Project AC0109 – Future patterns of ammonia emissions across the UK and the potential impact of local emission reduction measures

Appendix 1 - Detailed UK activity projections, NH_3 mitigation measures and emission scenarios

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1. Introduction – Scenario modelling

Five main ammonia (NH_3) emission mitigation scenarios were developed, using 'business as usual' projections for the year 2020 as a baseline. The inventory methodology used was the same as for the UK ammonia emission inventory submission for 2010 (Misselbrook *et al.*, 2011).

Mitigation methods were applied to the agricultural sector which accounts for *c.* 80% of total UK ammonia emissions. No additional mitigation options were applied to non-agricultural sources, however decreases are projected for transport emissions in particular, according to UEP43 scenario modelling (e.g., due to the next generation of technology filtering through the UK vehicle fleet). The five agricultural mitigation scenarios are described below - more details on individual measures can be found in the Ammonia Mitigation User Manual, compiled under Defra Project AQ0602 (Misselbrook et al., 2008).

All scenarios were assessed for exceedance of NH_3 Critical Levels, and selected sites for exceedance of nutrient nitrogen (N) Critical Loads, for the UK as a whole and for protected N sensitive Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs). The modelling was carried out at a 1 km grid resolution.

The spatial mitigation modelling was conducted using two approaches to reduce the impact of NH_3 emissions on sensitive sites:

- UK-wide (uniformly distributed) application of mitigation measures
- Targeted application of mitigation measures to maximise cost-benefit of measures for SACs/SSSIs.

The spatially targeted scenarios include the application of mitigation measures in, e.g., buffer zones of different widths surrounding SACs and SSSIs and in Nitrate Vulnerable Zones (NVZs). A hypothetical "maximum protectability" scenario was also explored, where modelled emissions were reduced further, to achieve non-exceedance of Critical Levels for all UK SACs/SSSIs (details below).

2. Business as usual projection for 2020 (baseline scenario)

Projected ammonia emissions for 2020 under a 'business as usual' scenario were estimated at 233 kt NH_3 from UK agriculture. Spatial patterns for 2020, for livestock numbers and fertiliser use, were developed based on projections made as part of the FAPRI project (Table

1). N.B. Implementation of Best Available Technologies for reducing emissions on large pig and poultry farms were projected to have taken place by 2020 due to the implementation of Integrated Pollution Prevention and Control legislation, from 2007 onwards.

Table 1: Projections of livestock populations (of animals) and fertiliser use for 2020 "business as usual", derived from FAPRI projections (2011)

NARSES livestock categories	**2008**	**2020 (FAPRI, 2011)**	**% difference**
Dairy cows & heifers	1,908,945	1,714,386	-10%
Dairy heifers in calf	416,002	387,299	-7%
Dairy replacements	462,305	421,762	-9%
Dairy calves	499,343	462,969	-7%
Beef cows & heifers	1,670,142	1,582,974	-5%
Beef heifers in calf	359,741	302,932	-16%
Beef >1yr	2,453,154	2,331,699	-5%
Beef calves	2,337,353	2,102,104	-10%
all cattle	10,106,985	9,306,125	-8%
Sheep	16,556,771	15,497,753	-6%
Lambs (under 1 yr old)	16,574,319	15,375,460	-7%
all sheep (inc. lambs)	**33,131,090**	**30,873,213**	**-7%**
Sows in pig & other sows (sows)	365,505	309,409	-15%
Gilts > 50 kg not yet in pig (maiden gilts)	111,767	100,257	-10%
Boars	17,292	14,446	-16%
Other pigs, >110 kg	49,842	44,128	-11%
Other pigs, >80-110 kg	682,666	539,380	-21%
Other pigs, >50-80 kg	1,049,569	833,464	-21%
Other pigs, >20-50 kg	1,211,506	967,541	-20%
Other pigs, < 20 kg	1,225,365	1,008,902	-18%
all pigs	4,713,512	3,817,528	-19%
Layers	25,939,837	27,605,894	6%
Breeding birds	9,068,223	10,045,762	11%
Broilers	109,858,933	108,031,575	-2%
Pullets	9,313,287	9,025,767	-3%
Turkeys	5,532,316	4,823,494	-13%
Other poultry (incl ducks)	6,487,053	7,314,372	13%
all poultry	166,199,649	166,846,865	0%
Horses	370,225	311,413	-16%
Goats	96,156	92,941	-3%
Deer	31,386	30,956	-1%

FERTILISER USE (kt N)	**2008**	**2020 (FAPRI, 2011)**	**% difference**
Fertiliser application to tillage	650	633	-3
Fertiliser application to grass	308	366	19
Total UK fertiliser application	**958**	**999**	**4**

3. Detailed description of mitigation scenarios and main measures

The five main agricultural mitigation scenarios consist of different sets of measures, for different levels of ambition. Individual measures are described below for each scenario. Table 2 summarizes the differences between the main scenarios in terms of measures applied. For all scenarios apart from the most ambitious (Mitig4), partial implementation of measures was assumed, with applicability constraints etc. taken into account. In Scenario Mitig4, 100% implementation was tested, with other equally effective measures assumed to be implemented where core measures were not applicable, e.g. injection on stony ground. Table 2 provides a summary of the measures applied in the main mitigation scenarios implemented as part of this project. UK emission totals for these scenarios are shown in Table 3.

Table 2: Summary of measures tested in the main mitigation scenarios. More detailed descriptions of each scenario are described in the text.

Measures	**LowEmSpr**	**Mitig1**	**Mitig2**	**Mitig3**	**Mitig4**	**Trees (AC0201)**
Urease inhibitors for Urea/UAN	✓	✓	✓	✓	✓	-
Rapid manure incorporation	✓	✓	✓	✓	✓	-
Slurry application by trailing shoe	✓	✓	✓	✓	-	-
Slurry application by injection	-	-	-	-	✓	-
Covering of slurry stores	-	✓	✓	✓	✓	-
Improved housing pigs/poultry	-	✓	-	✓	✓	-
Covering of FYM stores	-	-	✓	✓	✓	-
Manure storage pre-application	-	-	✓	✓	✓	-

Mitigation scenario 1 (Mitig1)

Implementation of mitigation methods, as described below, resulted in a total emission from UK agriculture of 184 kt NH_3 (i.e., 16% reduction compared with the baseline 2020 projection). Mitigation methods implemented were:

1. **Rapid incorporation of manures applied to arable land**. All livestock slurry, FYM and poultry manure applied to arable land for cultivation (but not to growing crops) to be incorporated into the soil by disc cultivation or ploughing within 4 hours of manure application. It is estimated that this would be applicable for 50, 70 and 90% of slurry, poultry manure and cattle/pig FYM applied to arable land (the remainder being applied to growing crops). Emission reductions achieved with this method, compared with leaving the manure on the soil surface, are 60, 70 and 85% for slurry, FYM and poultry manure, respectively. Total reductions in emission achieved through implementation of this method take into account a baseline implementation of <10% manure currently incorporated within 4 hours and *c*. 20% of slurry and FYM and 50% of poultry manure incorporated within 24 hours.

2. **Reduced emission slurry application techniques**. The scenario uses applications of pig and cattle slurry to grassland using trailing shoe applicators. A reduction efficiency of 60% is assumed (this requires applications to be made when grass sward height is >10 cm, with less than 60% reduction efficiency for shorter swards) and a baseline

implementation of zero (though 11 % of pig slurry to grassland applied by shallow injection). Use of shallow injection would give greater emission reduction, but the method is not universally applicable and can be more costly. Applications of pig and cattle slurry to growing crops on arable land (representing an estimated 50% of slurry applied to arable land) are calculated to achieve a reduction efficiency of 30% for trailing hose applicators. However, this could be greater as crop height increases, and a baseline implementation of 3% and 15% of pig and cattle slurry applied to arable land, respectively, is assumed, with a further 11% of pig slurry applied to arable land assumed to be applied using shallow injection.

3. **Covering slurry stores**. The majority of cattle slurry stores (80%) are assumed to develop a surface crust, which is an effective cover giving an emission reduction of 50%. Implementation within this scenario assumes a floating or flexible cover (50% emission reduction) is applied to the remainder of cattle slurry stores. Zero baseline implementation is assumed for pig slurry stores. A rigid cover is to be fitted to above-ground circular tanks, giving 80% emission reduction, and a floating or flexible cover applied to pig slurry lagoons, giving 60% emission reduction.
4. **Improved housing design for pig and poultry**. While IPPC/IED legislation applies only to large pig and poultry farms, above a certain livestock number threshold, in this scenario improved housing systems would be required of all pig and poultry farms. For pig farms, installation of improved part-slatted floor designs is assumed, giving a reduction efficiency of c. 30%. For poultry housing, installation of in-house drying systems is assumed to give a 30% reduction in emissions.
5. **Include a urease inhibitor with urea and Urea Ammonium Nitrate (UAN) fertilisers**. UAN is a liquid fertiliser associated with an emission factor less than that for urea but greater than that for ammonium nitrate. Inclusion of a urease inhibitor with these fertilisers reduces emissions by 70 and 40% for urea and UAN, respectively.

Mitigation scenario 2 (Mitig2, NVZ Scenario)

Measures implemented in this scenario are of a type that would be of co-benefit in Nitrate Vulnerable Zones (NVZ), rather than aimed specifically at maximising NH_3 emission reduction. For this scenario (total emission of 179 kt NH_3), manures and fertilisers were assumed to be applied with the same measures (i.e., low emission application techniques) and all slurry stores were covered (as described for Scenario 1 (bullet points 1, 2,3, 5 in previous document), however the housing related measures were not applied. Instead, all cattle, pig and duck FYM was stored prior to application and FYM stores were covered:

1. **Store all cattle, pig and duck FYM prior to application to land**. Following a period of storage, the ammonium nitrogen content of solid manures is very much lower than if spread directly from the livestock house (not for poultry manure) and total emissions from storage and spreading are less than from spreading alone of manure which has not been stored. The current proportion of manure estimated to be stored prior to application in the baseline scenario is 69% of pig and cattle FYM.
2. **Cover all cattle and pig FYM stores with plastic sheeting**. This mitigation method is estimated to give a mean reduction efficiency of 65%, and a zero baseline implementation is assumed.

Mitigation scenario 3 (Mitig3)

This scenario combines all the mitigation methods implemented in Scenarios 1 and 2, giving a total ammonia emission of 177 kt NH_3 from UK agriculture (i.e., 19% reduction compared with the baseline 2020 projection).

Mitigation scenario 4 (Mitig4)

This scenario (total emission of 161 kt NH_3) assumes that the most effective mitigations can be applied globally (i.e. implementation of 100%). For slurry spreading, all applications are assumed to be by shallow injection, giving 70% reduction in the emission factor. For FYM and poultry manure, all manure applied is assumed to be incorporated into the soil by ploughing within 4h, giving 70% reduction in emissions for FYM and 85% reduction for poultry manure. Slurry storage in tanks with a rigid cover (80% reduction) or in lagoons with a floating cover (60% reduction). All FYM is assumed to be stored prior to application.

Low Emission spreading (LowEmSpr)

This scenario was developed as a variant of Scenario Mitig1, for targeting mitigation to specific areas, e.g., around sensitive habitats. For this scenario, manures are assumed to be applied with the mitigation measures described for Scenario 1 (bullet points 1, 2, 5), i.e., low emission application techniques for manures and fertilisers. This scenario does not include any mitigation measures related to livestock housing and manure storage.

Mitigation by tree planting near emission sources

Planting additional trees near livestock houses and manure/slurry stores to capture NH_3 can help reduce NH_3 concentration and N deposition elsewhere (see Defra project AC0201, Bealey et al. 2013 for details). No agricultural mitigation measures are implemented, i.e. emissions are equal to 2020 baseline.

Table 3: Emissions from Agriculture for 2008, 2020 under "business as usual" (FAPRI, 2011) and five main mitigation scenarios (units: kt NH_3). Numbers may not add up precisely due to rounding.

	Baseline		**Mitigation scenarios for 2020**				
	2008	**2020**	**LowEmSpr**	**Mitig1**	**Mitig2**	**Mitig3**	**Mitig4**
Dairy cattle	72.5	68.8	59.6	58.4	57.8	57.2	53.0
Beef cattle	60.7	56.6	52.1	51.8	49.5	47.4	43.4
Total cattle	133.2	125.4	111.7	110.2	107.2	104.6	96.3
Sheep (incl. goats and deer)	10.5	9.9	9.9	9.9	9.7	9.7	9.7
Pigs	19.6	14.2	12.8	11.3	11.5	10.3	10.0
Layers	8.1	7.8	7.2	7.2	6.7	7.2	5.3
Other poultry	22.8	21.7	17.4	17.7	16.1	17.4	11.2
Horses	4.7	4.0	4.0	4.0	4.0	4.0	4.0
Total livestock	198.9	182.9	162.8	160.2	155.2	153.1	136.6
N fertilisers	31.8	35.6	24.0	24.0	24.0	24.0	24.0
Total agriculture	230.7	218.5	186.8	184.2	179.2	177.1	160.6
% reduction from 2020 base	n/a	0%	-15%	-16%	-18%	-19%	-27%

4. Spatially targeted mitigation scenarios

A large number of potential spatially targeted scenarios could be investigated. For instance, mitigation measures could be focused in areas surrounding sites protected under the Habitats Directive. This would achieve the largest reduction in atmospheric NH_3 concentrations (and hence Critical Level exceedances), compared with other spatial arrangements of measures implemented for the same proportion of UK land area. However, existing frameworks and designated spatially targeted mitigation zones (such as the Nitrates Directive/NVZs, Catchment Sensitive Farming areas), may have fewer barriers to implementing additional measures than zonations that would have to be newly created. In addition, NH_3 mitigation measures could be added as options to environmental stewardship schemes, with additional points given to encourage the implementation of such measures in areas surrounding sensitive sites.

For mitigation of N deposition and reduction in Critical Loads exceedance, the spatial targeting of mitigation is more complex, due to the different atmospheric processes and resulting spatial patterns of dry and wet deposition (and influence of oxidised N, which mainly originates from non-agricultural sources). Areas with larger dry deposition of NH_3 tend to be spatially correlated in regions with higher agricultural intensity and hence emissions, with the impact greatest on sensitive ecosystems in the vicinity, over a range of several kilometres. Wet deposition of reduced N, on the other hand, tends to occurs in areas with higher precipitation, i.e. at higher altitudes and in the western parts of the UK, and often at considerable distances from the emission sources. Therefore, spatial targeting of measures near sensitive sites, similar to those suggested above for reducing Critical Level exceedance, is expected to reduce dry deposition. More remote upland sites would benefit most from the implementation of measures over larger areas, due to the much larger footprint of emissions that affect them through wet deposition.

All scenarios described above were tested UK-wide, i.e. the mitigation measures were applied uniformly across the country. A sub-set of scenarios was spatially targeted near SACs/SSSIs and in NVZ, before being assessed for their effectiveness in protecting SACs/SSSIs. The difference in UK NH_3 emissions between a full implementation of the most stringent of the five main mitigation scenarios tested, Mitig4, and implementation in buffer zones of different width is shown in Table 4.

Spatially targeted scenarios included:

- **Application of measures inside buffer zones of different widths surrounding SACs/SSSIs**.
  - An example set of buffer zone scenarios has been analysed in detail, to provide an illustration of the effects of spatially targeted measures on nitrogen sensitive SACs across the UK. The most ambitious scenario, Mitig4, was tested here for buffer zones of fixed widths of 500m, 1 km, 2 km, and 5 km around all SACs and SSSIs, respectively.
  - In addition, variable buffer zones were assembled from these scenarios, using the minimum width required to achieve non-exceedance of the 3 $\mu g\ NH_3\ m^{-3}$ Critical Level. For example, SACs/SSSIs where the Critical Level was not exceeded in the baseline scenario were not assigned a buffer zone with associated mitigation measures. SACs/SSSIs which were exceeding the Critical Level without

a buffer zone, but were sufficiently protected by the 500m buffer scenario, received a 500m buffer zone in this variable zone scenario, etc.

- **Application of measures inside current spatially targeted schemes, Nitrate Vulnerable Zones (NVZ)**. To investigate the effectiveness of NH_3 measures complementary with NVZ rules (i.e. measures applicable to manure storage and spreading) on SACs/SSSIs, scenario Mitig2 was applied to current UK NVZ.
- **"Maximum protectability" scenario**: This scenario builds on the variable buffer zones scenarios (see above), with additional reductions in agricultural emissions near SACs/SSSIs until non-exceedance of the NH_3 Critical Level of 3 $\mu g\ m^{-3}$ is achieved. This was modelled by reducing agricultural emissions in a 5 km radius around 1 km grid squares still exceeding the CLE, to a level that would not exceed the CLE if no other significant non-agricultural sources or very intensive agricultural activity were present in the surrounding area (i.e. implementation of measures in the smallest possible area while achieving protection of all SACs/SSSIs). N.B. For this scenario, the additional emission reduction required on top of the variable buffer zone scenario was modelled simply by scaling down of agricultural emissions to a level where CLEs were no longer estimated to be exceeded at designated sites, or until agricultural emissions were reduced to zero.
- **Planting of trees near NH_3 emission sources** to reduce atmospheric NH_3 emissions, concentrations and N deposition while retaining 2020 baseline emission levels (linking to Defra Project AC0201, Bealey *et al.* (2013), draft final report with Defra)

Table 4: Comparison of 2020 emissions from agriculture sectors under implementation of Mitigation Scenarios UK-wide, across current NVZs and in spatially targeted in buffer zones of different widths (500m, 1km, 2km, 5km, variable) around N sensitive SACs and SSSIs (units: kt NH_3). NB. Numbers may not add up precisely due to rounding.

Scenario name	Buffer width	Total livestock emission (kt NH_3)	Total fertiliser emission (kt NH_3)	Total agriculture emission (kt NH_3)	% emission reduction from 2020 base
Baseline 2008	n/a	198.9	31.8	230.7	n/a
Baseline 2020	n/a	182.9	35.6	218.5	0%
UK – LowEmSpr	n/a	162.8	24.0	186.8	-15%
UK – Mitig1	n/a	160.2	24.0	184.2	-16%
UK – Mitig2	n/a	155.2	23.9	179.1	-18%
UK – Mitig3	n/a	153.1	24.0	177.1	-19%
UK – Mitig4	n/a	136.6	24.0	160.6	-27%
NVZ-Mitig2	n/a	166.8	26.7	193.6	-11%
SAC-buffers Mitig4	500m	180.6	35.2	215.8	-1%
	1km	178.6	35.0	213.6	-2%
	2km	175.0	34.2	209.2	-4%
	5km	165.1	32.4	197.6	-10%
	variable	171.8	34.1	205.9	-6%
SSSI-buffers Mitig4	500m	178.6	34.7	213.4	-2%
	1km	174.6	33.8	208.4	-5%
	2km	165.9	31.6	197.4	-10%
	5km	146.9	26.6	173.5	-21%
	variable	164.4	32.7	197.1	-10%
Max. protection SACs	variable	n/a	n/a	199.9	-9%
Max. protection SSSIs	variable	n/a	n/a	181.6	-17%
Additional trees	n/a	182.9	35.6	218.5	0%

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