of one kg emitted ammonia. The deposition is then scaled according to the actual emission and corrected for local meteorological conditions.

Based on the information supplied by the applicant, the deposition to a nature area is calculated as:

$$A(L) = E \times D(L) \times \frac{WF}{100} \times WK\,(WM)$$

Where A(L) is the annual deposition (kg N ha^{-1} $year^{-1}$), E is the emission from the point source (kg N $year^{-1}$), L is the distance from the source to the nature area, D is the standard deposition for the relevant combination of intermediate type of land surface and land surface of the nature area, WF is the wind frequency in the relevant wind sector, WM is the mean wind speed in the relevant wind sector and WK is the wind correction factor depending on WM.

Denmark has been divided into nine climatological regions based on data for wind speed and wind frequency provided by the Danish Meteorological Institute (Cappelen and Jørgensen, 2008). A wind correction is applied using tables generated from meteorological data representative for each specific region. The calculations may be performed applying roughness data for three different surface types that the applicant selects on basis of a guidance booklet with aerial photos.

The atmospheric N deposition to Danish land and sea surfaces are mapped within the national monitoring programme for water and nature (NOVANA). The background atmospheric N

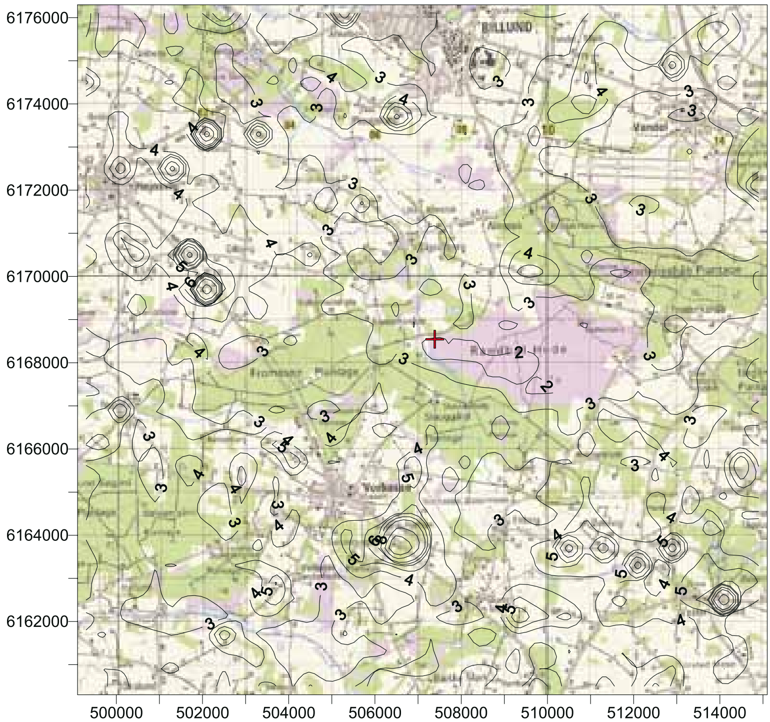

Figure 6.1: Modelled deposition (kg N ha^{-1} yr^{-1}) to a heath area in the western part of Denmark (Randbøl Heath) for the year 2006. Heathland and woodland are depicted in pink and green respectively. The modelled ammonia deposition is locally high around sources, e.g. farms (Ellerman *et al.*, 2007).

deposition at a resolution of 17 x 17 km is computed using the Danish Eulerian Hemispheric Model (DEHM), and for selected nature areas detailed mapping of NH3 deposition fluxes at a resolution of 400 x 400 m are calculated using the OML-DEP model (Ellermann *et al*., 2007). The resolution in the DEHM computations is soon to be increased to 5 x 5 km. The combination of DEHM and OML-DEP is termed DAMOS – the Danish Ammonia Modelling System (Hertel *et al.*, 2006a; Hertel *et al*., 2006b) and this system is applied in the NOVANA program and also in a number of assessment studies carried out for selected regions in Denmark.

A farm may include more than one point source, and information for all these are entered into the system, which then calculates the ammonia deposition from all the sources individually and in total. The point within the nature area with the largest total deposition, will be the starting point for the municipality administration, i.e. that is the point where the maximum atmospheric nitrogen deposition criteria must be complied with.

The model tool which has been used in the development of the regulatory system is the OML-Dep model (Olesen (1995); Olesen *et al*., 1992), which is a Gaussian plume model with a setup that allows for multiple point and area sources of ammonia. Furthermore the model has been extended with a deposition module based on the dry deposition routine of the EMEP model (Simpson *et al*., 2003; Emberson *et al*., 2000). OML-Dep calculates dispersion and deposition of ammonia from local sources within the model domain.

For the generation of the standard tables, the model has been setup with a domain of 4 km x 4 km, a resolution between receptor points of 100 m x 100 m and a single point source located in the left part of the domain. The meteorological data is obtained from the MM5 model for the year 2005, but the wind direction has been fixed at 270º, corresponding to a wind from west. All other meteorological parameters vary in response to changes in atmospheric stability, radiation input etc.

The OML-Dep model is also used in the national monitoring of nature areas. In this context the model setup includes a domain which typically extends to around 16 km x 16 km with a 400 m by 400 m resolution. All ammonia point and area sources are included in the calculation and background concentrations of ammonia are obtained from calculations with the Danish Eulerian Hemispheric Model (DEHM) which covers the northern hemisphere (Christensen (1997), Frohn *et al*., 2001; Frohn *et al*., 2002). An example of calculated deposition of ammonia for a Natura 2000 area (Randbøl Heath) for the year 2006 is shown in Figure 6.1.

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Netherlands - M. van Zanten and A. van Pul (National Institute for Public Health and the Environment, Netherlands) and E. Noordijk (Netherlands Environmental Assessment Agency)

A formal regulatory method to assess nitrogen depositions to Natura 2000 areas is not yet established. However, such assessments will be based on model calculations. To estimate the total nitrogen deposition from multiple sources on one receptor point or on a receptor grid, the Operational Priority Substances (OPS) model is applied (van Jaarsveld, 2004). Currently, calculations are done on a 5 by 5 km grid (data available at http://www.mnp.nl/nl/themasites/gcn/kaarten/index.html) but in the near future this will be changed to 1 by 1 km. The OPS model is also applied for local scale contributions in a variety of situations. For regulatory purposes, however, the model AagroStacks is used to assess contributions from local sources.

The assessments may also include measurements to support the calculations. These measurements are available from the Measuring Ammonia in Nature (MAN) monitoring network. Started in 2005, this network currently includes more than four years of monthly mean ammonia air concentration data from 121 monitoring sites in 30 Natura 2000 areas. These data may allow local or regional adjustments of calculated concentrations/deposition rates.

Characteristics of the OPS-model

- Annual emission data from various sources (animal housing, manure application, foreign, traffic, etc) is used. Emission data is available on a 500 m by 500 m resolution from the Dutch Emission Registration (ER). Emissions from all other European countries are also included, although with decreasing spatial detail on with increasing distance from the Netherlands.

- The meteorological input consists of hourly measurements and is taken from stations of the Dutch meteorological institute (KNMI). On the basis of the average wind regime The Netherlands has been divided into six meteorological regions. For every location within such a region the same dataset, derived from several stations within the region, is used.

- Roughness length data is included. This is available from maps with a 25 by 25 m resolution for the whole of the Netherlands.

- Within OPS nine land use classes are available. Information on the actual land use class to be taken is available from maps with a 250 by 250 m resolution for the whole of the Netherlands. When calculations are done for gridded receptor points the most dominant land use class in the grid cell is applied.

- Uncertainty in concentration and deposition flux calculations for a single receptor point is high (25 per cent and 100 per cent respectively). The largest uncertainty arises from the dry deposition estimates. For larger areas, this uncertainty is however considerably lower. This uncertainty is also largely reduced (typically halved) if more detailed information on deposition characteristics (roughness, vegetation type) of the area is known.

- The dry deposition module (DEPAC) is currently being updated to include a compensation point and an updated external resistance parameterisation. The latter is derived from ammonia dry deposition flux estimates above grassland. (Wichink Kruit *et al*., 2007).

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United Kingdom – M. Sharp, Scottish Agricultural College, Edinburgh, and D. Bruce, Northern Ireland Environment Agency, Belfast

Modelling assessments for farms in the UK are generally undertaken as part of the IPPC permitting process or as part of the planning process for the purposes of the Environmental Impact Assessment Directive (85/337/EEC). The regulatory process for undertaking assessments for IPPC permitting is more clearly set out than assessment processes used in EIA work.

Typical stages in the UK approach for IPPC permitted farms.

- Using National GIS databases European sites (SAC, SPA and RAMSAR) within a 10 km radius of the farm are identified. Sites of Special Scientific Interest (SSSI – Areas of Special Scientific Interest (ASSI) in N Ireland) within a five km radius and other wildlife sites such as ancient woodland within a 2km radius are also identified.

- Screening tools are then used to speed up the process and provide greater consistency to the permitting process. The tools used vary in different regions of the UK. Regulators in England and Wales and in Northern Ireland use a screening tool that uses generic emission factors and data provided in the IPPC application process applied to a generalised concentration/distance curve. Results are provided in the form of look up tables. In Scotland the SCAIL model (Theobald et al., 2009) is used for screening purposes.

- In cases where screening tools indicate that a farm has the potential to impact on a sensitive site then further detailed modelling is carried out. This is undertaken using advanced 'new generation' dispersion models such as the UK ADMS 4.1 and the American AERMOD. ADMS 4.1 is typical in that it uses the boundary layer height $\boldsymbol{h}$ and the Monin-Obukhov length L_{MO} to describe the atmospheric boundary layer and using a skewed Gaussian concentration distribution calculates dispersion under convective conditions. The model is applicable up to 60 km downwind of the source and provides useful information at distances of up to 100 km. Distances of interest for farms are typically 100 – 5000 m.

- In order to set permit conditions regulators have undertaken modelling as part of the permit assessment process using standard modelling assumptions and annual average emission factors. There are limitations to this approach and where more detailed modelling is required this has then to be provided by the operator.

- Annual average emission factors derived from the BREF document and the UK inventory are usually used but other factors may be used provided they are backed up by appropriate peer-reviewed research studies.

- A number of years (e.g. five years) of hourly averaged meteorological data from the nearest UK meteorological station are used for detailed modelling purposes.

- The source and group data used depends to a large extent on site specific features and emission characteristics of the farm and use of appropriate methods is largely dependant on the experience of the modeller and their familiarity with complex agricultural sources. Emissions can be modelled as point, area, line, volume, or jet sources. Emissions from housing and from separate manure storage are usually modelled whereas emissions from down stream operations such as slurry/manure spreading are not. Techniques for slurry/manure spreading to reduce ammonia emissions are however controlled by general rules.

- Currently it is usually only pig and poultry installations above the IPPC threshold sizes that are modelled (although other units may be modelled as part of the environmental impact assessment (EIA)/planning process.

- Increasingly in the UK, particularly in England and Wales, it is concentrations only that are being modelled for comparison with critical levels. This has advantages in that the operation is simpler and the uncertainties are reduced. It is the case that where very detailed assessments are required, critical loads are estimated and compared with background levels. Estimates are often made based on only two deposition velocities, one for short vegetation (0.02 m s^{-1}) and one appropriate for woodlands (0.03 m s^{-1}). Information on background levels and loads and estimates of exceedence are obtained from the UK Air Pollution Information System (APIS: www.apis.ac.uk). Wet deposition of ammonia is not modelled as it is not considered significant for short-range modelling (Loubet *et al*., 2009).

- A range of modelling assumptions may be used depending on the level of detail required. As far as possible these accurately reflect the situation on the farm, e.g. release heights, efflux velocities, temperature, location etc. Generally, terrain and buildings are not considered, but can be included if required. The addition of building effects means that sources have to be modelled as point sources and this is not always appropriate for farms. Usually the surface roughness length selected for the dispersion site is assumed to apply throughout the domain, a typical value for agriculture being 0.3 m. If the need arises, advanced models such as ADMS 4.1 have the facility to define a distribution of surface roughness over the domain.

- It is usual for model output to be plotted on to 1:10 000 or other appropriate scale maps. Additional specific points or transects across sensitive areas are included as required.

- UK regulators have agreed with the Conservation Agencies that where ammonia concentration, from all regulated sources, at a designated site exceeds the appropriate critical level an acceptable process contribution from the intensive livestock sector is 20 per cent of the critical level where it may impact on a European site, and 50 per cent of the critical level where it may impact on a SSSI/ASSI. Where only one livestock farm impacts on a designated site, all of that contribution is available to them. In cases where more than one permitted farm impacts on a site, in-combination effects are considered and the contribution is divided between the relevant farms. Regulators have also asked operators to review emission factors used and to investigate options to reduce emissions and present their findings in the form of an emission reduction plan. In Northern Ireland, where air dispersion modelling predicted that ammonia contributions from existing IPPC intensive livestock farms were likely to exceed 20 per cent of the critical level for any of the local designated European habitats, monitoring is being carried out to establish actual air ammonia concentrations in the vicinity of the farms and at the habitats.

- Often designated sites are large and sensitive areas within the site may be some distance from the farm. ‘Ground truthing’ of sites is sometimes undertaken to further establish the significance of impacts. In England and Wales the Conservation Agency is currently re-assessing the site condition of all sites that have resulted in farms receiving permit conditions to abate ammonia emissions resulting from the lowering of critical levels.

Typical stages in the approach for modelling developments as part of the EIA process are less clearly set out than the above process for IPPC permitting. However it is likely that the assessment process follows a similar pattern and uses the same assessment criteria although there may be greater variation in methodologies.

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6.3 The nitrogen load on Dutch Natura 2000 areas; local effects and strategies

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Abstract

- To assess nitrogen levels on a local scale, an experimental version of the OPS model was combined with monitoring measurements from Natura 2000 areas.
- In a pilot study, expected emission trends were converted into future local deposition levels. These levels define the nitrogen loads which limit the future development of habitats. Such levels may alter due to local policies and measures.
- Within a specific Natura 2000 area, local patterns of nitrogen deposition were used for defining core areas where desired habitats can develop. Other areas could function as buffer zones to minimise influences from outside.

6.3.1 Introduction

Nitrogen deposition in the Netherlands shows considerable local variation. This is caused by the high deposition velocity of ammonia, in combination with a large number of clustered ammonia sources. Agriculture is the most important contributor, especially from dairy farming and intensive cattle breeding, but traffic and natural sources can also dominate patterns, locally.

Considering the high critical load exceedances for Dutch Natura 2000 sites, we study the effects of exceedance on nature quality and define options to mitigate negative effects. Because of the high local variability in nitrogen deposition, a sophisticated approach is required.

Detailed deposition maps of all Dutch Natura 2000 areas can only be derived through model calculations. Such a spatial detail on a national scale is beyond the reach of measurements alone. However, measurements credibly present the real situation on a measurement site, whereas model calculations may differ considerably from reality. Thus, to create realistic deposition maps, both model calculations and measurements have to be combined. Most of this work will be executed in the near future, some preliminary results are presented here.

6.3.2 Aims and objectives

- To assess present and future nitrogen pressure on a local scale for Natura 2000 areas. Model calculations and measurements have to be combined, to produce nitrogen deposition maps on a scale of 500 m × 500 m or 250 m × 250 m..
- To assess the consequences of elevated nitrogen levels for the individual Natura 2000 areas. For this purpose, the deposition maps will be combined with local flora monitoring data.
- To define local policy options for individual Natura 2000 areas. Point of departure is present local exceedances of critical nitrogen loads and their future trend, following national emission and deposition scenarios. Local circumstances and opportunities will be included to define options for local policies.

6.3.3 Results and discussion

Concentrations and depositions rates of ammonia were calculated by the Dutch OPS model (Van Jaarsveld, 2004). This statistical trajectory model includes dispersion, air transport, dry and wet deposition and chemical reactions. In the case of ammonia, the model was expanded to include specific effects, such as re-emission. Currently, this specific model version has an experimental status (not yet official). Several measurement campaigns and nine monitoring sites served to verify the model results for ammonia.

Average monthly ammonia concentrations were collected from the Measuring Ammonia in Nature areas (MAN) network (Stolk *et al*., 2009). This network focuses on those Natura 2000 areas which are vulnerable to nitrogen deposition. These areas have sandy soils and are located in the east and south of the Netherlands and along the coast (dunes).

The measurements were compared with site-specific model calculations. In general, model and measurement were in good agreement (Figure 6.2). In the southern areas with intensive cattle farming and in the large Veluwe heathlands, the difference, on average, was less than a few percent. The model showed a slight overestimation of about 10 per cent in the intensive cattle farming areas in the east, and an underestimation of the same magnitude in areas with relatively extensive agriculture. Only the calculations for areas along the coast seriously underestimated the measured concentrations. This underestimation is an object for further study.

The model will be used for calculating deposition maps for all Natura 2000 areas, on an appropriate scale of 500x500 or 250x250m. These maps have to be combined with the information from the measurements. An easy and direct way is a simple multiplication of the map with the quotient of measurement and model averaged over the natural area, separately, or the average of this quotient over a larger area, such as the intensive cattle farming area in the east. The latter method also allows for a correction of the maps for natural areas without monitoring sites. More sophisticated methods, however, will also be explored to combine measurement and model.

To gain insight into future trends, the maps of nitrogen deposition will be scaled to future local nitrogen loads and effects, by use of projected emission trends. On the basis of these projected deposition charts, local strategies can be derived to comply with EU directives. Together with general national efforts to decrease the nitrogen load, these local strategies may include the mitigation of local sources, the management of the ecosystems involved, and the spatial organisation of natural areas and their surroundings.

These maps will become available in the near future. At this moment, only some preliminary exercises are available. These were based on calculations with an older model version and rely more on the monitoring data. A crude example of this approach is available for the Groote Peel, a Natura 2000 area with heathland, grassland, pools and bogs, in the south of the Netherlands.

Nine monitoring sites were set up in the Groote Peel. The measured concentrations were combined with OPS calculations to calculate estimated deposition levels for each site. Together with expected emission trends (a low and high scenario), future deposition levels were also derived (Figure 6.3).

For these sites, the nitrogen deposition excedance was calculated for several habitat types (Figure 6.4). This showed that critical loads for both heathland and bogs will still be exceeded in the future. On several more-favourable locations, future exceedance may be rather small if emissions follow the lower scenario. Thus, with proper additional measures, part of the area may develop into high-quality heathland. Other parts, with higher depositions, may serve as buffer areas between sensitive nature and agricultural land.

However, the Groote Peel was not put forward as a Natura 2000 area for its potential to as a heathland but as a peatland. Even within a low-emission scenario, the deposition will be much

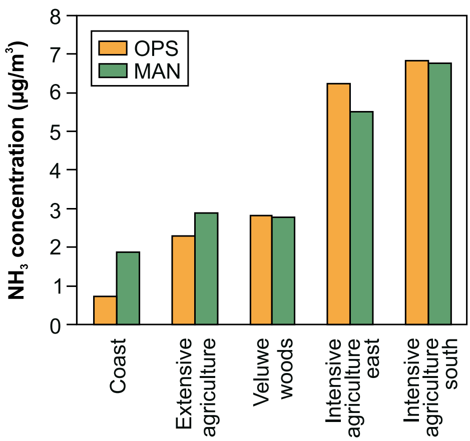

Figure 6.2: Operational Priority Substances (OPS) model and Measuring Ammonia in Nature (MAN) monitoring network values for ammonia concentration (µgm^{-3}), averaged over a number of Natura 2000 areas in the South and East of the Netherlands.

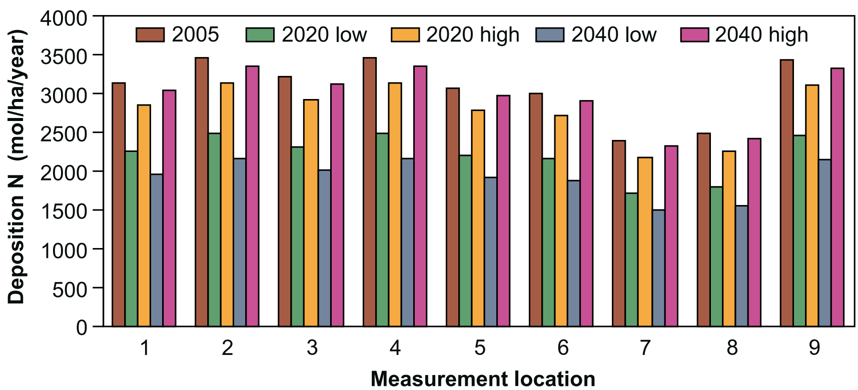

Figure 6.3: Present and future (estimated using expected emissions trends for 2020 and 2040 for as high and low scenario) deposition on Measuring Ammonia in Nature (MAN) -sites in the Natura 2000 area "Groote Peel".

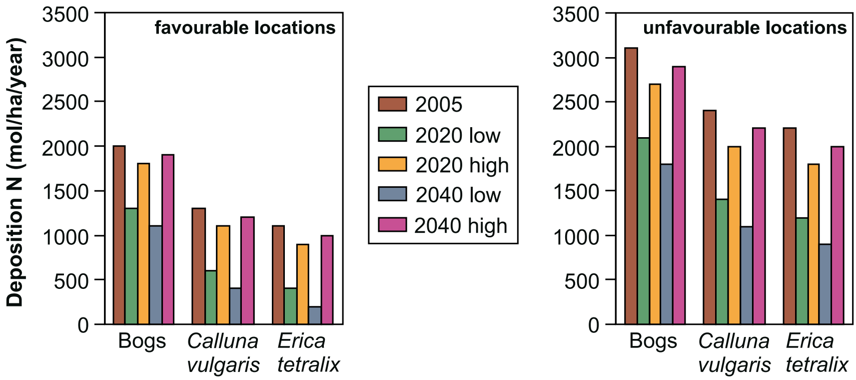

Figure 6.4: The exceedance of critical deposition levels in the Groote Peel, averaged over sites with low deposition (favourable) and with higher deposition (unfavourable) in 2005 and projected for 2020 and 2040.

higher than required to develop healthy peatland. Within the coming decades, achieving this aim would require unrealistically extreme efforts and, therefore, may not be appropriate for this area.

Further insight is needed into the effects of nitrogen critical load exceedance on biological end points, to clarify the consequences of policy options. To gain such insight, exceedance maps will be combined with flora monitoring data. Prior to this step, dominant effects of acidification and soil moisture content need to be excluded from the flora data by categorising the available data into sites with the same acidity and soil moisture content, but with differences in nitrogen load. This information can then be used for converting calculated nitrogen critical load exceedances into expected floral changes.

6.3.4 Conclusions

- To assess the present nitrogen load on Dutch Natura 2000 areas, a combination of model calculations and measurements is necessary.
- The new experimental version of the OPS model and the MAN monitoring network allowed a reliable estimate of ammonia concentrations on a very local scale. These concentrations were converted into local deposition levels, although results from this step are much more uncertain.
- Expected future deposition levels define which habitats may develop in a healthy way. Local patterns in the deposition may help in defining the core areas where these habitats may develop, and buffer areas that protect these habitats against influences from outside.

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