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Ammonia emission in Europe: Updated emission and emission variations

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ABSTRACT

The gridded ammonia (NH_3) emission inventory for Europe is updated using new emission factors for the emission from livestock and application of fertilizer.

An inquiry was made to investigate the differences in agricultural practice between countries (Appendix 1). As only information on part of the factors which can influence the emission became available, country-specific emission factors could not be computed. Therefore the same emission factors were applied for every country. These were mainly based on emission factors derived from research in The Netherlands.

The total gridded emission is about 7.6 Mtonne NH_3 yr^{-1}, which is 21 % more than the emission survey of Buijsman *et al.* (1987) gives. This difference is mainly caused by application of different emission factors and for a minor part by differences in the number of animals.

A detailed emission map for The Netherlands, Belgium and the western part of the F.R.G. is presented, showing much higher maximum densities for these areas than the less detailed inventory for Europe does.

The modelled average relative diurnal variation in the NH_3 emission rate is about a factor 5. The average seasonal variation derived from measured concentrations in air and precipitation, corrected for meteorological variations, is about a factor 2. There does exist a descrepancy between the seasonal variation in the emission rate for The Netherlands derived from information on agricultural practice and from measured concentrations in air and precipitation for March.

SAMENVATTING

De ammoniak (NH_3) emissie op rooster voor Europa is opnieuw berekend aan de hand van nieuwe emissiefaktoren voor vee en het gebruik van kunstmest.
Er werd een enquête gehouden om verschillen in de landbouwpraktijk tussen verschillende landen te onderzoeken (Appendix 1). Omdat alleen informatie over een deel van de faktoren, die de emissie bepalen, ter beschikking kwam, konden geen landen-specifieke emissiefaktoren afgeleid worden. Daarom werden dezelfde, hoofdzakelijk op grond van Nederlands onderzoek afgeleide emissiefaktoren, gebruikt voor alle landen.

De totale emissie is ongeveer 7,6 Mton NH_3 $jaar^{-1}$, hetgeen 21% meer is dan volgens de emissie-inventarisatie van Buijsman *et al.* (1987). Dit verschil wordt voor het belangrijkste deel veroorzaakt door het toepassen van andere emissiefaktoren en in mindere mate door een verschil in de dieraantallen in de inventarisaties.

Een gedetailleerde emissie-inventarisatie voor Nederland, België en het westen van de B.R.D. laat veel hogere maximum waarden voor de emissiedichtheid zien, dan de minder gedetailleerde emissie-inventarisatie voor Europa.

De gemodelleerde gemiddelde relatieve dagelijkse gang in de NH_3 emissie bedraagt ongeveer een faktor 5. De jaarlijkse gang in de NH_3 emissie, afgeleid van gemeten concentraties in lucht en neerslag, gekorrigeerd voor variaties in de meteorologische omstandigheden, bedraagt ongeveer een faktor 2. Er bestaat een verschil tussen de jaarlijkse gang berekend op basis van informatie over de landbouwpraktijk en aan de hand van gemeten lucht- en regenwater-concentraties voor de maand maart.

1. INTRODUCTION

Most ammonia (NH_3) emitted into the atmosphere originates from animal manure and application of fertilizers. In atmospheric transport models gridded NH_3 emission inventories are needed. Buijsman *et al.* (1987) made such an inventory for Europe for the year 1982. Since that time considerably more information has become available on emission factors, generally leading to somewhat higher emissions
Buijsman *et al.* (1987) did not use the same overall emission factors for each animal category (e.g. cattle) as were suggested by their publication. They had for most countries information on the number of animals for subcategories (e.g. cattle < 1 yr.). The total emission for such a subcategory was calculated by multiplying the number of animals of the category with an emission factor (kg NH_3 yr^{-1} $animal^{-1}$). The total emission for a category was then found by adding together the emissions of the subcategories.
This approach has the advantage of the age distribution of the animals being taken into account. It has, however, the disadvantage that the total emission computed in this way also to some extent could depend on the arbitrary way an animal category is divided into subcategories, which is different for different countries. In this way different overall emission factors could be obtained for an animal category. An overall emission factor is defined by the total emission of the category divided by the total number of animals of that category. For The Netherlands a different procedure was followed, where information on the amount of nitrogen in manure produced by each animal (sub)category was used, as computed by The Netherlands Central Bureau of Statistics. In Table 1 the overall emission factors for all European countries as derived from Buijsman *et al.* (1987) are presented, which shows that the computed overall emission factors for one animal category are in most cases not very different for different countries, but some exceptions occur.

At the National Institute of Public Health and Environmental Protection (RIVM), The Netherlands, a variable resolution statistical transport model for ammonia and ammonium was developed (Asman and van Jaarsveld, 1990, 1992) for which emission inventories based on more recent emission factors were needed. It was therefore decided to update the gridded emission inventory of Buijsman *et al.* (1987) for Europe and to make a more detailed emission inventory for the western part of the F.R.G. and Belgium. The latter was done to get better model results in the boundary areas of The Netherlands.

These (gridded) emission inventories are mainly made for use in atmospheric transport models, and not e.g. to calculate the reduction of emissions caused by certain technical measures, although it is possible to change the emissions presented here to simulate the effect of such reductions for use in model calculations.

For gridded emission inventories as the one presented here, it is required that:

a. There don't exist unrealistic differences in emission factors between neighbouring countries, as otherwise inaccuracies in computed concentrations in the boundary areas and in import/export balances could occur.
b. The geographical position of all sources and the geographical distribution of all factors which have influence on the emission should be known. This may not be the case for all source categories and factors. Emissions of such categories or such factors then cannot be taken into account even though the emission of this category for a country as a whole is known.

To get an impression of possible differences between countries an inquiry into some factors influencing the emission was made. This information could of course be taken into account in the calculations, but it was not known for every country . Moreover, no information was known on other factors which are equally important. Because of the time constraints, possible inaccuracies at the border and lack on information on some important factors, it was decided to use the same emission factor for an animal category for all Europe.

The NH_3 emission rate in one area is not constant but is a function of time, therefore it was tried to quantify the diurnal and seasonal variations in the emission rate in this report.

In the emission survey separate numbers are given for the F.R.G. (area until 1990) and the former G.D.R.. This is done to make a comparison possible with the emissions of Buijsman *et al.* (1987). For the same reasons the emission from (former) U.S.S.R. republics are still included in the emission of the U.S.S.R.

A draft version of the report was ready in January 1990. The main difference between this final version and the draft version is that the emission factors for fertilizer are different and that the animal statistics for the year 1989 is used instead of the statistics for 1987. Moreover, the emission factors applied are also different and are based on more research.

Due to other obligations, it took therefore some time before the report could be finished, which implied that some of the work presented in Appendix 1 (Inquiry on agricultural practice in Europe) is dated.

The numbers in the tables presented in this report are for computational reasons presented more accurately than they are actually known. They are also rounded off which can cause small differences between the sums presented in the tables and the sums which can be found from the rounded off numbers.

2. FACTORS INFLUENCING THE EMISSION

The NH_3 emission from livestock depends on many factors, e.g. (see also: Isermann, 1990):

a. Nitrogen content of the food and the relative share of different amino acids.
b. Conversion factor between N in animal food and N in the meat and in the milk (which determines the amount of N waste available).
c. Kind of animal and age/weight.
d. Housing system.
e. Way the manure is stored (pile, open/closed tanks).

Emission after spreading of manure depends on:

f. Meteorological/climatological conditions: temperature, turbulence, air humidity and precipitation. The emission generally increases with temperature and turbulence, but decreases with air humidity (slows down the evaporation of water from manure, which leads to a lower concentration if the components are dissolved in manure) and during and after precipitation periods.
g. Irrigation. If a field is irrigated the manure is diluted and enters the soil at a larger rate, both of which lead to a lower emission.
h. Properties of the soil (pH, calcium content, water content, buffer capacity and porosity etc.). The emission is generally increasing with pH, calcium content, and porosity, but is decreasing with buffer capacity and the water content.
i. Properties of the manure (pH, viscosity, content of dry matter). The emission is generally increasing with pH, viscosity and content of dry matter. A high viscosity prevents the manure or fertilizer to enter the soil.

j. Amount applied per ha. The fraction of N in manure which evaporates increases with the amount applied.
k. The way of applying the manure or fertilizer. If the manure is injected a much lower emission results.
l. Time between spreading and ploughing (for arable land). The emission is generally largest during the first hours after spreading. Ploughing shortly after spreading can reduce the emission considerably.

If the animals are grazing in the meadows, the manure is not stored, but deposited directly and it is therefore exposed immediately to other loss processes than volatilization of NH_3 to the atmosphere. These processes are: uptake by the grass, wetting by precipitation, leading to dilution and penetration of the soil with diluted manure, and nitrification. The NH_3 emission rate during the grazing period is for this reason less than if the animals were in the stable including the contribution during storage and subsequent spreading. The total emission from animals therefore depends on the fraction of the time they are in the meadows.

Emission from fertilizer depends on (Fenn and Hosner, 1985):
i. Kind (properties) of the fertilizer
and most of the factors mentioned under f-l above.

For the computation of the NH_3 emission it is necessary to have quantative information on all these factors. If the emission of one country is to be computed, one should have statistical information on factors influencing the emission, e.g. on the frequency of occurrence of certain housing systems etc. Emission factors are not only country-specific but will also vary within a country. Some information on the processes and statistics is available. But not all information is available for every country. This is one of the reasons that the same emission factors are used for all European countries.

Due to measures to reduce the NH_3 emission, emission factors are likely to change in the coming years and it may be difficult then to know whether these changes occur in reality or only on paper.

3. EMISSION FROM LIVESTOCK

The numbers of animals used for the computation of the emission were from the year 1989 (FAO, 1989). For The Netherlands more recent information is used (LEI/CBS, 1990). As the FAO only gives combined numbers for Belgium and Luxemburg, the numbers for Belgium were found by subtracting these numbers with the numbers for Luxemburg (STATEC, 1989).
For the USSR an emission inventory is made only for the (former) most Western republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithuania, Latvia, Armenia and Estonia. Data on livestock for these republics of the USSR are from the Statistical Bureau of the USSR (1988).
Table 2 shows the number of different categories of livestock for each country.

In The Netherlands a working group of agricultural scientists was established to evaluate the present knowledge on NH_3 emissions from livestock and to give better founded estimates of emission factors. They used the results of nutritional research of the past decades to determine nitrogen flows of the livestock. The loss during storage and in stables was determined by looking at the N/P ratio in excrements and in stored manure (NH_x is the sum of NH_3 and NH_4^+). P is regarded as a conservative component, whereas NH_x may evaporate as NH_3. Emission of NH_3 can then be computed from changes in the N/P ratio during the storage process (Klarenbeek, 1987). Later the emission factors were based on measured emissions (van der Hoek, 1991). The emission after spreading and during the grazing period were determined from experiments described in the literature and from additional experiments carried out by various research groups in The Netherlands (De Winkel, 1988; van der Hoek, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm., 1990 and 1991). Their results show that there exist large differences in emission due to differences in agricultural practice. Emissions from laying hens in different housing systems, e.g. may differ a factor 10. And emission after spreading on a field can be reduced by 30% if the field is ploughed within one day after spreading. Fig. 1 illustrates the flow of nitrogen and the ways NH_3 can reach the atmosphere.

The emission factors used for Europe were derived from The Netherlands emissions. These emissions were calculated by using the number of animals for each subcategory and the emission factors for each subcategory split up into emission from the stable + during

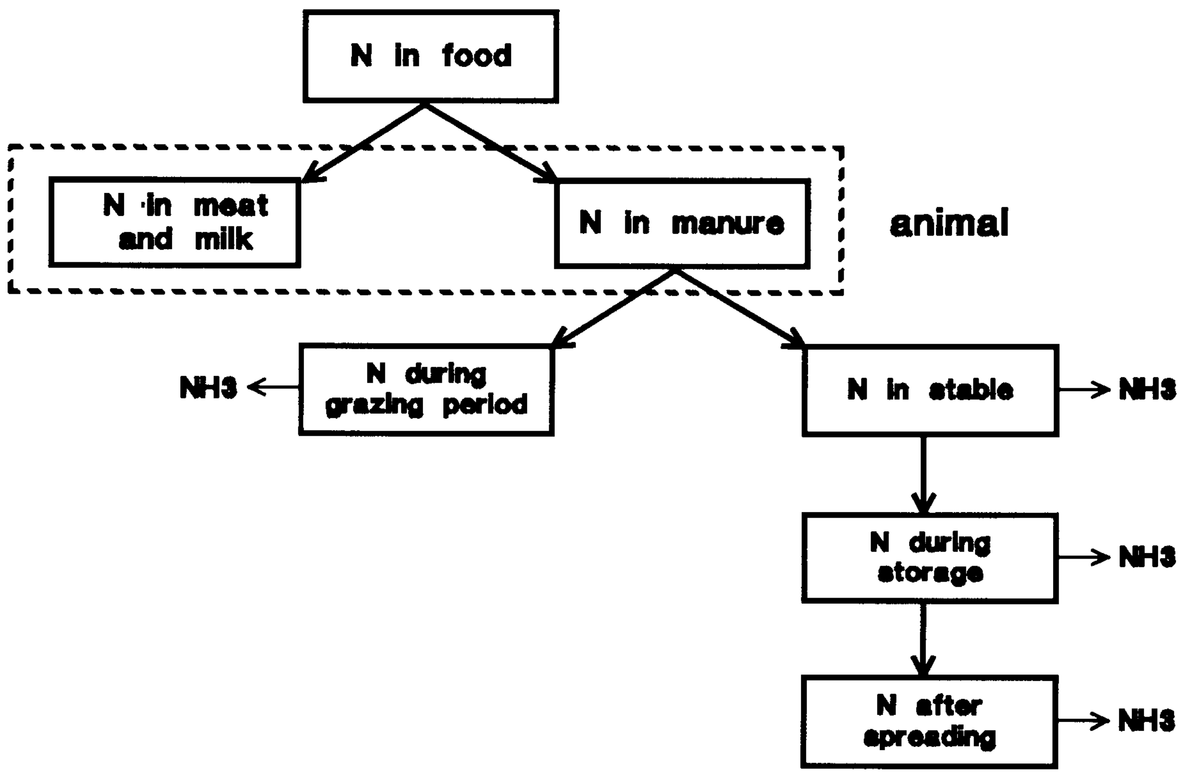

Fig.1. Nitrogen flow: from nitrogen in food to emission of NH_3 to the atmosphere. Losses of NH_3 other than to the atmosphere are not shown.

storage, after spreading and during grazing and are presented in Table 3 (LEI/CBS, 1990). Table 4 shows the emissions of the subcategories for The Netherlands so that one can see how important the contribution of the different subcategories is. The emission factors for animal categories were found by dividing the emission of a category by the number of animals of that category (Table 5). In this way it is assumed that the relative contribution of each subcategory to each category for all European countries is the same as for The Netherlands.

More detailed recent information on how the emission factors for animal husbandry were derived can be found in Asman and van der Hoek (1992).

4. EMISSION FROM APPLICATION OF FERTILIZERS

The emission from fertilizers depends on many factors (see section 2) and only for a few factors a geographical distribution is known. It was therefore decided to use the same emission factors for whole Europe. The information on consumption of the different fertilizers is taken from IFA (1990a) and is presented in Table 6.

Whitehead and Raistrick (1990) made measurements of the volatilization of NH_3 during application of different kinds of fertilizer on different soil types in the laboratory. This method has the great advantage that the emission from different fertilizers is measured under the same conditions. This makes it possible to compare the emissions. Otherwise, the emission factors for different kinds of fertilizer have to be found from field experiments, in most cases performed under different conditions, which makes it difficult to compare the results.

The values for emission factors used in this report were derived from the results of Whitehead and Raistrick (1990) and were used in combination with the consumption statistics for fertilizers of the International Fertilizer Industry Association (IFA, 1990a) to compute the emission from fertilizers for each country.
For the USSR only an emission inventory was made for the most Western republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithuania, Latvia, Armenia and Estonia. The N fertilizer consumption for this area was found from information on the area of arable land in this area, the area of arable land for the whole USSR, and on the N fertilizer consumption for the whole USSR. In this way it is implicitely assumed that the application rate of N fertilizer (tonne N km^{-2}) and the relative share of the different kinds of fertilizer is the same everywhere in the USSR.

IFA (1990a) does not discriminate between mono-ammonium phosphate and di-ammonium phosphate, but Whitehead and Raistrick (1990) give different values for these categories, the evaporation from di-ammonium phosphate being higher. K. Isherwood (IFA, Paris, France, pers. comm., 1991) estimates that well over 80% of the world production of ammonium phosphate is in the form of di-ammonium phosphate and that much of the mono-ammonium phosphate is used for the production of compound fertilizers. It was therefore assumed, that the ammonium phosphate mentioned in the IFA statistics is all di-ammonium phosphate.

Information on the emission from liquid NH_3 directly injected into the soil was provided by S. Sommer (Askov Esperimental Station, Vejen, Denmark, pers. comm., 1991) as being negligible if applied under the right conditions (the soil should not be too dry and no stones should be present). But as some emission can happen if the injector is pressed up by stones or if the soil is too dry, the emission factor of directly applied liquid NH_3 was arbitrarily set to 1% of the N content. Whitehead (AFRC Institute of Grassland and Environmental Research, Hurley, U.K., pers. comm., 1991) estimates that the emission from injection of liquid ammonia would be higher, maybe at least 5% because stony and dry soils are widespread.

Although different experts gave different values for the emission factors, there seems to be a reasonable agreement regarding the ranking of fertilizers according to the emission factors (D.C. Whitehead, AFRC Institute of Grassland and Environmental Research, Hurley, U.K.; O. Oenema, Netherlands Fertilizer Institute c/o Institute for Soil Fertility, Haren, The Netherlands; S. Sommer, Askov Experimental Station, Vejen, Denmark; pers. comm.s, 1991). Table 7 shows the emission factors used in this report and the factors used by Buijsman *et al.* (1987). Apart from urea and compound N, the emission factors used in this survey are lower than those of Buijsman *et al.*. This is especially important for ammoniumnitrate, for which the emission factor in this survey is 2% in stead of 10%. Buijsman *et al.* do not discriminate between so many kinds of fertilizer as is done in this survey.

The uncertainty in the emission factors is quite large. The emission factor for ammonium sulphate is 8% of the N content according to the table. But when applied to soils with pH < 5.5 it can be less than 2 % and when applied to calcareous soils it can be as high as 50% (Whitehead and Raistrick, 1990). Farmers may know this information and therefore do not apply this fertilizer on calcareous soils.

In Southern Europe urea is much used as a fertilizer. The relatively high temperatures in this area may lead to emission factors of 30% of the N content for this area instead of 15% mentioned in the table (O. Oenema, pers. comm., 1991). On the other hand the ratio of arable land to grassland is higher in this area than in Northern Europe and if the urea is incorporated into the soil or applied in solution, the emission will tend to be reduced (D.C. Whitehead, pers. comm., 1991).

In Table 8 the NH_3 emission for each fertilizer category is presented. Moreover, the average emission factor for fertilizers for each European country is shown. It appears that there can be a factor two difference in the average emission factor between countries. The average emission factor for The Netherlands is lowest in Europe, apparently because calcium ammonium nitrate is the dominating fertilizer used.

5. OTHER SOURCES

5.1. Emission from the production of NH_3 and N fertilizer

Important industrial NH_3 emissions originate from the production of NH_3 and N-fertilizer.

The production capacity and location for most industrial NH_3 plants is known (British Sulphur Corporation, 1987). In this report the emission is computed by assuming that the production is equal to the production capacity and assuming an emission factor of 0.97 kg NH_3 $tonne^{-1}$ produced N (Ministry of Housing, Physical Planning and Environment, 1983). The actual production will, however, be lower than the production capacity and therefore the emissions will be somewhat lower than presented in Table 9. But the contribution of this category to the total NH_3 emission is only about 2%. This emission cannot be taken into account in the gridded emission inventory because the location of some of the plants is not known. The NH_3 production capacity of Denmark is set to zero based on more recent information.

NH_3 originates also from the production of N-fertilizer, including the production of nitric acid and the production of different kinds of ammonium fertilizers. According to the Ministry of Housing, Physical Planning and Environment (1983) emission factors range from as low as 0.01 kg NH_3 $tonne^{-1}$ N for the production of nitric acid to 12.5 kg NH_3 $tonne^{-1}$ for the production of NPK-fertilizer. Because the amount of nitric acid and/or N-fertilizer produced in the individual industrial plants are not known, gridded emissions cannot be computed. The amount of NH_3 originating from these sources is estimated for each country as a whole by using information on the production of N-fertilizer (IFA,1990b), assuming the same average emission factor of 5 kg NH_3 $tonne^{-1}$ N produced as N-fertilizer as adopted by Buijsman *et al.* (Table 9).

The emissions from the Western part of the USSR are estimated by assuming that the relative share of this part of the USSR in the emissions of the whole USSR is equal to the relative share of the consumption of N-fertilizer (38.5%). This is of the same order as the relative share of this part of the USSR in the production capacity of NH_3 (31%; British Sulphur Corporation, 1987)

5.2. Emission from plants

Degradation of proteins in plants leads to formation of NH_4^+ and NH_3 in plants. Depending on the difference of the NH_3 concentration in the air and in the plant (expressed in comparable units) this NH_3 may escape. If the concentration in the air is higher than in the plant, dry deposition to the plant will occur. In the reverse case emission will occur. The airborne concentration at which neither dry deposition nor emission will occur is called "compensation point" of the plant (Farquhar *et al.*, 1980). It will depend on the N status of the plant and will therefore be different for different plants, growth stages and application rates of manure or fertilizer.

Based upon a limited set of experiments Duyzer *et al.* (1987) and Sutton et al. (1991) could not find any emission from natural (non fertilized) vegetation like moorland. But NH_3 emission from fertilized agricultural vegetation seems to exist (see Schjørring, 1991 for an overview). Emission only occurs during daytime when the stomata are open. Plants of medium and high N status like wheat may show two emission peaks during their life cycle: one peak near ear emergence and one during senescence. The emission rate depends on the nitrogen status of the vegetation. If during the reproductive growth phase the capacity for nitrogen incorporation into flowers, developing seeds and fruits is limited by unfavourable environmental and physiological conditions, the supply of nitrogen from vegetative plant parts may be too high, leading to high NH_3 losses (Schjørring, 1991). This means that there may exist considerable year to year variations in the emission from plants.

The emission is only known for a limited number of species and under a limited number of circumstances. Different authors (Schjørring, 1991) measured losses from 0.5 - 15 kg N ha^{-1} yr^{-1} (0.06 - 1.8 ktonne NH_3 km^{-2} yr^{-1}). Whitehead and Lockyer (1989) measured the NH_3 emission from decomposing grass herbage and suggested a rate of about 0.17 ktonne NH_3 km^{-2} yr^{-1} for grassland, which amounts for the UK to about 2.5% of the total NH_3 emission. Harper *et al.* (1987) found in a warm climate that 21% of the applied fertilizer

was lost as NH_3 to the atmosphere, but this was not only from the plants, but also from the soil.
Although not enough information seems to be known at the moment to produce any reliable number for this emission survey, it seems that fertilized agricultural vegetation may contribute significantly to the NH_3 emission, but it is certainly not dominating.
While emission generally occurs shortly after application of manure or fertilizer, emission from fertilized agricultural vegetation occurs first after some time, may be first in June-August.

5.3. Emission from other animals and other sources

There are many kinds of animals existing which give rise to NH_3 emission. These emissions can, however, not be incorporated in this gridded emission survey because no information is known on the numbers of animals, emission factors and/or geographical distribution, or this information is not known for all countries. Amongst these animals are dogs, cats, fur animals, reindeer and wild animals. They do not contribute much to the total emission of NH_3 in Europe, but their contribution may be important in some regions.

Emission from human beings is estimated to be 0.3 kg NH_3 $human^{-1}$ yr^{-1} (Buijsman *et al.*, 1984), which leads with about 550 milion people to an emission of 165 ktonne NH_3 yr^{-1}. Möller and Schieferdecker (1989) estimate an emission factor of 1.3 kg NH_3 $human^{-1}$ yr^{-1}, which would lead to an emission of about 715 ktonne NH_3 yr^{-1}. These numbers are rather small and emission by humans is therefore not incorporated in this survey.

Many other sources exist for NH_3 emissions e.g. car exhaust, sewage sludge, combustion/coking of coal and landfill. The emissions from these sources are very uncertain but not very important.

5.4. Natural emissions

Buijsman *et al.* (1987) estimated the natural emissions, e.g. from soils, for Europe to be 750 ktonne yr^{-1}, but this number is quite uncertain. Natural emissions were not incorporated in this gridded survey because of this uncertainty and the lack of information on their geographical distribution.

6. UNCERTAINTY IN THE TOTAL NH3 EMISSION

The agricultural practice differs from country to country. An inquiry was made to investigate these differences (Appendix 1). Although a reasonable overview was obtained of the possible differences the information from the inquiry was far from complete. For some countries no information is available at all. For other countries only some questions were answered and it was sometimes not clear how representative the answer was for the whole country. Moreover, no information was known on some other factors, which could be equally important (see Section 2 , where these factors are listed). This makes it difficult to take all the differences in practice into account. For this reason it was decided not to calculate any country-specific emission factors, but to apply emission factors derived for The Netherlands for all European countries. Some of the results from the inquiry can be used to get an impresssion of possible differences (see also Klaassen, 1990).

The contribution from cattle dominates the NH_3 emission in Europe. In the survey presented here, the emission factors were based on the situation in The Netherlands where most (dairy) cows are in the stable during 190 days of the year. In summertime a part of the cows in The Netherlands are at night or the whole day in the stable. About 30% of the excretion is collected in the stable and gives rise to more emission from the stable and more emission from spreading more manure than if they were in the meadows. For the average situation in The Netherlands the emission from dairy and calf cows is about 40 kg NH_3 animal^{-1} yr^{-1} (Table 3). But if these cows were always in the stable the emission would be about 59 kg NH_3 animal^{-1} yr^{-1} and if all cows were in the meadows in summertime the emission would be about 31 kg NH_3 animal^{-1} yr^{-1} (van der Hoek, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm., 1991).

The nitrogen content of the animal food in The Netherlands is maybe higher than elsewhere in Europe, however, differences in food conversion may occur. The emission factors used in this survey, which are derived from the situation in The Netherlands should for that reason lead to an over-estimation of the emission for Europe. But there exist some other factors which may compensate for this situation. In Southern Europe the temperature is generally higher than in The Netherlands. This would, under the same conditions, lead to higher emission factors for these countries than for The Netherlands. In Northern Europe the cattle are in the stable all time, which also leads to higher emission factors.

The housing system can have a large influence on the emission as was mentioned in Section 2. Different measures are available to reduce the emissions. It is very likely that some countries will try to reduce NH_3 emissions (see Appendix 1) by restricting the application of manure to certain amounts, or to the growing season, by requiring that manure spread on arable land has to be ploughed under within a certain time, by prescribing manure injection to grassland etc. Although this is a very positive development, in particular if this does not lead to extra problems with regard to the soil and the groundwater, it does not make the computation of NH_3 emissions to the air easier.

It is estimated, that the total NH_3 emission for a country has an uncertainty of at least 30-40%. More research on NH_3 emission factors will reduce the uncertainty in the emissions somewhat, but a large part of the uncertainty is caused by other things. If all the information on emission factors for all circumstances were known, there would still exist considerably uncertainty in the emission because statistics on the (gridded) geographical distribution of agricultural practice (type of stable, type of storage facility, time of application etc.), soil type and meteorology are in most cases not available.

With exactly the same number of animals, agricultural practice and soils, the emission would vary from year to year because of the variation in meteorological circumstances (temperature, turbulence, humidity, precipitation). For all those reasons it seems very hard to reduce the uncertainty in the emissions to a large extent.

Within a country there generally exists different agricultural practices, soil types and even meteorology, leading to a larger uncertainty in the emission computed for one grid element than for the country as a whole.

It is felt that the uncertainty in the emission factors for fertilizers is likely to be higher than the uncertainty in the emission factors for animals. This is, however, not so very important because the contribution from fertilizers to the total NH_3 emission is less important.

Model calculations of annually averaged concentrations and depositions of NH_3 and NH_4^+, using the slightly different emission inventories presented in the draft version of this report, show that there exists a good agreement with measurements for Europe (Asman and van Jaarsveld, 1990, 1992). This means that not only the absolute value of the emissions seems to be reasonable, but also the geographical distribution not only on an European scale, but also on a more local scale using more detailed emission inventories.

7. CALCULATION OF THE EMISSION FOR EUROPE

The gridded NH_3 emission was computed for each emission category for each country as a whole, using the information on the number of livestock, consumption of fertilizers and the emission factors. Appendix 2 gives some information on the programme and the files used to update the NH_3 emissions for Europe. Table 10 shows the computed emissions for each category and the average total emission density for each country (averaged over the whole surface of the country, i.e. not only over agricultural surfaces). It appears that the emission density is highest in The Netherlands, almost 6 times higher than the average density of Europe.

Table 11 shows the relative share of the different emission categories in the total gridded NH_3 emissions. In comparison to the (non-gridded) emissions from NH_3 and fertilizer production Table 9 shows that these emissions are only 2% of the gridded emissions. It appears that, apart from Greece, cattle is the category with the largest contribution to the emission, which is over 50% for 17 out of 27 countries.

In Table 12 the emissions are compared with those of Buijsman *et al.* (1987). Differences arise because Buijsman *et al.* used different overall emission factors for different countries and because they included asses and mules in the category "sheep" , whereas they in this report are included in the category "horses". In the first case the emission is probably underestimated and in the last last case it is probably overestimated, however, differences arise because the number of animals in 1989 was different from the one used by Buijsman *et al.*, which is valid for about the year 1982. Also the main reason for the differences is the differences in emission factors.
The large ratio's for poultry and horses for Portugal are maybe due to incompleteness of the old emission survey.

The total gridded emission is 21% higher than of Buijsman *et al.* (1987).
It has already been mentioned that the emission should be higher than by Buijsman *et al,* (1987) (Buijsman, 1987; Möller and Schieferdecker, 1989). But if the total emission becomes much higher than calculated in this survey, modelled concentration will become much higher than measured concentrations, as far as they are known at this moment (Asman and van Jaarsveld, 1990, 1992). In view of our present knowledge the remark of

Möller and Schieferdecker (1989) that the emission estimated by Buijsman *et al.* (1987) for Europe may be too low by a factor of 2, is not very likely to be correct.

In Table 13 this survey is compared to other emission surveys. The most important conclusion which can be drawn from this table is that the computed emissions still are uncertain. It should be mentioned here, however, that the surveys are of quite different quality and a few of them are not more than the "first educated guess".

To get the gridded emission survey the emissions for each category were distributed over the 75x75 km^2 IE grid elements within each country, assuming the same geographical distribution as Buijsman *et al.* (1987). By doing this it is implicitely assumed, that the geographical distribution for each emission category had not changed since about 1982. The IE grid is constructed in such way, that four IE grid elements constitute one EMEP grid element (see for further description of the IE and EMEP grids: Buijsman *et al.*, 1985).

Fig. 2 shows the geographical distribution of the NH_3 emissions in Europe. In Fig. A3-1 to A3-8 in Appendix 3 the emission for each category is given as a number for each EMEP grid element. Although the emission is available for the smaller IE grid elements this emission data is not presented here because the size of the numbers in the figures would then become too small to read.

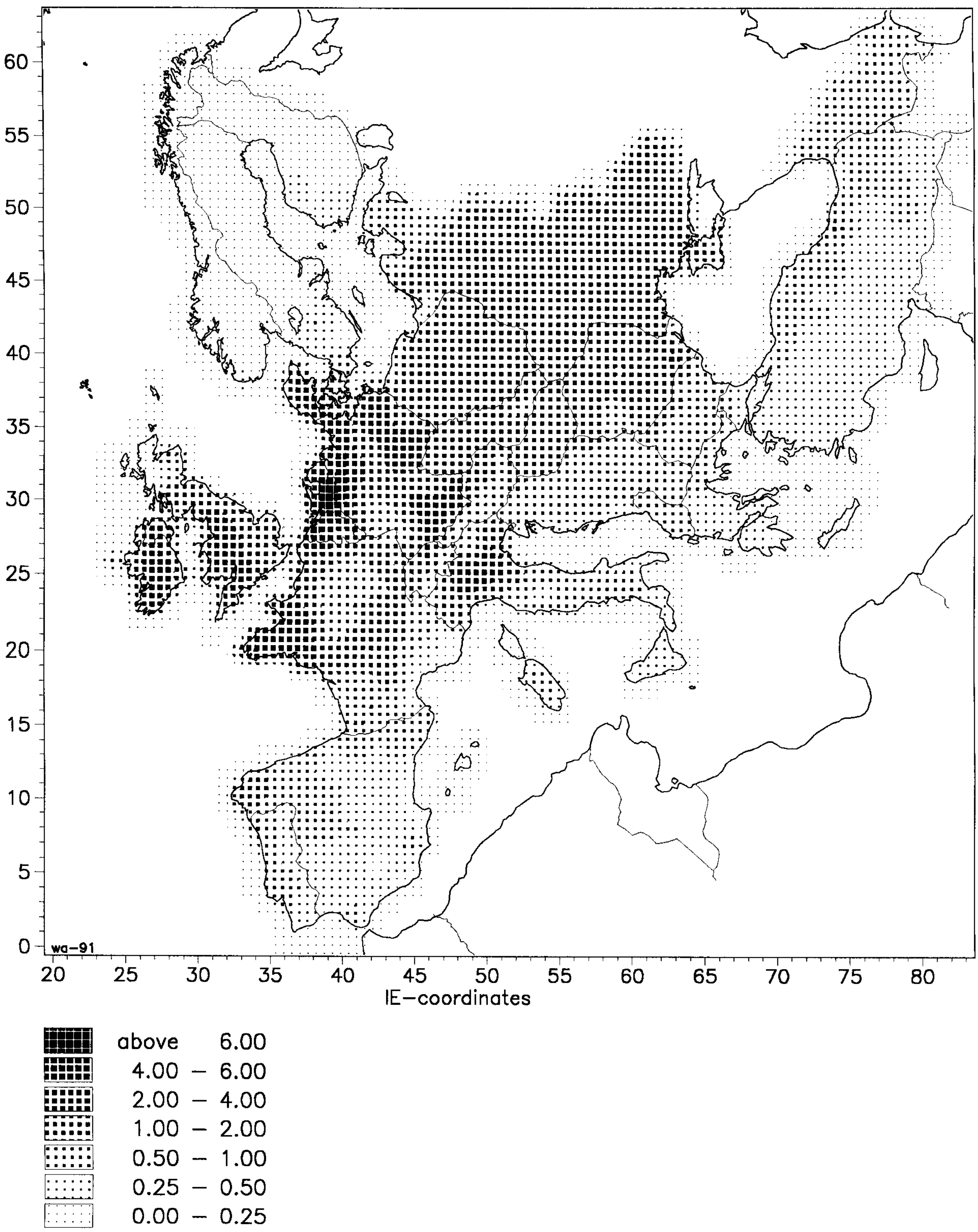

Fig. 2. Emission density total NH_3 emission on IE grid (75x75 km^2) in Europe (tonne NH_3 km^{-2} yr^{-1}).

8. DETAILED EMISSION SURVEY FOR BELGIUM AND THE WESTERN PART OF THE FRG

For the UK, The Netherlands and Denmark detailed emission surveys are available (ApSimon *et al.*, 1987; Buijsman *et al.*, 1984; Erisman, 1989; Asman 1990). To improve model results for The Netherlands in the areas near the borders, a detailed emission survey was made for Belgium and for the following IE grid elements of the western part of the F.R.G., characterized by the k respectively l coordinates: (38,33), (39,32), (39,38), (40,29), (40,30), (40,31), (40,32). (For a description of the coordinate system see Buijsman *et al.*, 1985). This emission survey was made in a different way. To start with a gridded emission survey was not made, but instead the emission for each category was computed for each municipality. From geographical maps (Administratieve kaart 1:300.000 van België, Nationaal Geografisch Instituut van België, Brussel; 1:200.000 maps of the "Regierungsbezirke Münster, Düsseldorf and Köln; Übersichtskarte von Niedersachsen 1:500.000, Verwaltungsausgabe) the geographical position of the centre of each municipality was determined. Moreover, two characteristic diameters of each municipality were determined in such way that the sum of the products of the two characteristic diameters of all municipalities is equal to the total area of the region. This procedure was followed to be able to treat each municipality as one area source with a characteristic radius, computed from the two characteristic diameters, so that its surface is equal to the products of the characteristic diameters. Later also a gridded survey was made from these emissions for the municipalities.

The detailed emission was computed using the same geographical distribution for each category as used by Buijsman *et al.*, (1987) for each municipality, but the number of animals, consumption of fertilizer and the emission factors were updated in the same way as for Belgium, respectively the F.R.G. as a whole. In this way emissions were obtained for all 596 Belgian municipalities, for 141 municipalities in Nordrhein-Westfalen and for 204 municipalities in Niedersachsen (also taking the formation of new municipalities into account). In Appendix 4 information is given on the programme and the files used. The emissions are presented in Fig. 3. The data for The Netherlands are taken from Erisman (1989).

It appears that the spatial variation in emission density can be very large. The maximum density is much larger than the averaged density derived from the European emission survey. Asman and van Jaarsveld (1990, 1992) showed how the spatial resolution of the NH_3 emission influences modelled concentrations of NH_x components.

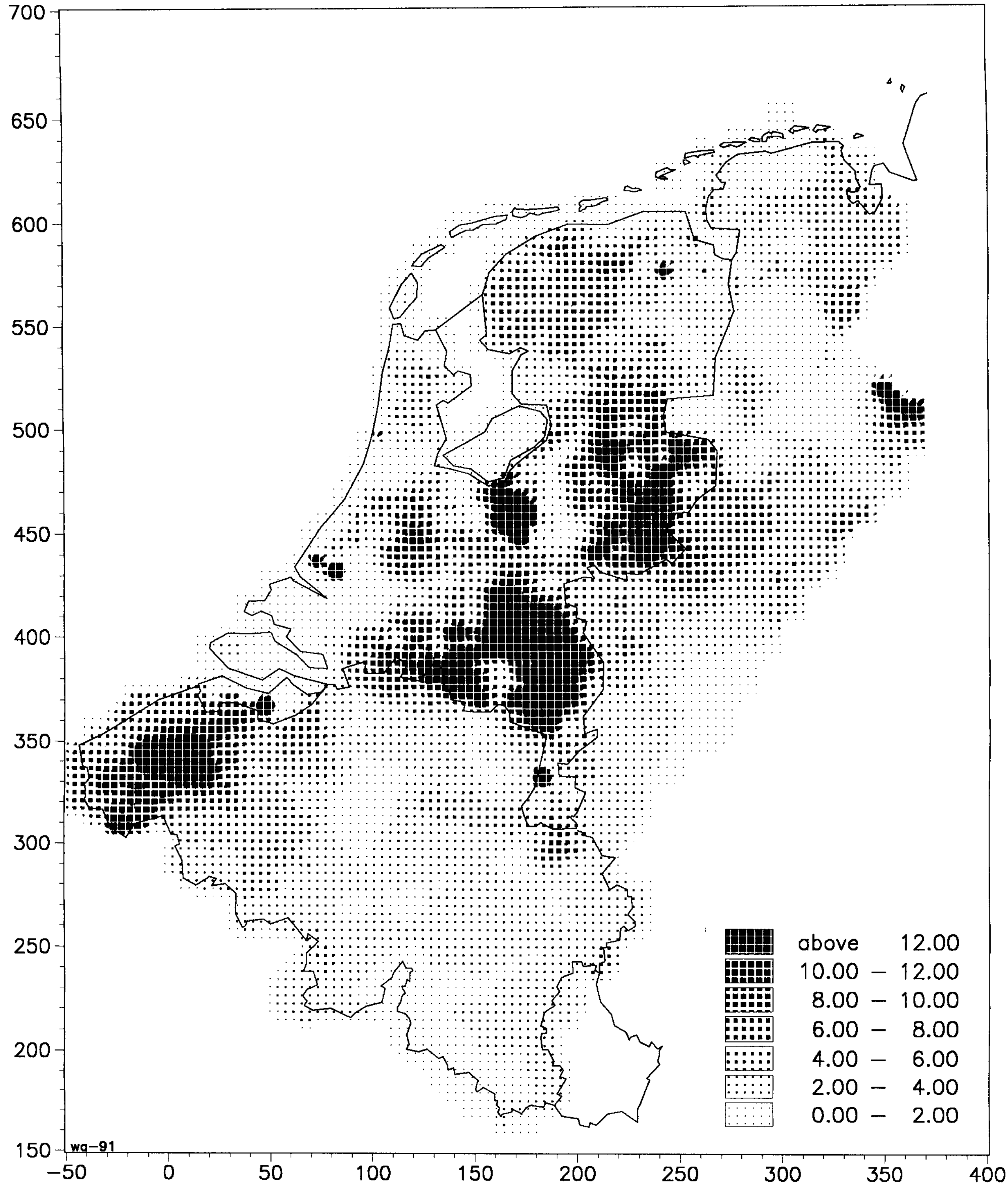

Fig. 3. NH_3 emission density on a 5x5 km^2 grid in The Netherlands, Belgium and the western part of the F.R.G. (tonne NH_3 km^{-2} yr^{-1}). Because of the interpolation procedure and the smoothing procedure there exist some emissions outside the boundaries of the countries or at sea.

9. DIURNAL VARIATION

With regard to the description of the average diurnal variation of the NH_3 emission rate, the emissions can be split up in the following categories, which show different emission patterns:

a. Emissions of animals in the stable, including from storage in the stable.
b. Emissions during storage of manure outside the building.
c. Emissions after application of manure and fertilizer and during the grazing period.
d. Industrial emissions.
e. Emissions from plants.

9.1. Emission after application and during the grazing period

About 70% of the emissions in Europe come from category c. It is therefore useful to look at this category in more detail.

The diurnal variation of the emissions of category c is to a large extent determined by the following phenomena:

- The variation in the soil temperature, which has a large influence on the NH_3/NH_4^+ equilibria in the soil and thereby on the NH_3 concentration at the soil surface.
- The variation in the atmospheric turbulence, which determines the maximum rate at which the NH_3 at the soil surface can be transported to the air.

These phenomena will now be considered in more detail, starting with the influence of the diurnal variation in the soil temperature.
The NH_3 /NH_4^+ equilibria in manure or in water in the soil can be described by the Henry's law constant (H) and the dissociation constant (K) for $NH_3.H_2O$ (the temperature T is given in K):

NH_3 (air) + H_2O <-> $NH_3.H_2O$;

$$H_{NH_3} = \frac{[NH_3.H_2O]}{[NH_3]_{air}} = 5.60 \times 10^1 \exp\left(4092\left(\frac{1}{T} - \frac{1}{298.15}\right)\right) \quad M\ atm^{-1} \qquad (1)$$

(Dasgupta and Dong, 1986).

$NH_3.H_2O + H^+ <-> NH_4^+ + H_2O$;

$$K_{NH_4^+} = \frac{[NH_3.H_2O][H^+]}{[NH_4^+]} = 5.67x10^{-10}exp(-6286(\frac{1}{T}-\frac{1}{298.15})) \quad M \qquad (2)$$

(Bates and Pinching, 1950).

From (1) and (2) follows the NH_3 concentration in air in equilibrium with a given NH_4^+ concentration:

$$[NH_3]_{air} = \frac{f\ [NH_4^+]}{[H^+]} \quad atm \qquad (3)$$

where:

$$f = \frac{K_{NH_4^+}}{H_{NH_3}} = 1.013x10^{-11}exp(-10378\ (\frac{1}{T}-\frac{1}{298.15})) \quad atm \qquad (4)$$

In Fig. 4 f is presented as a function of the temperature. It appears from Fig. 4 that the emissions will be strongly influenced by temperature fluctuations. It must be mentioned here that in many publications a wrong value is given for the temperature dependence of K_{NH4} (Wagman et al., 1965; Hoffmann and Jacob, 1984; Seinfeld, 1986).

The emission rate of emission category c (emission after application of manure and fertilizer and during the grazing period) is not only influenced by the temperature, but also by the same meterological factors which describe exchange of material across the Earth's surface by dry deposition. The influence of turbulence on the maximum emission rate can then be described in analogy with the dry deposition velocity by a concentration-independent emission velocity or exchange coefficient v_e (m s^{-1}) at a certain reference height:

$$v_e = (r_a + r_b + r_s)^{-1} \qquad (5)$$

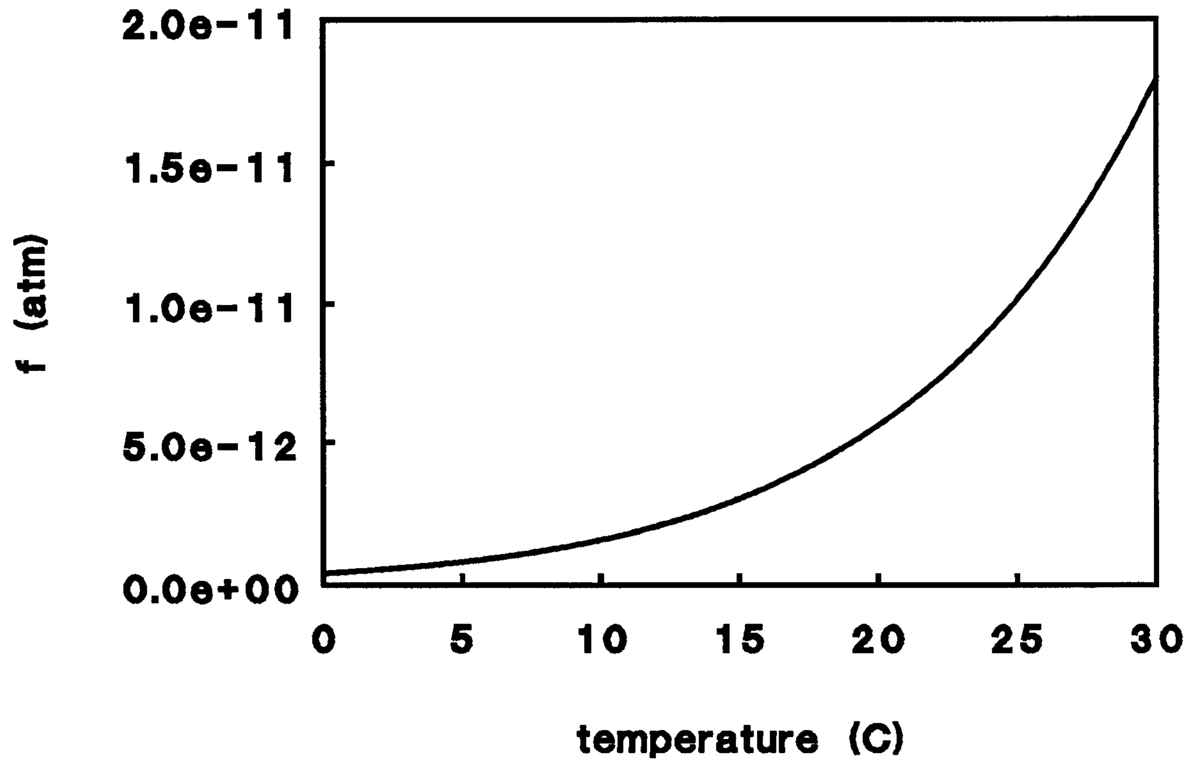

Fig. 4. f as a function of temperature.

where: r_a = aerodynamic resistance (s m^{-1}), which is a function of the friction velocity (u_*) and the Monin-Obukhov length (L).

r_b = laminar boundary layer resistance (s m^{-1}), which is approached by $r_b = 5\ Sc^{2/3}/u_*$, with Schmidt number $Sc = \upsilon/D$.

υ = kinematic viscosity in air ($m^2\ s^{-1}$).

D = diffusivity of NH_3 in air ($m^2\ s^{-1}$).

r_s = surface resistance (s m^{-1}). Experiments carried out by Martin Ferm (Swedish Environmental Research Institute, Gothenburg, Sweden, pers. comm., 1989) showed that the surface resistance during emission of NH_3 was negligible.

But the emission rate F can be lower than the maximum possible rate because it depends not only on the turbulence, but also on the difference in NH_3 concentration in air and in the air in the soil:

$F = v_e([NH_3])_{(air,\ soil)} - [NH_3]_{(air,\ reference\ height)})$ (6)

Combining equations (3), (5) and (6), and assuming there exists equilibrium between NH_3 and NH_4^+ in the soil or the manure or fertilizer and assuming that $[NH_3]_{(air,\ soil)} >> [NH_3]_{(air,\ reference\ height)}$ and $r_s = 0$, the following equation for the emission rate F can be found:

$F = E.c_r$ (7)

Where: E is the "potential emission rate" defined by $E = f\ (r_a + r_b)^{-1}$ (m atm s^{-1}).
c_r is the ensemble average of $[NH_4^+]/[H^+]$ ratio's in soil or spreaded manure over a large area.

Although c_r is not known, the relative diurnal variation in the emission rate can be computed from this equation, assuming that c_r is constant. Of course the real emission rate will be influenced by other factors like agricultural activities (e.g. spreading), precipitation and nitrification in the soil.
The values of r_a and r_b can be determined from meteorological observations , just as the value of f which only depends on the surface temperature. This is, however, a very locally determined parameter, which e.g. depends on soil properties, soil moisture content and vegetation. As an approximation of the soil temperature, the air temperature can be taken, which is measured routinely and is representative of larger areas.

Two climatological data sets were available to get an impression of the diurnal and seasonal variation of E:

a. A 30-year climatology of air temperatures measured at the Royal Netherlands Meteological Institute at De Bilt, The Netherlands (KNMI, 1968) in combination with a 10-year averaged diurnal variation of r_a and r_b computed from meteorological measurements of the National Air Quality Monitoring Network of RIVM.

b. A 10-year climatology for Kastrup, Denmark provided by the National Environmental Research Institute (NERI), Roskilde Denmark (N. Brown, pers. comm., 1991), based on measurements of the Danish Meteorological Institute.

In Fig. 5 the annually averaged relative diurnal variation of E is presented for both sites (the average value is set to 1). These curves are computed from the relative diurnal variations for each month. This was done to avoid that the larger variation during the summertime, when E is large, would dominate. The difference between the inland station of De Bilt and the coastal station of Kastrup is likely to be caused by the greater temperature variation and somewhat higher temperatures at De Bilt.

In Fig. 6 the relative seasonal variation of E is presented for Kastrup (the annual average is set to 1). This figure shows a variation of a factor 9 over the year, which is mainly caused by the seasonal variation in the temperature.

In Fig. 7 the relative diurnal variation of E for each month is presented in 12 different sub-figures, each showing the variation around the average value for that month (the average value for each month is set to 1). This figure was made to show how the relative diurnal variation varies from month to month. It is clear from this picture, that the relative variation in E is largest in summertime. This is partly caused by the higher temperatures (which is important because f is a non-linear function of the temperature) and by the larger temperature variation during summertime. But another important factor is the greater diurnal variation in u_* (friction velocity), during summertime caused by lower values of u_* during night-time when the atmosphere is generally more stable.

Figs. 5 and 7 could suggest that the diurnal pattern is the same every day. This is, however, not true. On a particular day the maximum of E may well occur during night-time, e.g. because the windspeed is higher than during day-time, while the temperature is maybe about the same.

The computed diurnal variation in the NH_3 emission rate of emission category c is of the same order and shows the same pattern as the observed one (Beauchamp *et al.* (1982); van der Molen *et al.*, 1990).
During and after periods of precipitation the emission rate is strongly reduced. If it is assumed, however, that the probability of the occurrence of precipitation is equally distributed over all days, precipitation will not have any influence on the **averaged** diurnal variation of the emission rate.
Manure is usually spreaded during daytime. The emission during spreading itself is not very large, but the emission is high during the first hours after spreading. This effect was not taken into account here, but it will certainly lead to somewhat higher relative emission rate during day-time than during night-time.

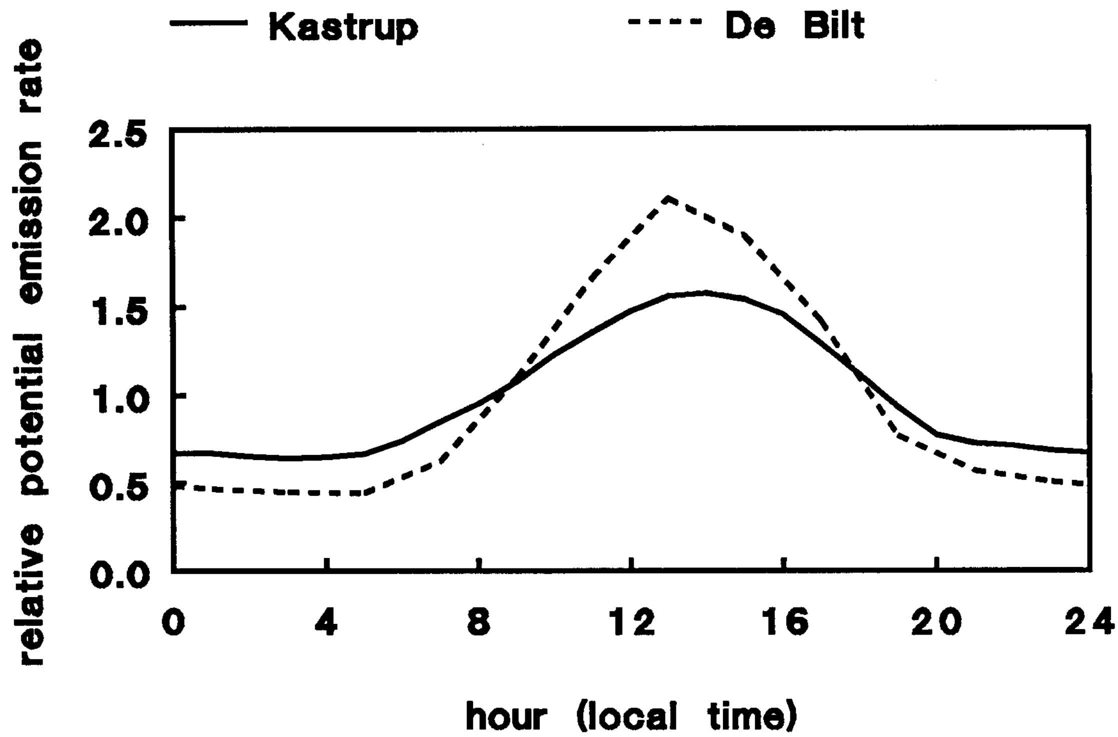

Fig. 5. Annually averaged relative potential emission rate for the system air/soil. (average value = 1)

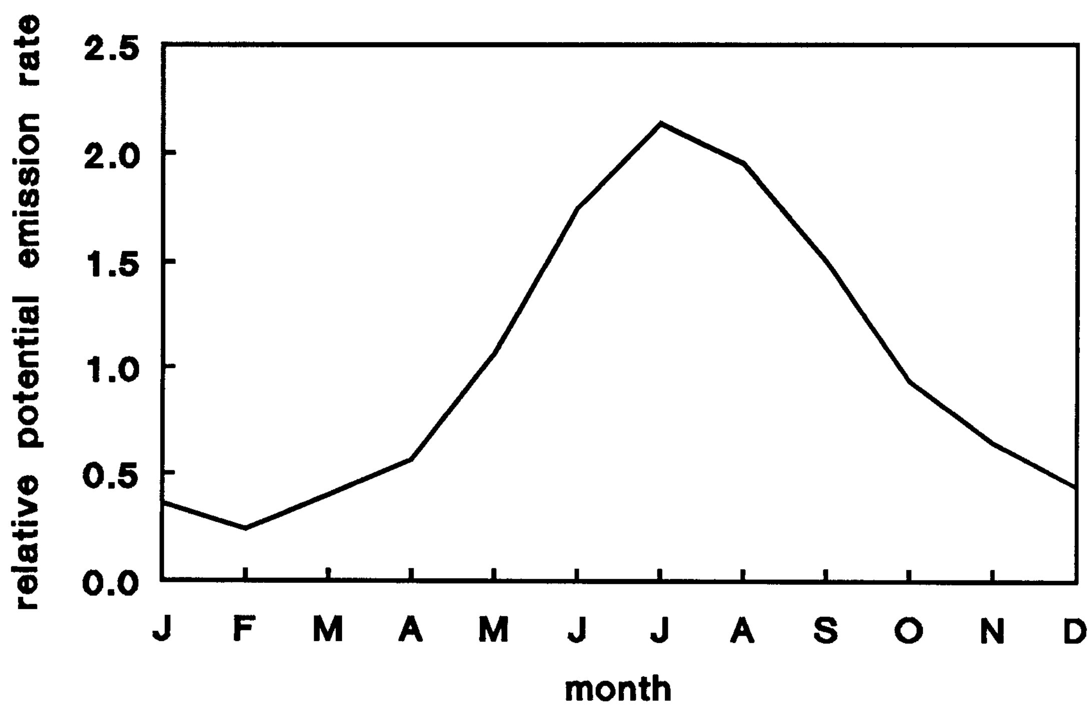

Fig. 6. Seasonal variation in the relative potential emission rate system air/soil, Kastrup. (average value = 1)

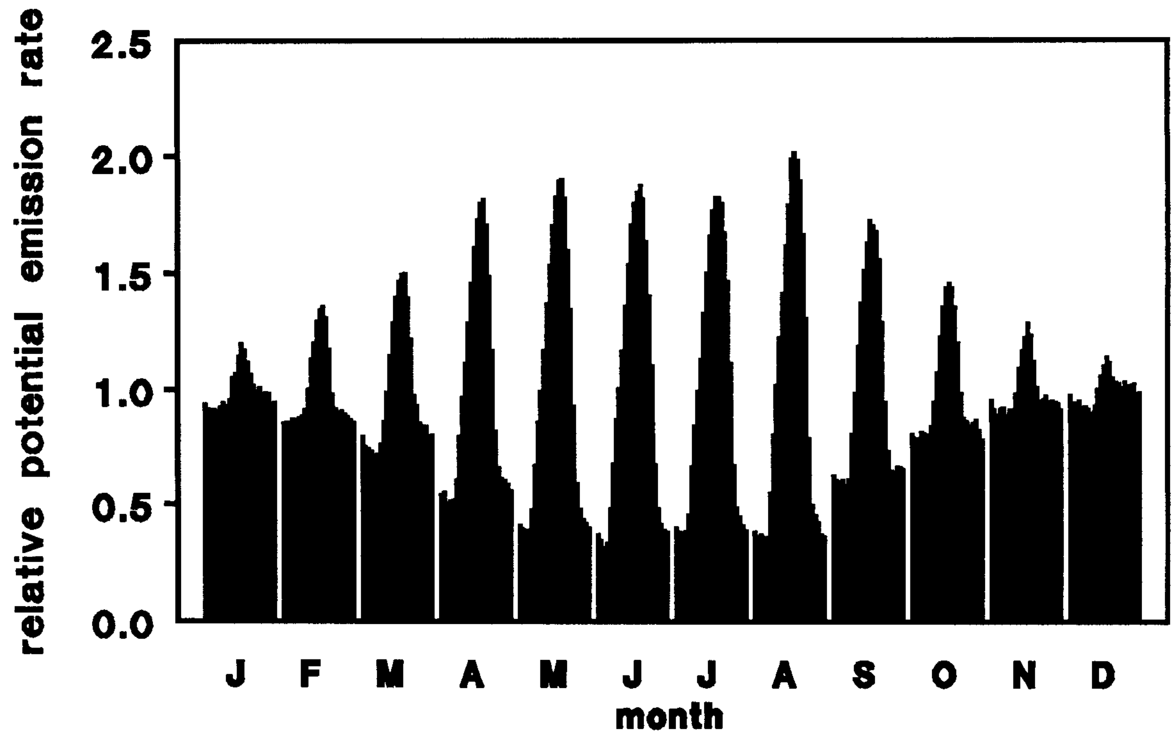

Fig. 7. The relative averaged diurnal variation in the potential emission rate for each separate month for Kastrup (average value for each month = 1).

9.2. Emission from stables and storage facilities

Until now, only the emission after application of manure and fertilizer and during the grazing period has been considered. In The Netherlands about 30% of the emission of NH_3 originates from livestock during the housing period or from storage of manure. In other countries in Europe, where a substantial part of the cattle remains in the stable this percentage may be slightly higher (40%).

The emission rate from stables and storage facilities is governed by the same factors as the emission rate in the field. There exists clear experimental evidence from closed animal housings with mechanical ventilation rate (usually for pigs and poultry) that the emission rate is higher at higher temperatures and at higher ventilation rates. In such housings there exists a minimum ventilation rate, as the animals otherwise would suffocate. In wintertime the ventilation rate is usually at its minimum. If the temperature becomes higher the ventilation rate is increased to keep the temperature in the buildings constant. In summer the temperature will often be so high that the ventilation rate is at its maximum for a substantial part of the day. The largest diurnal variation in the ventilation rate will therefore occur in the spring and in autumn, as then the ventilation rate is then totally governed by the variations in temperature.

For stables with natural ventilation (usually for cattle) little is known, as it is quite difficult to establish the ventilation rate, because it is influenced by openings in the building and by people who open doors. There exists maybe not a large diurnal temperature variation in such stables, but it is likely that a variation in wind speed will have some influence on the ventilation and as a result on the emission rate. This will also lead to a higher emission during day-time than during night-time.

The diurnal temperature variation in storage facilities will not be large, but it is likely that the diurnal variation in wind speed will lead to higher emissions during daytime than during night-time.

9.3. Total emission

For the reasons mentioned above the diurnal variations in the emission rate for housings and during storage will show the same diurnal pattern as the emission rate of category c (emission after application of manure and fertilizer and during the grazing period). The variations are, however, likely to be somewhat reduced. The contributions from industrial emissions and emissions from plants (categories d and e) to the total emission are relatively small and are therefore not taken into account here.
Emission from category c is mostly occurring in spring and to some extent in summer and in autumn. As the relative share of these emissions in the total emission is different for different seasons, the relative diurnal variation of the total NH_3 emission rate will be different in different seasons, being probably largest in spring and smallest in winter.
The curves presented in Fig. 5 could be a first approximation of the average relative diurnal variation, but it is likely that the variation will be somewhat smaller in reality.

Asman and van Jaarsveld (1990, 1992) compared the modelled and measured anually averaged diurnal variation of the NH_3 concentration in air at Elspeetsche Veld, The Netherlands. By adopting the diurnal variation in the emission rate of De Bilt of Fig. 5 in the model, the diurnal variation in the NH_3 concentration could be simulated very well. One should keep in mind, however, that this was only one station and more measurements at different sites are needed before any definite conclusions can be drawn.

10. SEASONAL VARIATION

10.1. Seasonal variation from agricultural information

The NH_3 emission rate is likely to show a seasonal variation due to seasonal variation in the agricultural practice (spreading of manure, grazing of cattle and application of fertilizer) and in meteorological circumstances (mainly temperature, as the potential evaporation of NH_3 increases with temperature and rainfall). The seasonal variation in the number of animals does not seem to be large. To investigate the seasonal variation in the agricultural practice in Europe and to get some additional information concerning the NH_3 emission an inquiry was made. The detailed results of the inquiry can be found in Appendix 1.

It appeared that in many countries the cattle are in the meadows during the months (May), June, July, August, September and (October). The months in between parentheses are not valid for northern Europe. In some countries like Denmark only a small fraction of the cattle come outside. The emission during grazing in The Netherlands is only about 40% of the combined emission from the stable, and from storage and from application of the resulting manure during a period of the same duration (De Winkel, 1988, see also Section 6). This means that in countries, where the cattle do not come outside, the annual NH_3 emission rate will be higher. Pigs and poultry are usually inside during the whole year. Sheep and goats are usually outside during the largest part of the year.

Manure is usually spread just before the growing season (February-May) and in autum for the winter crops (September-November). Manure is in most cases not spread in the summer as this is impossible because of the crops standing in the fields. Fertilizer is for the same reasons also applied during the same periods as manure. On grassland, however, fertilizer and manure may be applied during the summer as well. Spreading of manure will not always occur at the same time at different sites, and will at the same place not always occur at the same time in different years. This is partly caused by differences in meteorological circumstances. These will influence the growth of crops. Moreover, meteorological circumstances could make it impossible to spread manure on muddy soil after severe rain periods. As the soil properties can vary spatially with regard to the uptake of water, spreading on soils with different properties may occur at different times.

It is likely that the amount of manure applied in spring is larger than the amount applied in autumn. This is caused by the fact that cattle can be in the meadows in summertime, so that manure produced by cattle in this period is not stored and is not spread in autumn. Moreover, manure may not be applied at places where no crops are grown in wintertime. Due to changes in the temperature and the ventilation rate (for housings with mechanical ventilation) the emission rate during the summer, under otherwise the same circumstances, is likely to be a factor 2 to 4 higher than the average emission rate in wintertime. This variation is, however, not taken into account in the computations below, as it is rather uncertain.

From the emission factors for The Netherlands, which are split up into emission factors for emission from stables+storage, spreading and grazing, and information on occurrence of these activities (Table 14) a seasonal variation in the NH_3 emission rate for The Netherlands is estimated (Fig. 8). This information is only valid for the year 1989, because later additional measures to reduce the emission came into force. In the figure and in the table it was taken into account that the emission from spreaded manure from pigs and poultry was reduced by 28% in 1989, because it was obligatory to plough shortly after spreading, which reduces the emissions (van der Hoek, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm., 1991).

Analysis of the data shows that the computed seasonal variation in the emission rate shows two distinct peaks. The peak in March is caused by spreading of the manure collected in wintertime, whereas the peak in September-October is caused by spreading of manure collected in summertime. The second peak is not so high as the first one, because there is no contribution from the spreading of manure from cattle as they have been outside during summertime. The ratio between the highest and lowest monthly averaged relative emission rate is about 5.
It is likely that the seasonal variation in the NH_3 emission rate in Europe will show the same tendency as in The Netherlands, but peaks may occur earlier or later and be higher or lower.

Kruse *et al.* (1989) also present information on the seasonal variation in the NH_3 emission rate based on information on agricultural practice but for the U.K. They divide the year into 4 periods and find a maximum difference of a factor two between these periods. The highest emission rate is found for March-May, and the lowest is found for December-February, which agrees well with the information presented above.

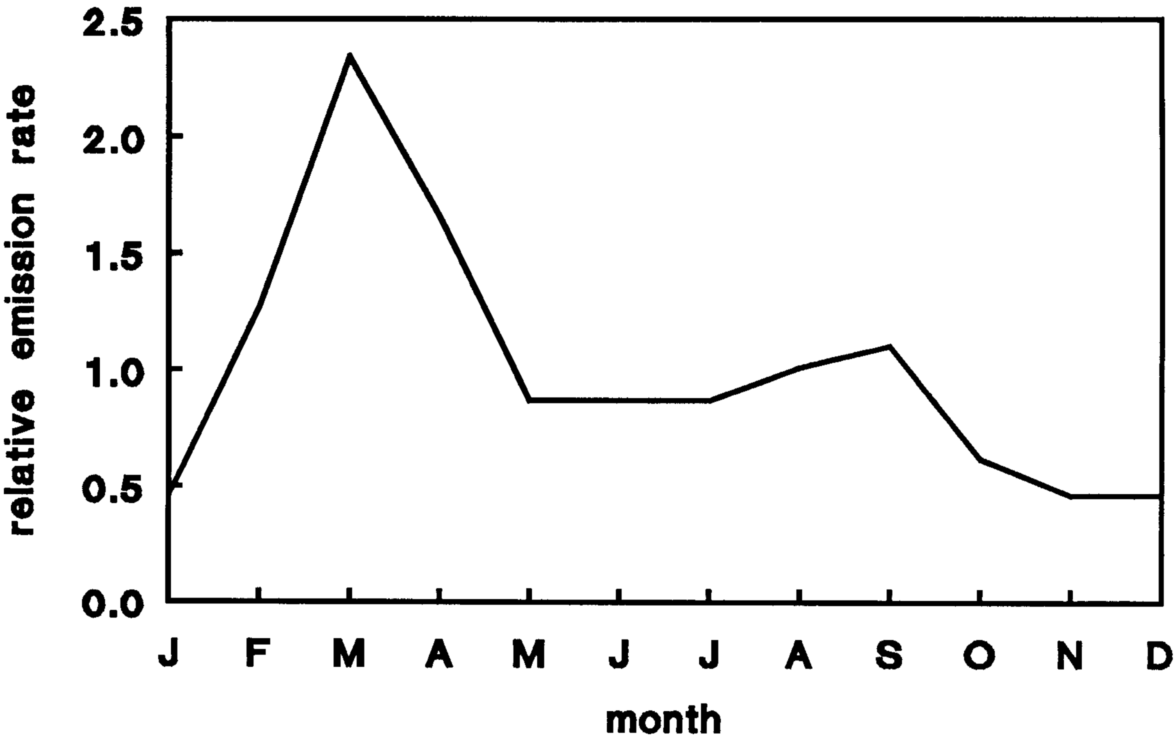

Fig. 8. Seasonal variation in the emission rate from information on agricultural practice, 1989, The Netherlands. (average value = 1)

10.2. Seasonal variation from measurements

The seasonal variation in the NH_3 emission derived from agricultural information should be so large that it should be easy to detect this variation also in measurements. Measurements may, however, be difficult to interpret as they are also influenced by meteorological conditions, like wind-speed, mixing height, wind-direction and rainfall. Wind-direction is in this respect an important parameter because it determines the sources which can influence concentrations at the receptor point. Moreover, seasonal variations in the conversion rate of NH_3, surface resistance to NH_3 and NH_4^+ aerosol, and the scavenging ratio's of NH_3 and NH_4^+ aerosol can also influence the concentrations and depositions. Asman and van Jaarsveld (1990, 1992) showed in a sensitivity study, that an uncertainty of a factor 2 in these parameters can lead to an uncertainty of 20-30% in the model results.

Until now it is only possible to correct the measured concentrations and depositions for the meteorological conditions. This is done by dividing the measured values for a station by the modelled values. By doing this for every month, the seasonal variation in this ratio is obtained, which is still not only influenced by the seasonal variation of the NH_3 emission rate, but also by the seasonal variation in other, atmospheric, processes.

It was decided to consider only measurements in The Netherlands because the meteorological statistics needed for each month was only available for The Netherlands. Meteorological statistics for short periods like a month would be less representative for a larger area than The Netherlands. Moreover, a detailed (5x5 km^2) NH_3 emission inventory is available for The Netherlands, which is also needed to model the NH_3 concentrations, which are determined to a large extent by local emissions. The model calculations were made with a statistical transport model (Asman and van Jaarsveld, 1990, 1992). Allmost all NH_3 in the air in The Netherlands originate from domestic sources. For NH_4^+ aerosol and wet deposition of NH_x the contribution from domestic sources is about 50%, and an additional 20-30% is from sources in Belgium and the F.R.G. (Asman and van Jaarsveld, 1990). The NH_4^+ aerosol concentration and the wet deposition of NH_x reflect therefore more the emission and atmospheric processes over a larger area than The Netherlands.

The ratio measured vs. modelled NH_3 concentrations was computed for 5 stations in The Netherlands for which daily measurements were available for the period 1983-1985 (Fig. 9; Erisman *et al.*, 1986). From Fig. 9 it appears that the seasonal variation in the ratio measured vs. modelled concentrations is rather different for different stations. The reason for this may be the influence of nearby sources, because the emission inventory is not detailed enough and/or spreading of manure takes place in other months than expected and/or errors in the measurements occur. Therefore, these measurements of the NH_3 concentration are not very suitable to derive seasonal variations in emission rate from. Fig. 10 shows the seasonal variation of the ratio measured vs. modelled NH_4^+ aerosol concentrations for the EMEP stations Bilthoven and Witteveen. It appears that this ratio shows a similar pattern for both stations for all years: the ratio is highest in spring and lowest in autumn and winter. But there certainly exist differences between the results for different years, reflecting differences in the rates of the processes involved for different years.

The ratio measured vs. modelled monthly NH_x wet deposition averaged over the period 1978-1986 was computed for 12 stations in The Netherlands. Wet deposition of NH_x is

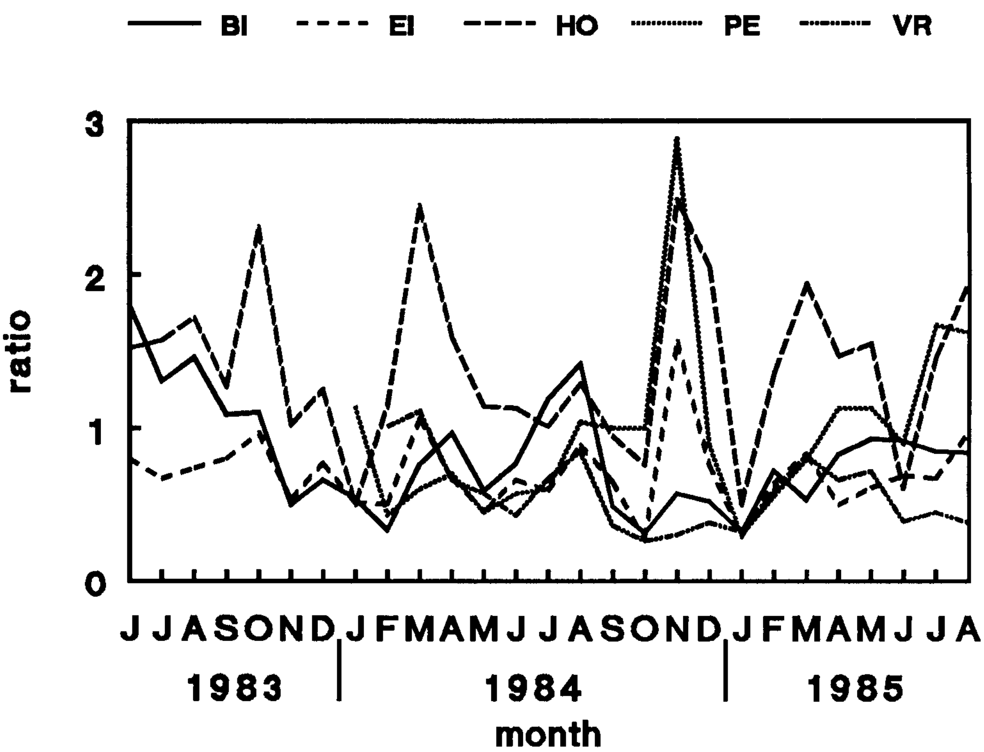

Fig. 9. Seasonal variation ratio measured vs. modelled NH_3 concentrations for different stations in the Netherlands. BI = Bilthoven; EI = Eibergen; HO = Houtakker; PE = Petten; VR = Vredepeel.

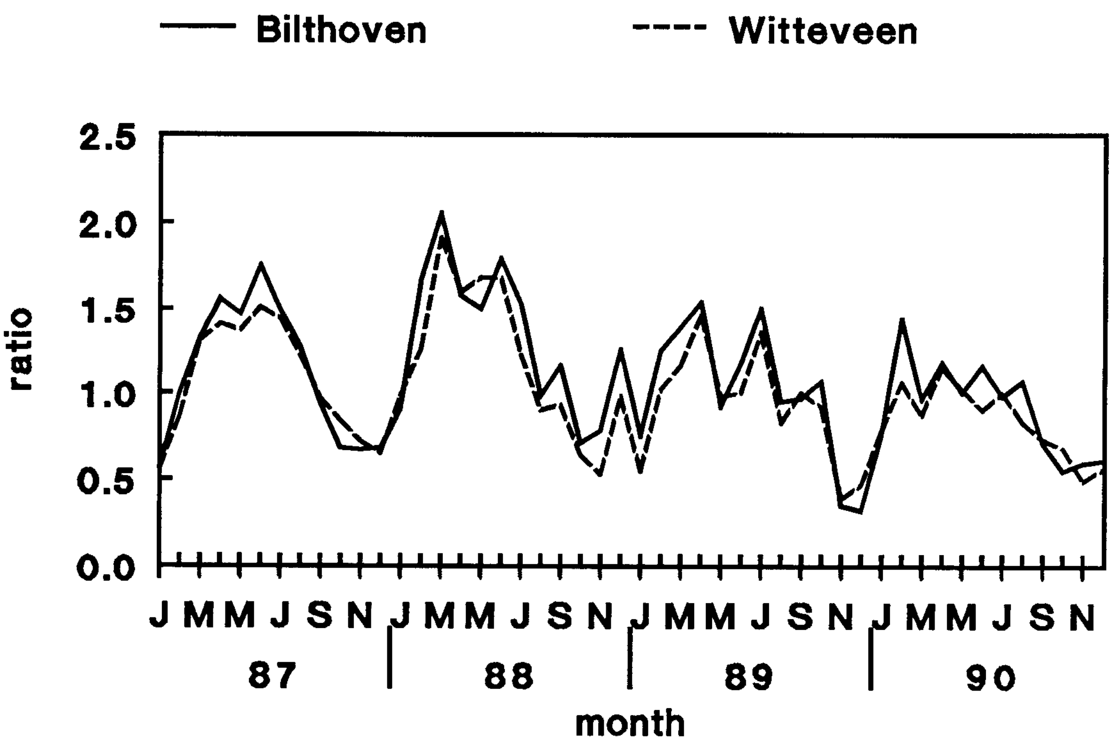

Fig 10. Seasonal variation ratio measured vs. modelled NH_4^+ aerosol concentration for two EMEP stations in the Netherlands.

measured as NH_4^+ but is caused by scavenging of both NH_3 and NH_4^+ aerosol. Therefore the term NH_x is used in this case. There does not exist a large seasonal variation in the amount of precipitation for this period, which could have influenced the wet deposition. The measured values were reduced by 25% to correct for dry deposition in the bulk collectors (E. Buijsman, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm.). The ratio measured vs. modelled monthly wet deposition of NH_x for each station is presented in the Figs A5-1 to A5-12 in Appendix 5. It appears that apart from three coastal stations, the ratio shows the same tendency at all stations: a maximum in spring and summer and minimum in autumn and winter.

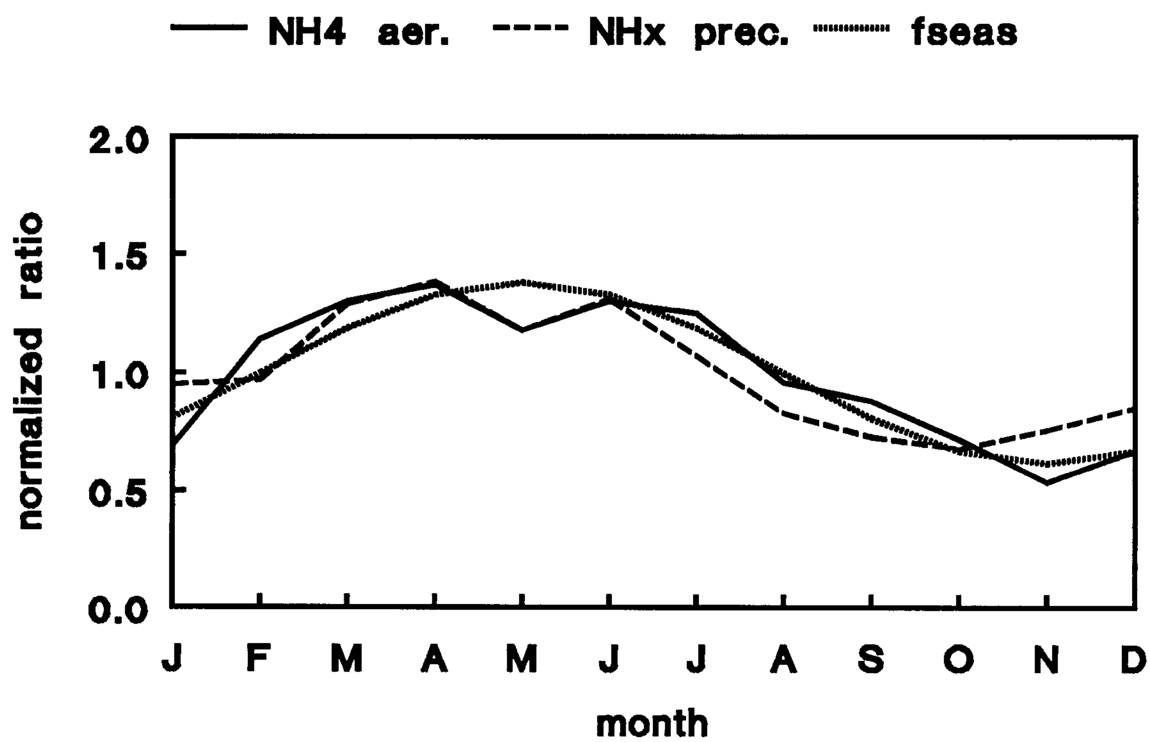

Fig. 11. Normalized seasonal variation in the ratio measured vs. modelled NH_4^+ aerosol concentration and wet deposition of NH_x (annually average value = 1) and function f_{season}.

Fig. 11 shows the seasonal variation of the average ratio measured/modelled values for the NH_4^+ aerosol concentration (2 stations) and wet deposition of NH_x (12 stations). The ratio's are normalized in such a way that the annually averaged ratio was exactly made equal to 1.00. The corrections which had to be made were, however, very small: 5% for the NH_4^+ aerosol concentration and 12% for the wet deposition of NH_x, being the difference between the annually average for measured and modelled. It appears that the seasonal variations of the ratio's for the two components are very similar and can be approached by the following function f_{season}:

$$f_{season} = 1 + 0.38\sin\left(\frac{2\pi(d-45)}{12}\right) \qquad (8)$$

Where: d = Julian day number.

10.3. Comparison of the two methods to estimate the seasonal variation

Fig. 12 shows the seasonal variations derived from measurements and from agricultural practice. The variations derived from measurements are averages for several years, whereas the variation derived from agricultural practice is strictly spoken only valid for 1989 and will be slightly different for other years, because of differences in agricultural practice. The figures agree reasonably well for wintertime, but there exist three striking differences:

a. A descrepancy in March, when the emission derived from agricultural practice is much higher.

b. A difference in summertime, when the emission derived from measurements is somewhat higher.

c. A difference in September, when the "second peak" is not found in the measurements.

With the present knowledge it is impossible to explain descrepancy a. There is no doubt that the emission must show a peak in this month, because a large fraction of the manure which is spread. One reason could be that the reaction rate of NH_3 to NH_4^+ or the dry deposition rate of NH_3 could be different. A hypothesis could be, that the emission rate is so high during (parts of) this month that not enough acid is present or can react with NH_3 to form NH_4^+. As a result the lifetime of NH_3 could be longer than average, resulting in a relative high dry deposition of NH_3, which was not measured on a regular basis. As a result NH_4^+ concentrations in air and wet deposition of NH_x could be lower than otherwise could be the case.

A second reason could be that farmers spread just before they expect rain to occur, which greatly reduces the emission. On the other hand this could also be the case during other months. The smaller difference during summertime could well be explained by the general tendency of higher emission rates at higher temperatures and perhaps by emission from plants. The difference in September is maybe not significant.

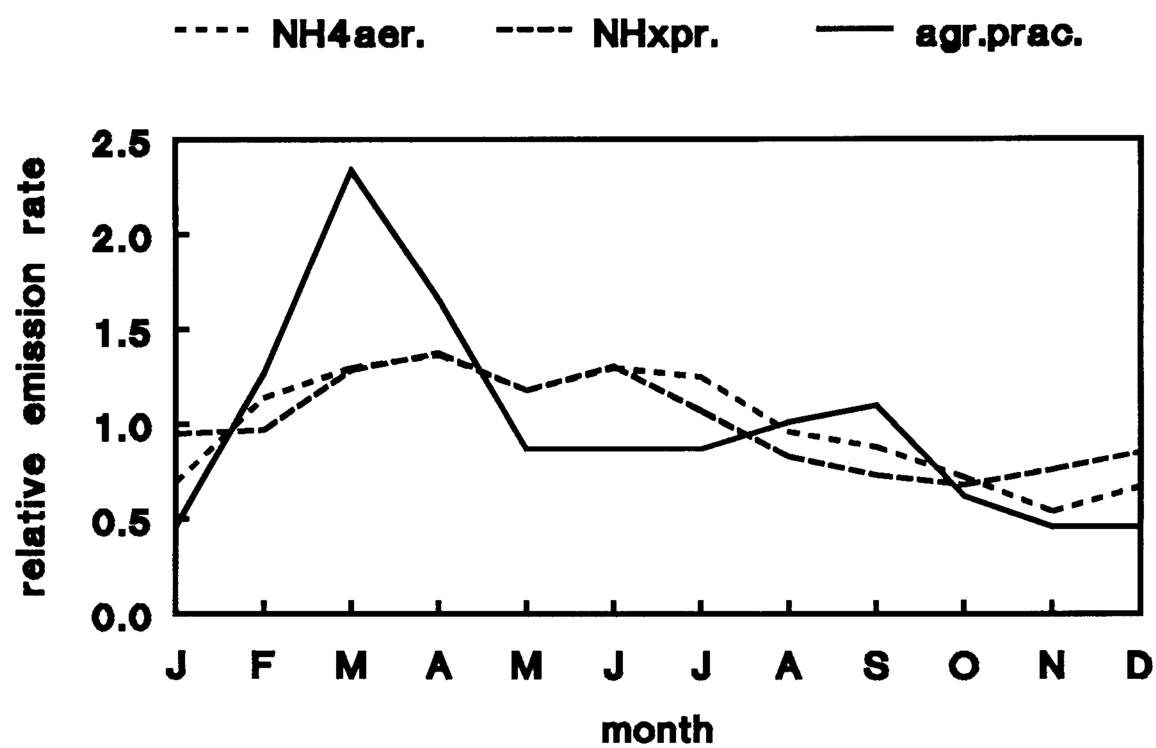

Fig. 12. Comparison of the seasonal variation in the emission rate derived from measurements of NH_4^+ in aerosol and precipitation and from agricultural practice.

11. CONCLUSIONS AND DISCUSSION

The NH_3 emissions in Europe have been recomputed in a more consequent way using recent information on the number of animals, consumption of fertilizers as well as on emission factors. These emissions are for Europe as a whole 21% higher than computed by Buijsman *et al.* (1987). The uncertainty in the emissions is of the order of 30-40% and is difficult to reduce because statistics on the (local) agricultural practice (housing system, time of spreading etc.), soil type and meteorology should be known.

The relative diurnal variation in the emission rate of NH_3 from land can be computed from theoretical considerations on chemical equilibria and standard meteorological measurements. This variation is in agreement with the measured diurnal variation in the emission rate from fields spread with manure, urine or fertilizer. Less is, however, known about the less important emissions from stables and storage facilities. There exist almost no measurements with a high time-resolution for NH_x components, so that it is not known how diurnal variations in the NH_3 emission are reflected in the diurnal variations of the concentrations of these components. The modelled diurnal variation in the NH_3 concentration at one site in The Netherlands using the relative diurnal variation suggested in this report agreed well with the measured variation.

The expression derived for the relative diurnal variation in the NH_3 emission can easily be put into transport models as the basic information to be used. It is derived from standard meteorological measurements, which usually already are used in models.

The seasonal variation of the NH_3 emission rate was computed from information on the seasonal variation in the agricultural activities and from information on the agricultural practice. The seasonal variation derived from measured concentrations or depositions, corrected for meteorological conditions, was much lower than the first one. This descrepancy cannot be explained yet. Until more information is known the seasonal variation derived from measurements could be used.

Although much more is known about the NH_3 emission in Europe than 10 years ago, there still exists a lack of knowledge on (in arbitrary order):

- Emission from stables, especially naturally ventilated stables.
- Emission in cities. At the moment the emission in cities in emission surveys are non-existant apart from some industrial emissions. This is not very realistic, although emissions in cities will not contribute much to the emissions of a country.
- Emission from plants. Although this emission is certainly not dominating on an annual basis, it cannot yet be excluded that they are dominating in summertime.
- Emission from other natural sources like wildlife.
- Diurnal variation in NH_3 and NH_4^+ concentrations in air, which could lead to a deeper understanding of spatial, diurnal and seasonal variations in the emission rate. Fortunately there exist methods now to measure NH_3 continuously, even at low concentrations.
- Seasonal variation in the emission.
- Conversion rate of NH_3 to NH_4^+ in the atmosphere (spatial, diurnal and seasonal variation) and dry deposition rate of NH_3 and NH_4^+ (seasonal variation). If more information on these processes were known, it would be possible to find better estimates of the variations in the NH_3 emission rate by comparing model results and measurements.

Information how to obtain the gridded emission survey

The gridded emission survey can be obtained from Willem A.H. Asman, Assensvej 6, 4000 Roskilde, Denmark. An additional survey for the other part of the USSR and for Mediterranean will probably be made in the course of 1992.

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REFERENCES

ApSimon H.M, Kruse M. and Bell J.N.B. (1987) Ammonia emissions and their role in acid deposition. *Atmospheric Environment* **21**, 1939-1946.

Asman W.A.H. (1990) A detailed ammonia emission inventory for Denmark. Report DMU LUFT-A133, National Environmental Research Institute, Roskilde, Denmark.

Asman W.A.H. and van der Hoek K.W. (1992) A new ammonia emission inventory for Europe: emission factors and diurnal and seasonal variations. Article intended for publication in Atmospheric Environment.

Asman W.A.H. and van Jaarsveld J.A. (1990) A variable-resolution statistical transport model applied for ammonia and ammonium. Report No. 228471007, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands.

Asman W.A.H. and van Jaarsveld (1992) A variable-resolution transport model applied for NH_x for Europe. *Atmospheric Environment* **26A**, 445-464.

Bates R.G. and Pinching G.D. (1950) Dissociation constant of aqueous ammonia at 0 to 50 C from E.m.f. studies of the ammonium salt of a weak acid. *Am. Chem. J.* **72**, 1393-1396.

Beauchamp E.G., Kidd G.E. and Thurtell G. (1982) Ammonia volatilization from liquid dairy cattle manure in the field. *Can. J. Soil Sci.* **62**, 11-19.

Bónis K. (1981) A nitrogénvegyületek légköri mérlege Magyarország fölött (The atmospheric budget of nitrogen compounds over Hungary, in Hungarian). *Időjárás* **85**, 149-156.

British Sulphur Corporation (1987) *World fertilizer atlas*, 8th Edition, British Sulphur Corporation, London, pp. 117.

Buijsman E. (1987) Ammonia emission calculation, fiction and reality. In: Asman W.A.H. and Diederen H.S.M.A. (eds.): *Ammonia and acidification. Proceedings EURASAP symposium*, Bilthoven, The Netherlands, 13-15 April 1987.

Buijsman E., Maas J.F.M. and Asman W.A.H. (1984) Een gedetailleerde ammoniak-emissiekaart van Nederland (A detailed ammonia emission map of The Netherlands. In Dutch with summary in English) Report V-84-20, Institute for Meteorology and Oceanography, State University Utrecht, The Netherlands.

Buijsman E., Maas J.F.M. and Asman W.A.H. (1985) Ammonia emission in Europe. Report R-85-1, IE-annex, Institute for Meteorology and Oceanography, State University Utrecht, The Netherlands, pp. 197.

Buijsman E., Maas J.F.M. and Asman W.A.H. (1987) Anthropogenic NH_3 emissions in Europe. *Atmospheric Environment* **21**, 1009-1022.

Dasgupta P.K. and Dong S. (1986) Solubility of ammonia in liquid water and generation of trace levels of standard gaseous ammonia. *Atmospheric Environment* **20**, 565-570.

De Winkel K. (1988) Ammoniak-emissiefactoren voor de veehouderij (Emission factors for ammonia from livestock, In Dutch). Report Lucht-76, Ministry of Housing, Physical Planning and Environment, Leidschendam, The Netherlands.

Duyzer J.H., Bouman A.M.H., Diederen H.S.M.A. and van Aalst R.M. (1987) Measurements of dry deposition velocities of NH_3 and NH_4^+ over natural terrains. Report R 87/273, TNO Division for Society, Delft, The Netherlands.

Erisman J.-W. (1989) Ammonia emissions in The Netherlands in 1987 and 1988. Report 228471006, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands.

Erisman J.-W., Vermetten A.W.M., Asman W.A.H., Mulder W., Slanina J. and Waijers-Ypelaan A. (1986) Ammoniak en ammonium koncentraties in de Nederlandse buitenlucht (ammonia and ammonium concentrations over The Netherlands, in Dutch with summary in English). Report R-86-3, Institute for Meteorology and Oceanography, State University Utrecht, The Netherlands.

Fabry H., Leibold R. and Rüsseler M. (1990) Emissionen von Ammoniak, Quellen, Verbleib, Wirkungen, Schutzmassnahmen. Report Bundesamt für Ernährung und Forstwirtschaft, Frankfurt/M, F.R.G.

FAO (1989) *Production yearbook 1989*, Vol. 43, Rome, Italy.

Farquhar G.D., Firth P.M., Wetselaar R. and Weir B. (1980) On the gaseous exchange of ammonia between leaves and the environment: Determination of the ammonia compensation point. Plant Physiol. **66,** 710-714.

Fenn L.B. and Hossner L.R. (1985) Ammonia volatilization from ammonium or ammonium-forming nitrogen fertilizers. In: Stewart B.A., *Advances in soil science*, Springer Verlag, New York, USA.

Harper L.A., Sharpe R.R., Langdale G.W. and Giddens J.E. (1987) Nitrogen cycling in a wheat crop: soil, plant, and aerial nitrogen transport. Agron. J. **79,** 965-973.

Healy T.V., MacKay H.A.C., Pilbeam A. and Scargill D. (1970) Ammonia and ammonium sulphate in the troposhere over the United Kingdom. *J. geophys. Res.* **75,** 2317-2321.

Hoffman M.R. and Jacob D.J. (1984) Kinetics and mechanics of the catalytic oxidation of dissolved sulfur dioxide in aqueous solution: an application to night-time fog water chemistry. In: Calvert J.G., *SO_2, NO and NO_2 oxidation mechanisms: atmospheric considerations* , Butterworths, Boston, USA.

IFA (1990a) World fertilizer consumption statistics, No. 22, 1986/87 to 1988/89, International Fertilizer Industry Association Limited (IFA), Paris, France.

IFA (1990b) Nitrogen fertilizer statistics 1984/85 to 1988/89, International Fertilizer Industry Association Limited (IFA), Paris, France.

Isermann K. (1990) Ammoniakemissionen der Landwirtschaft als Bestandteil ihrer Stickstoffbilanz und Lösungsansätze zur hinreichenden Minderung. In: *Ammoniak in der Umwelt*, KTBL, Darmstadt-Kranichstein, FRG, 1-1 to 1-76.

Jarvis S.C. and Pain B.F. (1990) Ammonia volatilisation from agricultural land. Proceedings No. 298, The Fertiliser Society, London, U.K.

Klaasen G. (1990) Emissions of ammonia in Europe. Working Paper WP-90-68, IIASA, Laxenburg, Austria.

Klarenbeek J.V. (1987) Ammonia emissions from livestock operations in The Netherlands. In: Asman W.A.H. and Diederen H.S.M.A. (Eds.): *Ammonia and acidification. Proceedings EURASAP Symposium*, Bilthoven, The Netherlands, 13-15 April 1987.

KNMI (1968) Klimatologische gegevens van Nederlandse stations. No 1. Normalen voor het standaardtijdvak 1931-1960 (Climatological data from stations in The Netherlands. No.1 Standard values for the period 1931-1960, In Dutch). Report Royal Netherlands Meteorological Institute, De Bilt, The Netherlands.

Kruse M., ApSimon H.M. and Bell J.N.B. (1989) Validity and uncertainty in the calculation of an emission inventory for ammonia arising from agriculture in Great Britain. *Environ. Pollut.* 56,237-257.

LEI/CBS (1990) Landbouwcijfers 1990 (Agricultural Statistics, in Dutch), Netherlands Central Bureau of Statistics, The Hague, The Netherlands.

Ministry of Housing, Physical Planning and Environment (1983) *Handbook of emission factors, part 2: Industrial sources.* Government Publishing Office, The Hague, The Netherlands.

Möller D. and Schieferdecker H. (1982) Zur Rolle des atmosphärischen Ammoniaks im biogeochemischen Stickstoff-Kreislauf. *Z. ges. Hyg.* **28,** 797-802.

Möller D. and Schieferdecker H. (1985) On a relationship between agricultural NH_3 emissions and the atmospheric SO_2 content. *Atmospheric Environment* **19,** 695-700.

Möller D. and Schieferdecker H. (1989) Ammonia emission and deposition of NH_x in the G.D.R. *Atmospheric Environment* **23**, 1187-1193.

Niskanen R., Keränen S. and Pipatti R. (1990) Ammonia emissions in the 1980s. In: Kauppi P., Antilla P. Kenttämies (Eds.): *Acidification in Finland*, Springer Verlag, Berlin, 29-39.

Royal Society (1983) *The nitrogen cycle of the United Kingdom, A study Group Report.* The Royal Society, London, U.K.

Ryden J.C., Whitehead D.C., Lockyer D.R., Thompson R.B., Skinner J.H. and Garwood E.A. (1987) Ammonia emission from grassland and livestock prodiction systems in the U.K. *Environ. Pollut.* **48,** 173-184.

Schjørring J.K. (1991) Ammonia emission from the foliage of growing plants. In: Sharkey T.D., Mooney H.A. and Holland E.A. (Eds.) *Trace gas emissions by plants*, Academic Press, New York, USA, in press.

Seinfeld J.H. (1986) *Atmospheric chemistry and physics of air pollution,* John Wiley, New York, 204.

Sommer S. (1985) Kvælstofkredsløbet via atmosfæren (Nitrogen cycle via the atmosphere, in Danish), Report Miljøstyrelsens Center for Jordøkologi, Søborg, Denmark.

STATEC (1989) Recensement agricole du 15 Mai 1989. Service Central de la Statistique et des Etudes Economiques, Luxemburg.

Statistical Bureau of the USSR (1988) Narodnoe chozajstvo SSSR 1987, Mosow, USSR.

Sutton M.A., Moncrieff J.B. and Fowler D. (1992) Deposition of atmospheric ammonia to moorlands. *Environ. Pollut.* **75,** 15-24.

Van der Hoek K.W. (1991) Emission factors for ammonia in The Netherlands. Paper presented at the "Workshop on Ammonia Emissions in Europe: Emission Factors and Abatement costs, IIASA, Laxenburg, Austria, Febr. 4-6.

Van der Molen J., van Faassen H.G., Leclerc M.Y., Vriesema R. and Chardon W.J. (1990) Ammonia volatilization from arable land after application of cattle slurry; 1. Field estimates. *Neth. J. Agric. Sci.* **38,** 145-148.

Wagman D.D. Evans W.H. Halow I.,Parker V.B.,Bailey S.M. and Schumm R.H. (1965) Selected values of chemical thermodynamic properties. Part I. Tables for the first twenty-three elements in the standard order of arrangement,Technical Note 270-1, National Bureau of Standards, Washington D.C., pp. 124.

Whitehead D.C. and Lockyer D.R. (1989) Decomposing grass herbage as a source of ammonia in the atmosphere. *Atmospheric Environment* **23,** 1867-1869.

Whitehead D.C. and Raistrick N. (1990) Ammonia volatilization from five nitrogen compounds used as fertilizers following surface application to soils. *J. of Soil Science* **41**, 387-394.

Závodský D. and Mitošinková M. (1984) Estimation of atmospheric budget of nitrogen compounds over Czechoslovakia. *Idöjárás* **88,** 202-209.

Table 1. Apparent emission factors used by Buijsman *et al.* (1987) for different countries ($kg\ NH_3\ animal^{-1}\ a^{-1}$).

Country	Cattle	Pigs	Poultry	Horses[1)]	Sheep[2)]
Albania	18.20	2.83	0.26	9.43	6.43
Austria	21.09	1.32	0.22	9.30	1.86
Belgium	18.97	2.11	0.23	9.51	3.07
Bulgaria	18.69	2.83	0.26	9.43	3.07
Czechoslovakia	17.67	2.83	0.26	9.43	3.08
Denmark	21.57	2.17	0.25	10.75	3.09
Finland	18.09	3.02	0.30	10.96	2.71
France	18.96	2.19	0.21	9.53	3.11
Germany D.R.	18.20	2.83	0.26	9.48	3.08
Germany F.R.	16.81	2.12	0.24	10.12	2.99
Greece	18.21	2.60	0.26	9.44	3.08
Hungary	18.20	2.83	0.26	9.43	3.07
Ireland	13.85	1.91	0.22	12.66	2.84
Italy	18.74	2.18	0.26	9.12	3.02
Luxemburg	18.87	2.01	0.26	13.31	3.47
Netherlands	16.61	2.10	0.18	3.20	3.12
Norway	19.29	2.77	0.21	8.96	2.64
Poland	18.20	2.83	0.26	9.43	3.08
Portugal	18.20	2.83	0.26	9.59	3.08
Romania	18.09	2.82	0.26	9.43	3.06
Spain	18.08	2.82	0.26	9.39	3.05
Sweden	17.46	2.84	0.26	9.43	3.08
Switzerland	21.17	2.04	0.25	10.72	2.58
UK	13.65	1.80	0.29	9.43	2.28
Yugoslavia	19.48	1.87	0.25	9.41	3.14
Turkey	23.18	7.87	0.25	9.21	3.08
USSR*	18.20	2.83	0.26	12.57	3.08
Whole area	18.29	2.49	0.25	10.06	2.97

[1)] Includes mules and asses.
[2)] Includes goats.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 2. Number of animals in European countries in 1989 (1000 heads) from FAO (1989).

Country	Cattle	Pigs	Poultry	Horses[1)]	Sheep[2)]
Albania	707	201	5000	116	2661
Austria	2541	3874	14000	44	288
Belgium	2752	5874	34913	22	190
Bulgaria	1636	4119	41000	475	9043
Czechoslovakia	5075	7384	48000	44	1097
Denmark	2226	9105	16000	29	86
Finland	1379	1327	6000	36	62
France	21780	12480	222000	306	13104
Germany D.R.	5710	12464	49000	102	2653
Germany F.R.	14659	22589	76000	363	1516
Greece	732	1226	31000	311	16346
Hungary	1690	8327	60000	81	2231
Ireland	5637	961	9000	75	5000
Italy	8842	9359	151000	386	12837
Luxemburg	215	76	87	2	8
Netherlands#	4771	13729	91430	67	1447
Norway	932	750	4000	16	2340
Poland	10733	18835	66000	1005	4419
Portugal	1359	2326	23000	276	6099
Romania	7380	15400	149000	736	19800
Spain	5050	16100	55000	471	26897
Sweden	1662	2320	11000	58	396
Switzerland	1850	1869	6000	51	420
UK	11902	7626	138000	189	29107
Yugoslavia	4759	7396	73000	358	7564
Turkey	12540	10	62000	2030	47950
USSR*	43800	33300	417700	1639	20800
Total	182319	219027	1859130	9288	234361

1) Includes mules and asses.
2) Includes goats.

#For The Netherlands information from LEI/CBS (1990) was used, to make this survey compatible with the survey for The Netherlands. The differences between these numbers and the numbers given by the FAO are, however, very small.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 3. Number of animals and annually averaged emission factors for livestock subcategories in The Netherlands in 1989 (kg NH_3 animal^{-1} yr^{-1}).

From LEI/CBS(1990) and van der Hoek (National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm., 1991).

CBS no	Subcategory	Number	Stable+ storage	Spread.	Grazing	Total
201-209	Young cattle	1602000	3.870	6.340	2.830	13.040
211	Dairy and calf cows	1913000	12.870	21.090	5.760	39.720
213	Breeding bulls > 2 yr.	40000	10.580	17.330	0.000	27.910
215	Fattening calves	597000	1.600	3.630	0.000	5.230
217-227	Young cattle for fattening	536000	5.760	9.430	0.000	15.190
229	Fattening/grazing cattle > 2 yr.	83000	0.000	0.000	8.220	8.220
235-237	Piglets < 20 kg (included in 239)	5088000	0.000	0.000	0.000	0.000
239-241	Fattening pigs	6976000	3.180	3.800	0.000	6.980
243	Breeding sows 20-50 kg	159000	2.420	2.800	0.000	5.220
245	Breeding sows > 50 kg	217000	8.090	8.040	0.000	16.130
247-251	Other sows	1248000	8.090	8.040	0.000	16.130
253	Boars > 50 kg	13000	3.180	3.800	0.000	6.980
255	Mature boars	28000	5.520	5.480	0.000	11.000
260-263	Horses and ponies	66674	3.900	3.600	4.700	12.200
265	Lambs (included in 266)	740000	0.000	0.000	0.000	0.000
266	Ewes	649000	0.700	1.280	1.390	3.370
268	Rams (included in 266)	16000	0.000	0.000	0.000	0.000
269	Broilers	37995000	0.065	0.102	0.000	0.167
271	Mother animals < 6 months	3138000	0.141	0.128	0.000	2.690
273	Mother animals > 6 months	4305000	0.315	0.283	0.000	0.598
275	Laying hens < 18 weeks	10908000	0.050	0.120	0.000	0.170
276-278	Laying hens > 18 weeks	33442000	0.100	0.205	0.000	0.305
282	Milch goats	42000	2.300	4.100	0.000	6.400
284	Other goats (included in 282)*	0	0.000	0.000	0.000	0.000
287	Ducks	713000	0.117	0.000	0.000	0.117
291	Turkeys for slaughter	888000	0.429	0.429	0.000	0.858
293	Turkeys < 7 months	21000	0.445	0.445	0.000	0.890
295	Turkeys > 7 months	20000	0.639	0.639	0.000	1.278

*No number known from statistics.

Table 4. Ammonia emission in The Netherlands*, 1989 (tonne NH_3 yr^{-1}). This table is derived from Table 3.

(Sub)category		Stable + storage	Spreading	Grazing	Sum
201-209	Young cattle	6200	10157	4534	20890
211	Dairy and calf cows	24620	40345	11019	75984
213	Breeding bulls > 2 yr.	423	693	0	1116
215	Fattening calves	955	2167	0	3122
217-227	Young cattle for fattening	3087	5054	0	8142
229	Fattening/grazing cattle > 2 yr.	0	0	682	682
Sum emission from cattle		35286	58417	16235	109937
235-237	Piglets < 20 kg (included in 239)	0	0	0	0
239-241	Fattening pigs	22184	26509	0	48692
243	Breeding sows 20-50 kg	385	445	0	830
245	Breeding sows > 50 kg	1756	1745	0	3500
247-251	Other sows	10096	10034	0	20130
253	Boars > 50 kg	41	49	0	91
255	Mature boars	155	153	0	308
Sum emission from pigs		34616	38935	0	73552
269	Broilers	2470	3875	0	6345
271	Mother animals < 6 months	442	402	0	844
273	Mother animals > 6 months	1356	1218	0	2574
275	Laying hens < 18 weeks	545	1309	0	1854
276-278	Laying hens > 18 weeks	3344	6856	0	10200
287	Ducks	83	0	0	83
291	Turkeys for slaughter	381	381	0	762
293	Turkeys < 7 months	9	9	0	19
295	Turkeys > 7 months	13	13	0	26
Sum emission from poultry		8644	14063	0	22707
260-263	Horses and ponies	260	240	313	813
Sum emission from horses		260	240	313	813
265	Lambs (included in 266)	0	0	0	0
266	Ewes	454	831	902	2187
268	Rams (included in 266)	0	0	0	0
282	Milch goats	97	172	0	269
284	Other goats (included in 282)	0	0	0	0
Sum emission from category sheep		551	1003	902	2456
Total		79357	112658	17450	209466

* In this table no emission reductions due to regulations are taken into account, because these emissions are used to derive emission factors to compute emissions for Europe.

Table 5. Annually averaged emission factors for livestock categories for Europe (kg NH_3 $animal^{-1}$ yr^{-1}). This table is derived from Table 3.

Category	Stable+ storage	Spreading	Grazing	Total
Cattle	7.396	12.244	3.403	23.043
Pigs	2.521	2.836	0.000	5.357
Poultry	0.095	0.154	0.000	0.248
Horses	3.900	3.600	4.700	12.200
Sheep	0.381	0.693	0.623	1.697

Table 6. Consumption of N-fertilizers in Europe in 1988/1989 (1000 tonne N yr^{-1}). Source: IFA (1990a).

Country	ammsul	urea	ammni	camni	ammon	N-sol	o-sN	tot-sN	amphos	o-NP-N	NK-N	NPK-N	tot-cN	Total
Albania	0.0	31.0	38.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.3
Austria	0.3	2.1	0.0	86.4	0.0	0.0	0.1	0.0	2.3	0.0	0.0	50.6	0.0	141.8
Belgium	2.7	0.9	0.0	126.4	0.0	0.0	4.6	0.0	0.0	0.0	0.0	44.9	0.0	179.5
Bulgaria	7.4	114.6	185.0	0.0	0.0	128.0	0.0	0.0	0.0	0.0	0.0	0.0	113.0	548.0
Czechoslovakia	46.2	76.3	92.2	150.3	1.1	116.9	16.6	0.0	6.9	13.3	0.0	124.6	0.0	644.4
Denmark	0.5	5.2	0.0	106.7	80.3	0.0	4.2	0.0	1.5	0.7	0.4	177.4	0.0	376.9
Finland	0.0	2.6	0.0	22.4	0.0	0.0	0.2	0.0	0.0	3.8	0.0	182.2	0.0	211.2
France	41.2	259.5	1081.2	0.0	50.8	536.9	4.7	0.0	0.0	92.9	0.0	537.0	0.0	2604.2
Germany D.R.	165.0	234.0	0.0	354.0	17.0	56.6	0.0	0.0	0.0	0.0	0.0	0.0	46.6	873.2
Germany F.R.	4.2	105.7	0.0	1082.4	0.0	0.0	9.2	0.0	0.0	70.5	0.0	267.9	0.0	1539.9
Greece	41.1	9.1	110.6	51.6	0.0	0.0	0.0	0.0	0.0	152.5	2.3	37.0	0.0	404.2
Hungary	0.4	185.1	233.4	85.7	4.2	19.1	5.7	0.0	0.0	4.3	0.0	108.4	0.0	646.3
Ireland	2.0	55.0	0.0	119.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	169.0	349.0
Italy#	60.0	373.0	0.0	220.0	1.0	6.0	19.0	0.0	59.0	67.0	2.0	180.0	0.0	987.0
Luxemburg	0.3	0.1	0.0	11.6	0.0	0.0	0.4	0.0	0.0	0.0	0.0	4.1	0.0	16.5
Netherlands	1.0	2.0	0.0	344.6	2.4	0.0	8.0	0.0	1.0	0.0	0.0	76.0	0.0	435.0
Norway	0.0	0.9	0.6	10.6	0.0	0.0	6.6	0.0	0.0	0.0	2.6	88.8	0.0	110.1
Poland	84.1	421.8	673.8	174.4	0.0	0.6	0.3	0.0	80.9	0.0	0.0	42.7	0.0	1478.6
Portugal	14.6	11.5	2.6	79.7	0.0	1.7	2.2	0.0	1.4	0.0	0.0	42.8	0.0	156.5
Romania	10.0	120.0	340.0	0.0	0.0	60.0	0.0	0.0	0.0	190.0	0.0	0.0	0.0	720.0
Spain	101.4	235.7	200.5	215.0	27.9	51.8	36.7	0.0	40.2	0.0	4.9	207.1	0.0	1121.2
Sweden	0.0	5.4	5.6	65.1	0.7	3.5	63.0	0.0	0.0	12.6	3.7	62.9	0.0	222.5
Switzerland	1.9	17.1	3.0	34.9	0.0	0.0	0.6	0.0	1.5	0.1	0.0	12.4	0.0	71.5
UK	0.0	120.0	700.0	50.0	4.0	70.0	4.0	0.0	0.0	0.0	0.0	514.0	0.0	1462.0
Yugoslavia	0.0	69.0	0.0	225.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	240.0	0.0	540.0
Turkey	91.2	262.6	2.9	423.8	0.0	0.0	0.0	0.0	98.7	210.5	0.0	50.8	0.0	1140.5
USSR*	155.8	1000.4	1611.1	0.0	345.1	360.2	3.5	0.0	242.4	482.9	0.0	257.0	0.0	4458.4
Total	831.3	3720.6	5280.8	4039.6	534.5	1417.3	193.6	0.0	535.8	1301.1	15.9	3308.6	328.6	21507.7

#According to the official Italian statistics the consumption of calcium ammonium nitrate is 206.1 and that of ammonium nitrate is 10.1 (in 1000 tonne N yr^{-1}). This is just opposite the IFA numbers. This does not lead big changes in the emission because the emission factors for both components are the same.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Codes fertilizer

ammsul: ammonium sulphate
urea: urea
amni: ammonium nitrate
camni: calcium ammonium nitrate
ammon: ammonia, directly applied
N-sol: nitrogen solutions
o-sN: other straight nitrogen
tot-sN: total straight nitrogen (only to be used when no information on subcategories is available)
amphos: ammonium phosphate
o-NP-N: other NP-N
NK-N: NK-N
NPK-N: NPK-N
tot-cN: total compound nitrogen (only to be used when no information on subcategories is available)
Total: sum of all categories

Table 7. Emission factors for N fertilizers (% loss of N content).
The factors of this survey are compared with the factors of Buijsman *et al.* (1987).

Category	This survey	Buijsman *et al.* (1987)
Ammonium sulphate	8	15
Urea	15	10
Ammonium nitrate	2	10
Calcium ammonium nitrate	2	2
Ammonia, direct application	1	-
Nitrogen solutions	2.5	-
Other straight nitrogen	2.5	-
Total straight nitrogen	4	-[1)]
Ammonium phosphate	4	5
Other NP N	3	-
NK N	2	-
NPK N	4	-
Compound N	4	1

\- = Emission factor for this category is not given by Buijsman *et al.* (1987).

[1)] = Only used if no information was available on the fertilizer consumption of the individual categories.

Table 8. Emission from N-fertilizers in 1988/1989 (tonne NH_3 yr^{-1}) and % of N in fertilizer which evaporates.

Country	ammsul	urea	amni	camni	ammon	N-sol	o-sN	tot-sN	amphos	o-NP-N	NK-N	NPK-N	tot-cN	Total	%
Albania	0	5646	930	0	0	0	0	0	0	0	0	0	0	6577	7.8
Austria	29	383	0	2098	0	0	3	0	112	0	0	2458	0	5082	3.0
Belgium	262	164	0	3070	0	0	140	0	0	0	0	2181	0	5816	2.7
Bulgaria	719	20874	4493	0	0	3886	0	0	0	0	0	0	5489	35460	5.3
Czechoslovakia	4488	13898	2239	3650	13	3549	504	0	335	485	0	6052	0	35212	4.5
Denmark	49	947	0	2591	975	0	128	0	73	26	10	8617	0	13414	2.9
Finland	0	474	0	544	0	0	6	0	0	138	0	8850	0	10012	3.9
France	4002	47266	26258	0	617	16299	143	0	0	3384	0	26083	0	124051	3.9
Germany D.R.	16029	42621	0	8597	206	1718	0	0	0	0	0	0	2263	71435	6.7
Germany F.R.	408	19253	0	26287	0	0	279	0	0	2568	0	13012	0	61807	3.3
Greece	3993	1658	2686	1253	0	0	0	0	0	5555	56	1797	0	16998	3.5
Hungary	39	33715	5668	2081	51	580	173	0	0	157	0	5265	0	47729	6.1
Ireland	194	10018	0	2890	0	0	121	0	0	0	0	0	8209	21432	5.1
Italy	5829	67939	0	5343	12	182	577	0	2866	2441	49	8743	0	93980	7.8
Luxemburg	29	18	0	282	0	0	12	0	0	0	0	199	0	540	2.7
Netherlands	97	364	0	8369	29	0	243	0	49	0	0	3691	0	12842	2.4
Norway	0	164	15	257	0	0	200	0	0	0	63	4313	0	5013	3.7
Poland	8170	76828	16364	4235	0	18	9	0	3929	0	0	2074	0	111627	6.2
Portugal	1418	2095	63	1936	0	52	67	0	68	0	0	2079	0	7777	4.1
Romania	971	21857	8257	0	0	1821	0	0	0	6921	0	0	0	39829	4.6
Spain	9850	42931	4869	5221	339	1573	1114	0	1953	0	119	10059	0	78028	5.7
Sweden	0	984	136	1581	9	106	1913	0	0	459	90	3055	0	8332	3.1
Switzerland	185	3115	73	848	0	0	18	0	73	4	0	602	0	4917	5.7
UK	0	21857	17000	1214	49	2125	121	0	0	0	0	24966	0	67332	3.8
Yugoslavia	0	12568	0	5464	0	182	0	0	0	0	0	11657	0	29871	4.6
Turkey	8859	47831	70	10292	0	0	0	0	4794	7668	0	2467	0	81983	5.9
USSR*	15135	182216	39127	0	4191	10935	106	0	11774	17591	0	12483	0	293557	5.4
Total	80755	677681	128248	98105	6490	43025	5877	0	26025	47397	386	160703	15961	1290653	4.9

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Codes fertilizer

ammsul:	ammonium sulphate
urea:	urea
amni:	ammonium nitrate
camni:	calcium ammonium nitrate
ammon:	ammonia, directly applied
N-sol:	nitrogen solutions
o-sN:	other straight nitrogen
tot-sN:	total straight nitrogen (only to be used when no information on subcategories is available)
amphos:	ammonium phosphate
o-NP-N:	other NP-N
NK-N:	NK-N
NPK-N:	NPK-N
tot-cN:	total compound nitrogen (only to be used when no information on subcategories is available)
Total:	sum of all categories

Table 9. Production of NH_3[1)] and N fertilizer and related NH_3 emissions 1986. Production statistics are from British Sulphur Corporation (1987). These emissions are **not** part of the gridded emission survey.

Country	Production (1000 tonne N yr^{-1})		Emission (tonne NH_3 yr^{-1})		
	NH_3 pr.	N fert. pr.	NH_3 pr.	N fert. pr.	Total
Albania	91	69	88	347	435
Austria	410	222	398	1108	1505
Belgium	606	666	588	3330	3918
Bulgaria	971	825	942	4123	5064
Czechoslovakia	736	586	714	2929	3642
Denmark	0	191	0	955	955
Finland	80	281	78	1406	1483
France	2592	1615	2514	8075	10589
Germany D.R.	1317	1382	1277	6911	8188
Germany F.R.	2065	919	2003	4593	6596
Greece	498	426	483	2128	2611
Hungary	952	548	923	2742	3665
Ireland	387	252	375	1260	1635
Italy	1216	1202	1180	6010	7190
Luxemburg	0	0	0	0	0
Netherlands	2437	1825	2364	9127	11491
Norway	647	451	628	2254	2881
Poland	2520	1614	2444	8069	10513
Portugal	468	159	454	795	1248
Romania	3904	1920	3787	9600	13387
Spain	700	955	679	4776	5455
Sweden	51	126	49	632	681
Switzerland	33	33	32	166	198
UK	1919	1100	1861	5500	7361
Yugoslavia	1210	629	1174	3144	4318
Turkey	454	854	440	4270	4710
USSR*	9109	5801	8836	29004	37840
Total	35373	24650	34312	123248	157560

[1)] For NH_3 production it is the production capacity, not the production.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 10. Gridded NH_3 emission in European countries in 1989 (tonne NH_3 yr^{-1}) and emission density (tonne NH_3 yr^{-1} km^{-2})#.
Gridded emissions include emissions from livestock and application of fertilizers, but not from other possible sources.

Country	Cattle	Pigs	Poultry	Horses[1)]	Sheep[2)]	Tot.an.	Fertil.	Total	Density
Albania	16291	1077	1242	1415	4516	24542	6577	31118	1.1
Austria	58552	20755	3477	537	489	83809	5082	88891	1.1
Belgium	63414	31469	8671	268	322	104145	5816	109961	3.6
Bulgaria	37698	22067	10183	5795	15348	91091	35460	126551	1.1
Czechoslovakia	116942	39559	11921	537	1862	170821	35212	206034	1.6
Denmark	51293	48779	3974	354	146	104546	13414	117960	2.7
Finland	31776	7109	1490	439	105	40920	10012	50932	0.1
France	501872	66860	55136	3733	22241	649843	124051	773894	1.4
Germany D.R.	131574	66774	12170	1244	4503	216266	71435	287701	2.7
Germany F.R.	337785	121018	18875	4429	2573	484680	61807	546487	2.2
Greece	16867	6568	7699	3794	27743	62672	16998	79670	0.6
Hungary	38942	44611	14902	988	3787	103230	47729	150958	1.6
Ireland	129892	5148	2235	915	8486	146677	21432	168109	2.4
Italy	203745	50140	37502	4709	21788	317884	93980	411863	1.4
Luxemburg	4954	407	22	24	14	5421	540	5961	2.3
Netherlands	109937	73552	22708	817	2456	209470	12842	222312	6.1
Norway	21476	4018	993	195	3972	30654	5013	35667	0.1
Poland	247319	100906	16392	12261	7500	384378	111628	496005	1.6
Portugal	31315	12461	5712	3367	10352	63208	7777	70984	0.8
Romania	170056	82504	37006	8979	33606	332150	39829	371979	1.6
Spain	116366	86254	13660	5746	45651	267677	78028	345706	0.7
Sweden	38297	12429	2732	708	672	54838	8332	63170	0.1
Switzerland	42629	10013	1490	622	713	55467	4917	60384	1.5
UK	274256	40855	34274	2306	49402	401093	67332	468425	1.9
Yugoslavia	109661	39623	18130	4368	12838	184620	29872	214491	0.8
Turkey	288957	54	15398	24766	81384	410558	81982	492541	0.6
USSR*	1009275	178401	103740	19996	35303	1346715	293556	1640272	1.4
Total	4201143	1173413	461733	113314	397771	6347373	1290652	7638027	1.1

Defined by: total emission country/total surface country; i.e. the emission density for the country as a whole and not only for the agricultural area. This value is most important for long-range transport models for air pollution.

1) Includes mules and asses.
2) Includes goats.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 11. Fraction of the NH_3 emission caused by different categories in 1989.

Country	Cattle	Pigs	Poultry	Horses[1]	Sheep[2]	Tot.an.	Fertil.	Total
Albania	0.52	0.03	0.04	0.05	0.15	0.79	0.21	1.00
Austria	0.66	0.23	0.04	0.01	0.01	0.94	0.06	1.00
Belgium	0.58	0.29	0.08	0.00	0.00	0.95	0.05	1.00
Bulgaria	0.30	0.17	0.08	0.05	0.12	0.72	0.28	1.00
Czechoslovakia	0.57	0.19	0.06	0.00	0.01	0.83	0.17	1.00
Denmark	0.43	0.41	0.03	0.00	0.00	0.89	0.11	1.00
Finland	0.62	0.14	0.03	0.01	0.00	0.80	0.20	1.00
France	0.65	0.09	0.07	0.00	0.03	0.84	0.16	1.00
Germany D.R.	0.46	0.23	0.04	0.00	0.02	0.75	0.25	1.00
Germany F.R.	0.62	0.22	0.03	0.01	0.00	0.89	0.11	1.00
Greece	0.21	0.08	0.10	0.05	0.35	0.79	0.21	1.00
Hungary	0.26	0.30	0.10	0.01	0.03	0.68	0.32	1.00
Ireland	0.77	0.03	0.01	0.01	0.05	0.87	0.13	1.00
Italy	0.49	0.12	0.09	0.01	0.05	0.77	0.23	1.00
Luxemburg	0.83	0.07	0.00	0.00	0.00	0.91	0.09	1.00
Netherlands	0.49	0.33	0.10	0.00	0.01	0.94	0.06	1.00
Norway	0.60	0.11	0.03	0.01	0.11	0.86	0.14	1.00
Poland	0.50	0.20	0.03	0.02	0.02	0.77	0.23	1.00
Portugal	0.44	0.18	0.08	0.05	0.15	0.89	0.11	1.00
Romania	0.46	0.22	0.10	0.02	0.09	0.89	0.11	1.00
Spain	0.34	0.25	0.04	0.02	0.13	0.77	0.23	1.00
Sweden	0.61	0.20	0.04	0.01	0.01	0.87	0.13	1.00
Switzerland	0.71	0.17	0.02	0.01	0.01	0.92	0.08	1.00
UK	0.59	0.09	0.07	0.00	0.11	0.86	0.14	1.00
Yugoslavia	0.51	0.18	0.08	0.02	0.06	0.86	0.14	1.00
Turkey	0.59	0.00	0.03	0.05	0.17	0.83	0.17	1.00
USSR*	0.62	0.11	0.06	0.01	0.02	0.82	0.18	1.00
Total	0.55	0.15	0.06	0.01	0.05	0.83	0.17	1.00

[1] Includes mules and asses.
[2] Includes goats.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 12. Ratio this emission vs. emission computed by Buijsman *et al.* (1987).

Country	Cattle	Pigs	Poultry	Horses[1)]	Sheep[2)]	Tot.an.	Fertil.	Total
Albania	1.87	3.04	1.92	3.49	0.77	1.54	1.49	1.53
Austria	1.09	4.01	1.37	1.65	0.81	1.35	0.57	1.25
Belgium	1.11	2.95	1.71	0.94	0.93	1.41	1.34	1.41
Bulgaria	1.12	2.05	0.96	5.12	0.44	1.00	1.13	1.04
Czechoslovakia	1.29	1.96	0.93	1.29	0.61	1.34	0.90	1.24
Denmark	0.83	2.41	0.99	0.80	0.82	1.20	0.58	1.07
Finland	1.02	1.60	0.64	2.00	0.37	1.07	2.55	1.20
France	1.12	2.61	1.13	1.41	0.50	1.14	0.95	1.11
Germany D.R.	1.27	1.95	0.91	1.62	0.66	1.36	1.69	1.43
Germany F.R.	1.33	2.54	0.94	1.19	0.73	1.47	1.75	1.50
Greece	1.11	2.28	0.99	0.96	0.71	0.91	0.69	0.85
Hungary	1.11	1.74	1.26	0.87	0.39	1.24	1.13	1.20
Ireland	1.36	2.61	1.04	1.06	0.90	1.33	4.01	1.46
Italy	1.24	2.58	1.07	1.89	0.69	1.26	0.93	1.16
Luxemburg	1.19	2.98	0.69	1.83	1.30	1.24	2.22	1.29
Netherlands	1.26	3.42	1.43	4.33	0.65	1.63	1.05	1.58
Norway	1.15	2.11	0.86	0.87	0.75	1.12	0.76	1.05
Poland	1.14	1.83	0.95	0.75	0.62	1.21	1.39	1.25
Portugal	1.47	1.80	5.30	15.27	1.20	1.65	1.07	1.56
Romania	1.49	2.35	1.31	1.68	0.62	1.40	0.75	1.28
Spain	1.43	2.72	1.23	2.53	0.91	1.51	1.58	1.53
Sweden	1.15	1.64	0.92	1.32	0.50	1.20	1.49	1.23
Switzerland	1.03	2.36	0.96	1.29	0.82	1.14	1.36	1.16
UK	1.53	2.84	0.92	1.75	0.66	1.30	0.75	1.18
Yugoslavia	1.03	2.70	1.09	0.81	0.55	1.11	1.03	1.10
Turkey	0.73	0.62	1.03	3.43	0.38	0.65	1.74	0.73
USSR*	1.31	1.90	1.04	1.02	0.55	1.29	1.40	1.31
Total	1.19	2.27	1.09	1.45	0.56	1.21	1.18	1.21

1) Includes mules and asses.
2) Includes goats.

*Only the following republics: Ukraine, White-Russia, Georgia, Azerbajdzjan, Moldavia, Lithunia, Latvia, Armenia and Estonia.

Table 13. Comparison of the results of this gridded inventory with other independent* surveys. All numbers in 1000 tonne NH_3 yr^{-1}.

Country	This survey	Other survey	Year	Reference
Czechoslovakia	206	127-222	1981	Závodský and Mitošinková (1984)
Denmark	118	136	mid 1980's	Sommer *et al.* (1985)
Finland	51	52	1986	Niskanen *et al.* (1990)
Germany D.R.	288	513	1980	Möller and Schieferdecker (1982)
		182	1980	Möller and Schieferdecker (1985)
		419	1985	Möller and Schieferdecker (1989)
Germany F.R.	546	641	1986	Isermann (1990)
		290	1988	Fabry *et al.* (1990)
Hungary	151	89-154	1976	Bónis (1981)
U.K.	468	100	1960's	Healy *et al.* (1970)
		712	1980	Royal Society (1983)
		452	1981	Kruse *et al.* (1989) (excluding Northern Ireland)
		406	1980's	Ryden *et al.* (1987) (excluding use of fertilizer to arable land)
		203	1988	Jarvis and Pain (1990)

* Independent surveys are defined here as surveys where not the general emission factors of Buijsman *et al.* (1987) or the emission factors of the preliminary version of this report were used.

Table 14. Factor* by which the emission in The Netherlands was reduced in 1989 and fraction of the emission taking place each month for the year 1989. (The sum of the fractions for each category for the whole year is 1).

(Van der Hoek, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, pers. comm., 1991).

Category	Fact	Jan	Febr	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Cattle stable+storage	1.00	0.119	0.119	0.119	0.119	0.048	0.048	0.048	0.048	0.048	0.048	0.119	0.119
Cattle spreading	1.00	0.000	0.120	0.250	0.180	0.090	0.090	0.090	0.090	0.090	0.000	0.000	0.000
Cattle grazing	1.00	0.000	0.000	0.000	0.000	0.167	0.167	0.167	0.167	0.167	0.167	0.000	0.000
Pigs stable+storage	1.00	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Pigs spreading	0.72	0.000	0.250	0.500	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pigs grazing	1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Poultry stable+storage	1.00	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Poultry spreading	0.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.500	0.250	0.000	0.000
Poultry grazing	1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Horses stable+storage	1.00	0.167	0.167	0.167	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.167
Horses spreading	1.00	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000
Horses grazing	1.00	0.000	0.000	0.000	0.000	0.167	0.167	0.167	0.167	0.167	0.167	0.000	0.000
Sheep stable+storage	1.00	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333
Sheep spreading	1.00	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000
Sheep grazing	1.00	0.000	0.000	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.000
Fertilizer application	1.00	0.000	0.000	0.250	0.250	0.125	0.125	0.125	0.125	0.000	0.000	0.000	0.000

* This factor is only applied to compute the seasonal variation of the NH_3 emission for The Netherlands, but not to compute the emission factors used for Europe because in other countries these emissions are not reduced.

APPENDIX 1. INQUIRY ON THE AGRICULTURAL PRACTICE IN EUROPE (December 1988).

1 a. During which period are the cattle in the stable?

Austria:	September/October - May/June; average period in the meadows: 109 days.
Belgium:	Milk cows from 15 November - 15 April in stables (+ 1 month in the Ardennes). Cattle for meat production for 90% of the year in stables.
Czechoslovakia:	1 October - 1 May.
Denmark:	Cattle for milk production 1 October - 1 May. (68% comes outside). Other cattle comes less often outside.
Finland:	1 October - 1 June.
Germany F.R.:	Mostly in the stable; in Schleswig-Holstein, northwestern Niedersachsen, Allgäu and in parts of Hessen and Bavaria, however, the cattle are in the meadows during daytime from 1 May - 1 November. On the average are cattle for 80% in the stable.
Hungary:	1 November - 1 May.
Italy:	In Po-valley: never outside (6 million), on the Alps (80,000): outside from 1 September - 1 May.
Luxemburg:	1 November - 1 May.
Netherlands:	1 November - 1 May.
Norway:	15 September - 15 May. In summer season partly in the meadows.
Sweden:	Milkcows: 1 September - 15 May, calves: 1 October - 15 May. There exist large differences within the country.
Turkey:	15 November - 15 March.
UK:	November - April; Northern England/Scotland: October - April.

1 b. In which way is the manure from cattle stored (open piles/tanks or in closed tanks?)

Austria:	Mostly solid manure (no information on way of storage).
Belgium:	In cellars under or near to the stables; 50% open piles/tanks, 50% closed.
Czechoslovakia:	Usually open piles.
Denmark:	About 20% is handled as solid manure. The remaining part is stored in tanks of which 10% is covered with a lid (including manure from pigs).
Finland:	20% of cattle manure is handled as slurry and 80% as solid manure; 60% of cattle slurry is stored in closed tanks and 40% in open tanks; 50% of solid cattle manure is stored in covered storages and 50% in uncovered storages. Covering does not prevent ammonia escape.
Germany F.R.:	Approximately 70% in open piles/tanks, the rest in closed tanks.
Hungary:	Open piles.
Italy:	40% open piles; 60% open tanks.
Luxemburg:	Usually in tanks under the stables.

Netherlands:	20% of the cattle manure is solid manure, stored in open piles; 80% is slurry stored under the stables or in open tanks.
Norway:	Usually in closed tanks during winter-season, during summer-season the manure might be stored in open piles/tanks in addition to closed tanks.
Sweden:	About 1/3 of manure from livestock as a **whole** is stored as solid manure , 1/3 as liquid manure and 1/3 as a mixture. For cattle more than 1/3 will be stored as solid manure.
Turkey:	Open piles.
UK:	Solid manure in open piles, slurry in open tanks. About 20% of all cattle waste is solid manure (with straw bedding) and about 80% is semi-liquid slurry.

1 c. Is the manure from cattle usually diluted or not?

Austria:	Only in case of liquid manure systems water is used.
Belgium:	No dilution, only in exceptional cases (cleaning, problems with the vacuum tank).
Czechoslovakia:	No dilution.
Denmark:	Yes (17-18 tonne liquid manure per cow per year + 4-8 tonne of water).
Finland:	Cattle slurry consists for 15% of wahing water and rain water.
Germany F.R.:	No, apart from cleaning or if problems with mixing exist.
Hungary:	No dilution.
Italy:	No dilution.
Luxemburg:	Only manure from (fattening) calves is diluted.
Netherlands:	No, apart from water used fro cleaning the milking equipment.
Norway:	Usually no dilution in the winter-season.
Sweden:	Usually not.
Turkey:	Usually not.
UK:	Slurry is normally diluted with water. (parlour and yard washings, rainfall).

1 d. Is there natural or mechanical ventilation in the stables for cattle?

Austria:	Mainly natural ventilation.
Belgium:	Mainly natural ventilation.
Czechoslovakia:	Usually mechanical ventilation; natural ventilation in calf and heifer hutches and open air housings.
Denmark:	Mainly mechanical ventilation.
Finland:	Old stables (30%) natural ventilation, new stables (70%) mechanical ventilation.
Germany F.R.:	Mostly natural. In many stables there are ventilators, but they are only used a few days per year.
Hungary:	Mainly natural ventilation.
Italy:	Natural ventilation.
Luxemburg:	Usually natural ventilation.
Netherlands:	Mainly natural ventilation.

Norway:	Usually mechanical ventilation.
Sweden:	Usually mechanical ventilation.
Turkey:	-
UK:	Natural ventilation.

2 a. Are pigs kept in stables or are they also outside during a substantial fraction of the year?

Austria:	Almost always in the stable.
Belgium:	Almost always in the stable; ± 5% are outside during the day.
Czechoslovakia:	In stables.
Denmark:	In stables.
Germany F.R.:	In stables, in some regions are the sows outside for some days after the piglets have been born.
Finland:	In stables.
Hungary:	Only in stables in cooperatives and state farms.
Italy:	In stables.
Luxemburg:	In stables.
Netherlands:	In stables, about 1% are outside during daytime.
Norway:	In stables during winter season.
Sweden:	Usually in stables.
Turkey:	There are almost no pigs in Turkey.
UK:	Mostly in stables all year.

2 b. In which way is the manure from pigs stored?

Austria:	Usually in a open tank (Güllegrube).
Belgium:	In cellars under the stable (closed system).
Czechoslovakia:	In closed systems.
Denmark:	About 14% is stored as solid manure. The remaining part is stored in tanks. About 10% of the tanks ic covered with a lid (for bothh cattle and pig manure).
Finland:	60% of pig manure is handled as slurry and 40% as solid manure. 60% of pig slurry is stored in closed tanks and 40% in open tanks. 30% of the solid pig manure is stored in covered storages and 70% in uncovered storages. The covered storages for solid pig manure are rather loose and do not prevent ammonia escape.
Germany F.R.:	Approximately 80% in open systems and 20% in closed systems. In Nordrhein-Westfalen is the liquid manure often stored in the stable.
Hungary:	Open system.
Italy:	Open tanks or lagoons.
Luxemburg:	90% in reservoirs made in the ground (often under the stables), 10% in open reservoirs above the ground.
Netherlands:	In cellars under the stables.
Norway:	Usually in closed systems in winter season.

Sweden:	Open system.
Turkey:	-
UK:	50% open, 50% closed systems.

2 c. Is the manure from pigs usually diluted or not?

Austria:	Normally not diluted, only with water from cleaning or sometimes to increase the possibility uptake of nitrogen by plants after spreading.
Belgium:	Usually not diluted, but water is used for thoroughly cleaning the stables at the end of the fattening period.
Czechoslovakia:	Diluted.
Denmark:	Only diluted with water for cleaning.
Finland:	Pig slurry consists for 15% of washing water and rainwater.
Germany F.R.:	Normally not diluted, only if there exist problems with mixing.
Hungary:	Diluted.
Italy:	Diluted.
Luxemburg:	Not diluted.
Netherlands:	Usually not diluted, but water is used for thoroughly cleaning the stables at the end of the fattening period.
Norway:	Usually not diluted in the winter season.
Sweden:	Almost all manure of fattening pigs is diluted, but the manure from sows is usually not.
Turkey:	-
UK:	Usually diluted with water.

2 d. Is there usually natural or mechanical ventilation in the stables for pigs?

Austria:	Mostly mechanical.
Belgium:	About 40% mechanical.
Czechoslovakia:	Mostly mechanical.
Denmark:	About 95% mechanical.
Finland:	About 80% mechanical.
Germany F.R.:	Mostly mechanical. Natural ventilation only exists in regions with large stables.
Hungary:	Mainly mechanical ventilation except in stables for sows, boars, gilts.
Italy:	Mechanical ventilation in stables for sows and piglets, natural in other sectors.
Luxemburg:	Usually natural ventilation, but mechanical ventilation in stables for fattening pigs.
Netherlands:	About 80% mechanical ventilation, 20% natural ventilation.
Norway:	Usually mechanical ventilation.
Sweden:	Usually mechanical ventilation.
Turkey:	-
UK:	About 40% natural ventilation, 60% mechanical ventilation.

3 a. Are poultry usually kept in stables or are they also outside during a substantial fraction of the year?

Austria:	Mostly in stables.
Belgium:	Usually in stables.
Czechoslovakia:	Layers, chickens and turkey hens are in stables; geese and ducks are outside about 4 months a year.
Denmark:	In stables.
Finland:	In stables.
Germany F.R.:	In stables.
Hungary:	Always in stables.
Italy:	In stables.
Luxemburg:	This category is of no importance in Luxemburg.
Netherlands:	In stables but 75% of the ducks are kept outside.
Norway:	In stables.
Turkey:	Usually kept in stables.
UK:	Mostly in buildings.

3 b. In which form is the manure from poultry stored? (open/closed?)

Austria:	Both systems are used.
Belgium:	70% in closed systems.
Czechoslovakia:	Closed systems.
Denmark:	Open systems.
Finland:	40% in covered storages and 60% in uncovered storages (Remark: Ammonia escape is not prevented by covering).
Germany F.R.:	Liquid manure is stored in closed systems (about 60%) and dry manure is stored in open systems.
Hungary:	Open systems.
Italy:	Closed systems.
Luxemburg:	-
Netherlands:	60% of the manure is solid, 40% of the manure is slurry, stored in the stables or in closed tanks.
Norway:	Closed systems.
Sweden:	Open systems.
Turkey:	Open systems.
UK:	Both in closed and open systems (50% for each).

3 c. Is the manure from poultry usually diluted with water or not?

Austria:	Only very rarely diluted with water.
Belgium:	The tendency is to keep the manure as dry as possible. Ventilation is sometimes used to eliminate moisture. Sometimes, water is used to clean the cellars which are used to store the manure.
Czechoslovakia:	Is only diluted with water before use.
Denmark:	Only in 10% of the cases the manure is diluted.
Finland:	Not diluted.
Germany F.R.:	Usually not diluted, only if needed to be able to pump the manure away.
Hungary:	Only very rarely diluted.
Italy:	Not diluted.
Luxemburg:	-
Netherlands:	Usually not diluted, only if needed to be able to pump the manure away.
Norway:	Usually not in the winter season.
Sweden:	Usually not diluted.
Turkey:	Usually not diluted.
UK:	Usually not diluted.

3 d. Is there usually natural or mechanical ventilation in the stables for poultry?

Austria:	-
Belgium:	In general mechanical ventilation.
Czechoslovakia:	Usually mechanical ventilation.
Denmark:	Almost only mechanical ventilation.
Finland:	For 90% mechanical ventilation.
Germany F.R.:	Mechanical ventilation.
Hungary:	Always mechanical ventilation.
Italy:	Mechanical ventilation.
Luxemburg:	-
Netherlands:	60% mechanical ventilation, 40% natural ventilation.
Norway:	Usually mechanical ventilation.
Sweden:	Mechanical ventilation.
Turkey:	-
UK:	Mechanical ventilation.

4 a. Indicate whether sheep are usually inside or outside buildings and for which fraction of the time.

Austria:	Mostly outside during the whole year.
Belgium:	Mostly outside during the whole year.
Czechoslovakia:	Sheep for fattening are inside, female sheep and lambs outside.

Denmark:	Usually outside 9 months a year.
Finland:	Outside 1 June - 30 September.
Germany F.R.:	Outside from about 15 March - 15 November, depending on the region.
Hungary:	Outside except in case of intensive fattening.
Italy:	-
Luxemburg:	This category is of no importance in Luxemburg.
Netherlands:	2 - 3 months a year inside.
Norway:	In buildings in the winter-season.
Sweden:	Outside 15 May - 1 October.
Turkey:	Both inside and outside buildings
UK:	Outside all year.

4 b. Indicate whether goats are usually inside or outside buildings.

Austria:	There are almost no goats in Austria.
Belgium:	-
Czechoslovakia:	Outside, but there are not many.
Denmark:	Outside 9 months a year.
Finland:	Outside 1 June - 30 September.
Germany F.R.:	Usually outside from about 15 March - 15 November, depending on the region.
Hungary:	-
Italy:	-
Luxemburg:	-
Netherlands:	Goats for milk production are kept in stables.
Norway:	In buildings in the winter season.
Sweden:	Milk goats: outside 15 May - 15 September.
Turkey:	Both inside and outside buildings.
UK:	-

4 c. Indicate whether horses are usually inside or outside buildings.

Austria:	During most of the time in stables.
Belgium:	-
Czechoslovakia:	Only outside from 1 May - 1 October during day-time.
Denmark:	About 50% of the time outside.
Finland:	Outside 1 June - 30 September.
Germany F.R.:	Young horses are outside from 1 May - 1 November. Riding horses are mostly inside. It is estimated that 40% of all horses on the average is outside.
Hungary:	-
Italy:	-
Luxemburg:	In half-open or closed buildings.

Netherlands:	In winter-season mostly inside, in summer-season 50% of the time outside.
Norway:	In buildings in the winter-season.
Sweden:	Outside from 15 May - 15 September.
Turkey:	Both inside and outside.
UK:	Mostly during the day but inside at night.

5. During which months does spreading of most manure usually occur? And when is there no spreading?

Austria:	Manure is mostly spread in autumn. When the soil is frozen, almost no manure is spread (not economical, can cause ground- and surface water pollution).
Belgium:	Manure is mostly spread in February, March, April, (May) and also some in September and October.
Czechoslovakia:	Spreading in (August), September (October).
Denmark:	Spreading in September, October, November and March and April.
Finland:	Spreading: 8% on frozen soil in winter, 52% in spring (May), 2% on vegetation during growing season, 4% on fallow in summer, 33% in autumn (September-December).
Germany F.R.:	No manure is spread from about 1 December - 15 February. Most manure is spread from 15 February - 30 March and from 1 August to 30 September. For each "Bundesland" the spreading period will be different, as spreading is prohibited during certain periods in some "Bundesländer". In Schleswig-Holstein spreading may only occur from 1 March - 30 September, In Nordrhein-Westfalen from 15 February - 15 October on fields and from 1 February - 31 October on meadows.
Hungary:	Spreading mainly during July, August, September, October.
Italy:	Spreading in July, August, September, October. In December, January and February no spreading.
Luxemburg:	Usually in wintertime and on corn fields before they are sown.
Netherlands:	Manure is mostly spread in February, March, April and in October and November. On grassland also from May until September.
Norway:	Usually in spring (April, May).
Sweden:	15 March - 1 May and from 1 September - 15 October.
Turkey:	Spreading occurs in spring and autumn.
UK:	September-November and February-March. Spreading occurs throughout the year, but mainly in autumn and winter when weather and soil conditions permit.

6. During which months is most fertilizer applied?

Austria:	During the vegetation period.
Belgium:	March, April, May.
Czechoslovakia:	For the greatest part in (August) September (October) and partially during March-May.
Denmark:	March, April.

Finland:	For spring cereals, potatoes, root crops etc. in May. For grassland in May, June and August. For winter cereals in August-early September, but the amounts of nitrogen applied in fall are rather small.
Germany F.R.:	Depends much on the crops that are grown. Usually from 15 March - 15 May, but mostly in March and April.
Hungary:	In spring-time, July, August, September, October.
Italy:	In spring.
Luxemburg:	April - May.
Netherlands:	February, March, April. On grassland up until August.
Norway:	Usually in spring (April, May).
Sweden:	April, May (and some in August, September).
Turkey:	In spring and autumn.
UK:	Mostly March to April but also through growing season on grassland up until September.

7. Are there any restrictions in your country regarding application of manure? If so, indicate amount/ha, time of the year spreading is allowed.

Austria:	In one of the nine provinces (Steiermark) is spreading of manure on frozen soil forbidden by law. In all other provinces spreading is not restricted. Spreading in nature reserves is forbidden everywhere.
Belgium:	In Flanders one is in the process of making a law; amount of manure/ha and period during which spreading is allowed is not yet known (October 1989).
Czechoslovakia:	There are no restrictions; only recommended rations exist. The amount of nitrates in products is watched.
Denmark:	Spreading of manure is forbidden from the harvest until 1 November on land without crops on which first will be sown in spring. Liquid manure applied to areas without vegetation shall be ploughed into the soil as quickly as possible and within 12 hours after application. Liquid manure shall not be applied to areas without vegetation which are frozen or covered with snow, unless it can be ploughed down within 12 hours after application. Within a farm holding operating on the basis of cattle rearing, the quantity of farm yard manure applied shall not exceed manure from 2.3 livestock units ha^{-1} yr^{-1}. In pig holdings and farm units without animal production the maximum quantity of manure to be applied is manure from 1.7 livestock units ha^{-1} yr^{-1} and for other livestock holdings 2.0 livestock units ha^{-1} yr^{-1}. Spreading shall not take place closer than 50 m from common water abstraction plants or 25 m from individual water abstraction plants used for supply of drinking water.
Finland:	Spreading of slurry is forbidden on frozen soils and in certain areas with susceptible water resources.
Germany F.R.:	In water protection areas (drinking water) no (liquid) manure is to be spread. There exist no other restrictions for the F.R.G. as a whole, but there exits restrictions in Niedersachsen (Gülleerlass) and in Nordrhein-Westfalen (Gülleverordnung) and in more "Länder" restrictions are being prepared.

Hungary: There are different restrictions issued by OVH (= National Water Authority). For example: on ploughed land without any plant: one can spread slurry without restrictions. Spreading of slurry has to stop 3 weeks before beginning of grazing. Application of slurry has to stop in orchards and vineyards 45 days before harvesting. Quantity of slurry to be spread depends on the nutrient demand of the plant, e.g. 300 m^3 ha^{-1} yr^{-1} for maize. Total N (kg ha^{-1} yr^{-1}): cereals 200, root crops 300, fodder plants: 400-500.

Italy: Spreading is forbidden in December, January and February.

Luxemburg: Since 1987 there exists a directive (but nothing is forbidden officially): cattle manure : 40 m^3 ha^{-1} yr^{-1} and pig manure: 30 m^3 ha^{-1} yr^{-1}. It is recommended to spread manure from 1 February - 15 October. For water protection areas (drinking water) there exist restrictions (at some distance from where water is pumped up) or is spreading forbidden (near the area where the water is pumped up).

Netherlands: There are several restrictions. (December 1989)

a. The maximum amount per ha, expressed in kg P_2O_5:

land use	1-4-87 1-1-91	1-1-91 1-1-95	1-1-95 2000
grassland	250	200	ca. 175
maize	350	250	ca. 175
arable land	125	125	125

b. The period during which spreading of manure is not allowed:

grassland: October and November and from January until 15 February if the soil is covered with snow.

arable land (incl. maize) on sandy soils: from harvest until 31 October.

c. Preventing emission of ammonia and runoff: arable land (incl. maize): ploughing not later than the day after spreading manure.

d. In water protection areas (drinking water) if neccesary the values mentioned in a are lowered.

Norway: The manure should not be placed outside in the winter-season.

Sweden: There are restrictions on the number of animals per ha. These are different for different kinds of animals. Spreading is forbidden from 1 December - 28 February. And when not applied to growing crops or before sowing in autumn in the coastal areas from Stockholm to Bohuslän and in Blekinge, Skåne, Halland and Gotland.

Turkey: There exist no restrictions.

UK: No restrictions; a maximum rate per application of 50 m^3 ha^{-1} is recommended.

8. Is it likely that there will exist any restrictions in your country in the future regarding application of manure, type of stables, food etc., that may influence the ammonia emission? Give if possible some details.

Austria: Vorarlberg is already for a long time the only province, which has an agreement with the neighbouring province of Switzerland and with Bavaria of recommending a value of

	value of 2-3 "Grossvieheinheiten" per ha. It is, however, possible that in Austria in a few years the "Grossvieheinheiten" per ha will be limited.
Belgium:	See question 7.
Czechoslovakia:	There are at the moment no plans for restrictions.
Denmark:	There will possibly come some rules concerning coverage of tanks used to store manure. From 1993 farmers should have a storage capacity for manure of at least 9 months. (December 1989)
Finland:	There will be restrictions concerning manure storages. The storages are supposed to be equipped with water-tight bottoms. In addition, the application rate of manure may be restricted in the future. In Finland one was concerned mainly of pollution of water resources and not so much for atmospheric pollution caused by manure and fertilizers. In Finland the annual emission of ammonia from manure and fertilizers is estimated to be 38.000 tonne N.
Germany F.R.:	The installations which need a permission according to the "TA-Luft" should cover their manure reservoirs.
Hungary:	It is expected that there will come more restrictions, also for waste water and pollution in general. At present no financial assistance for building stables with flushing slurry removal system can be obtained.
Italy:	The spreading of slurry by sprinkle devices will not be allowed.
Netherlands:	See question 7.
Norway:	From January 1989 the area for cattle in the meadows should at least be 4 da for each individual. There will also be some regulations regarding the size of the tanks in which the manure is stored.
Sweden:	It is likely that there will come regulations for ploughing just after spreading, covering of tanks and spreading equipment.
Turkey:	-
UK:	-

APPENDIX 2. UPDATING AMMONIA EMISSIONS FOR EUROPE

A2.1 Overall-emission factors for livestock

Overal-emission factors for livestock categories for Europe may be obtained in two different ways:

a. Computation of the factors from information on the number of animals and the emission factors (stable+storage, spreading and grazing) for each animal subcategory for The Netherlands. First the emission is calculated for each subcategory. Then the overall-emission factors are found by summoning up the emissions of the subcategories belonging to a category and dividing the emissions by the summed up total number of animals for each category.
b. By directly changing the emission factors in the file **IEEMF2.DAT**.

In the following, information is given on the programme and files used for way a.

The programme to compute the overall-emission factors is: **NLEM2.FOR**.
Input file:

NLNREMF.DAT : Contains : CBS code subcategory and name subcategory, number of animals subcatecory, emission factors (kg NH_3 animal^{-1} yr^{-1}) for subcategory for emissions from stable+storage, spreading and grazing, code overall-animal category to which subcategory belongs.
Format: A52, I8, 3(F10.3,1X), I8.

NLSEASON.INP : Contains : code emission category, code source, name category+source, factor by which the emission has to be multiplied, a number which indicates the relative importance of the emission of each month for that category and source for the annual emission (In the programme this number is divided by the sum for all months to get the fraction of the emission for each month).
Format: I1, I2, 1X, A23, F5.2, 12(I4).

Output files:

NLEM89.DAT : Gives information on the input data, emission for subcategories and the overall emission factors (also splitted up according to stable+storage, spreading and grazing).

NLCHECK.DAT : Gives for each emission category+source category: the name, factor by which the emission has been multiplied and for each month the fraction of the annual emission of that emission and source category taking place.
Format: A23, 1X, F5.2, 12F6.3.

IEEMF2.DAT : Contains: code of the animal category, overall emission factor (kg NH_3 animal^{-1} yr^{-1}) and name of the category. The emission factors for camels has been added to this file. The file is used in the further computation of the European emissions.
Format: I2, 1X, F10.5, A10.

A2.2 Computation of European emissions

The programme to compute the emission is : **IEEM2.FOR**.

The emission of each category of each country as a whole is computed from the updated number of animals and emission factors for livestock and from the updated consumption of different kinds of fertilizer and the emission factors for these fertilzer categories. Then the emission for each category of each country is distributed over the IE grid elements in the same fashion as done by Buijsman *et al.* (1987).

Input files:

IEEMOLD.DAT : Gives for each country emissions for each emission category for each IE grid element within that country.

Contains: x,y coordinates of IE grid element and emissions (tonne NH_3 yr^{-1}) of the following categories:

1. Cattle
2. Pigs
3. Poultry
4. Horses
5. Sheep
6. Camels
7. Total emission from livestock
8. Application of fertilizer

-. (Industrial NH_3 production; this category is not being used in the updated emission inventory)

9. Total emission (sum of all categories)

Then follows the country number and the country name.

Format: 2I4, 10F9.2, I5, 2X, A15.

IENR2B.DAT : Contains for each country: country number, updated number of animals (1000 heads) of the 6 categories (see IEEMOLD.DAT).

Format: I2, 1X, 6F10.0, 1X, A15.

IEEMF2.DAT : see Section A2.2

IEFER2.DAT : Contains for each country: country number, consumption of fertilizer (1000 tonne N yr^{-1}) for the following **fertilizer categories:**

1. ammonium sulphate
2. urea
3. ammonium nitrate
4. calcium ammonium nitrate
5. ammonia, directly applied
6. nitrogen solutions
7. other straight nitrogen
8. total straight nitrogen (only to be used when no information on subcategories is available)
9. ammonium phosphate
10. other NP-N
11. NK-N

12. NPK-N
13. total compound nitrogen (only to be used when no information on subcategories is available)

Then follows the country name.
Format: I3, 13F8.1, 1X, A15.

IEFF2.DAT : Contains code fertilizer category, emission factor (fraction of N in fertilizer which evaporates) and fertilizer name.
Format: I2, F10.3, 2X, A10.

Output files:

IEEM2.CON : Gives information on the input data, emission for each fertilizer category for each country, overall-emission factor for fertilizers for each country, new emission for each country, ratio new/old emissions for each category for each country, relative share of the different emission categories in the total emission of the countries.

IEEMNEW2.DAT : New emission file to be used in atmospheric transport models. Gives for every country the emissions for each category for each IE grid element.
Contains: x,y coordinates of the IE grid element, emissions (tonne NH_3 yr^{-1}) for the 9 categories (see IEMOLD.DAT), country number and country name.
Format: 2I4, 9F9.2, I5, 2X, A15.

The programme **IETOT2.FOR** can be used to make a file with for each IE grid element for each category the sum of the contributions of each country within that grid element (in stead of the same information for each separate country).

Input file:

IEEMNEW2.DAT : see above.

Output file:

IETOT2.DAT : same format as IEEMNEW2.DAT, but without the country name (A15).

The programme **IEMEP2.FOR** can be used to make a similar file as IEEMNEW2.DAT but then with emissions on EMEP grid.

Input file:

IEEMNEW2.DAT : see above.

Output file:

EMEPNEW2.DAT : Contains: x,y coordinates of the EMEP grid element, emissions (tonne NH_3 yr^{-1}) for the 9 categories (see IEMOLD.DAT), country number and country name.
Format: 2I4, 9F9.2, I5, 2X, A15.

The programme **EMEPTOT2.FOR** can be used to make a file with for each IE grid element for each category the sum of the contributions of each country within that grid element (in stead of the same information for each separate country).

Input file:

EMEPNEW2.DAT : see above.

Output file:

EMEPTOT2.DAT : same format as EMEPNEW2.DAT, but without the country name (A15).

APPENDIX 3. EUROPEAN AMMONIA EMISSIONS ON EMEP GRID

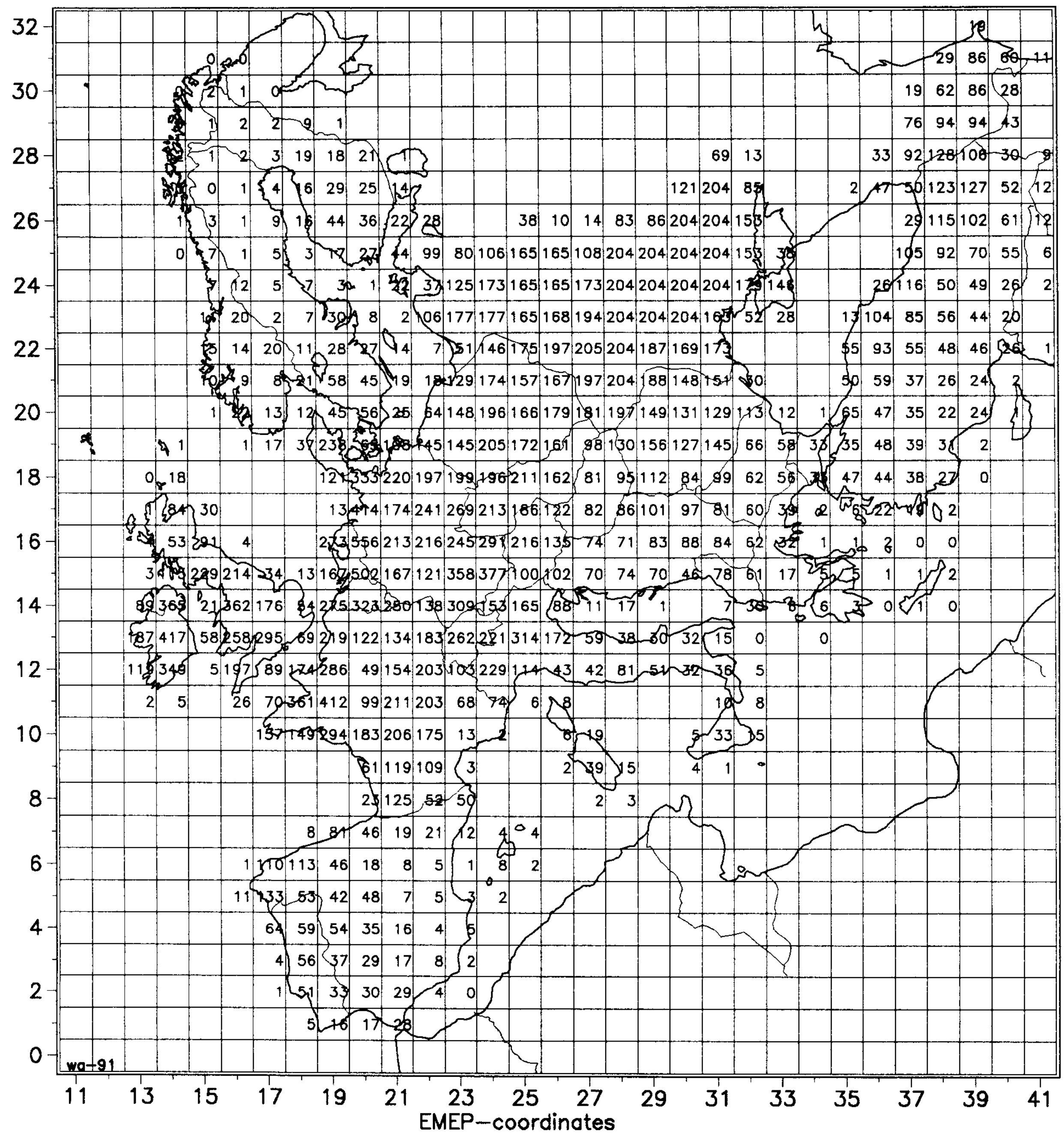

Fig. A3-1. NH_3 emission from cattle in Europe (100 tonne NH_3 yr^{-1} per EMEP-grid element).

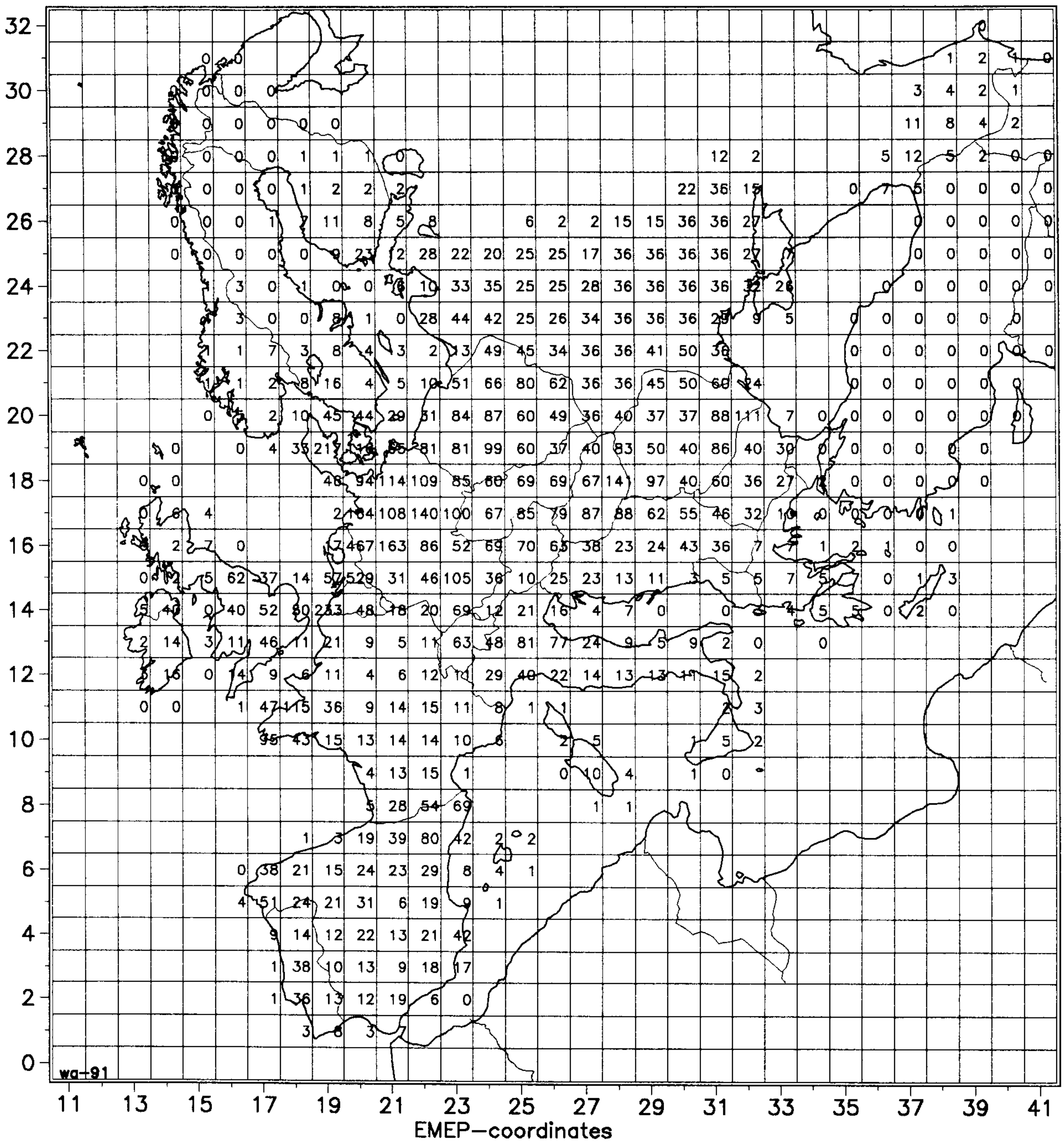

Fig. A3-2. NH_3 emission from pigs in Europe (100 tonne NH_3 yr^{-1} per EMEP-grid element).

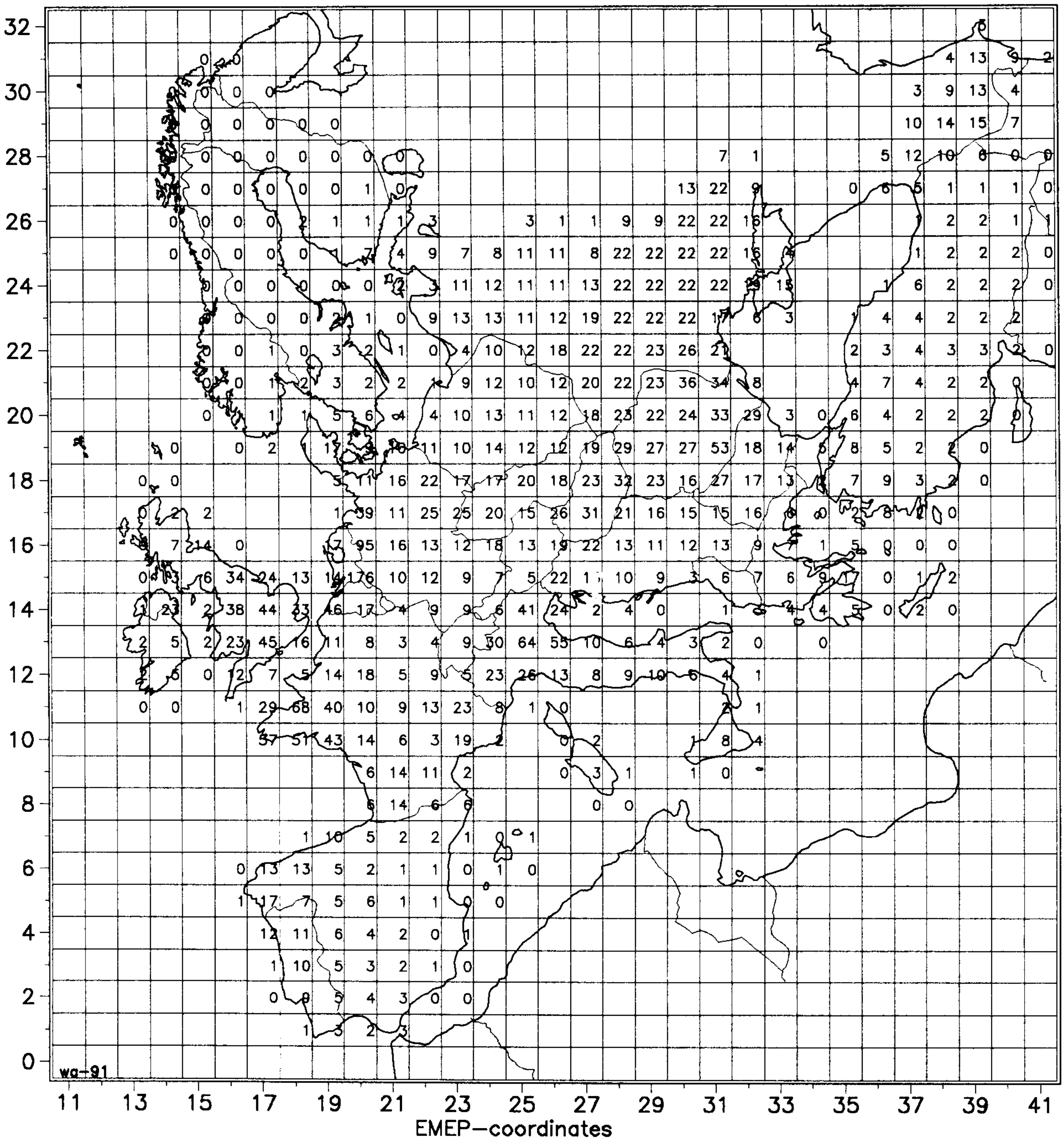

Fig. A3-3. NH_3 emission from poultry in Europe (100 tonne NH_3 yr^{-1} per EMEP-gridelement).

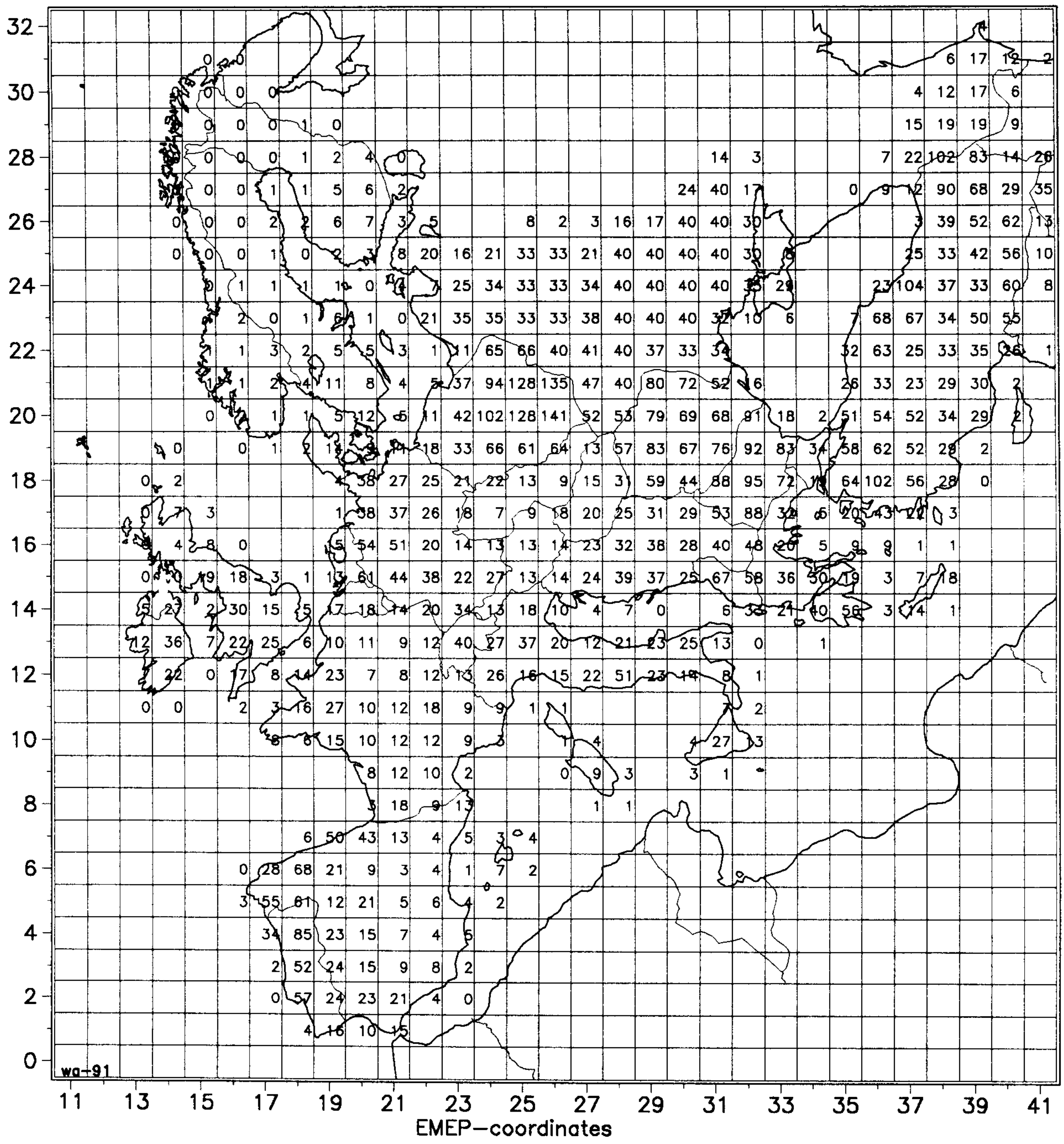

Fig. A3-4. NH_3 emission from horses in Europe (10 tonne NH_3 yr^{-1} per EMEP-grid element).

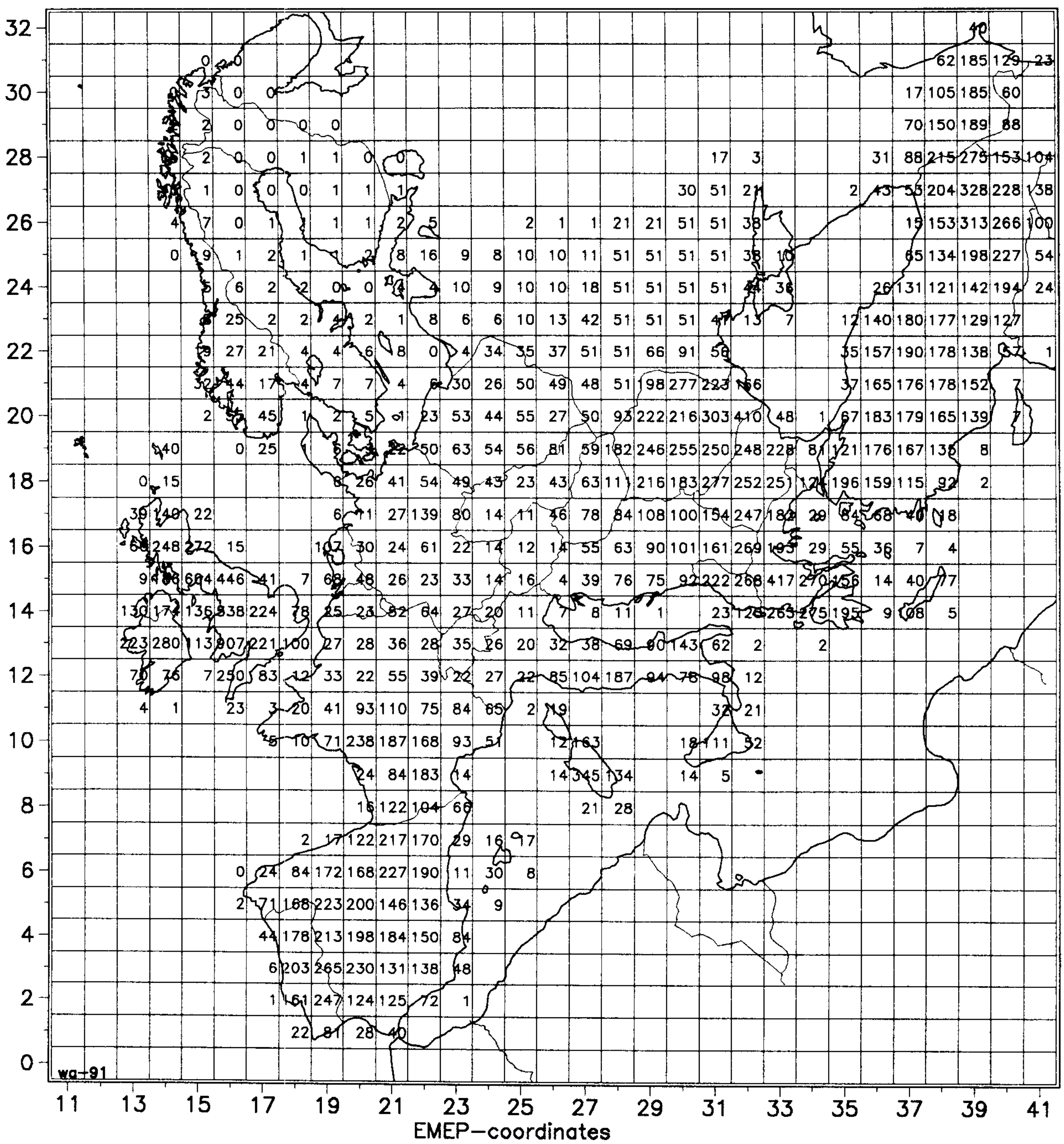

Fig. A3-5. NH_3 emission from sheep in Europe (10 tonne NH_3 yr^{-1} per EMEP-grid element).

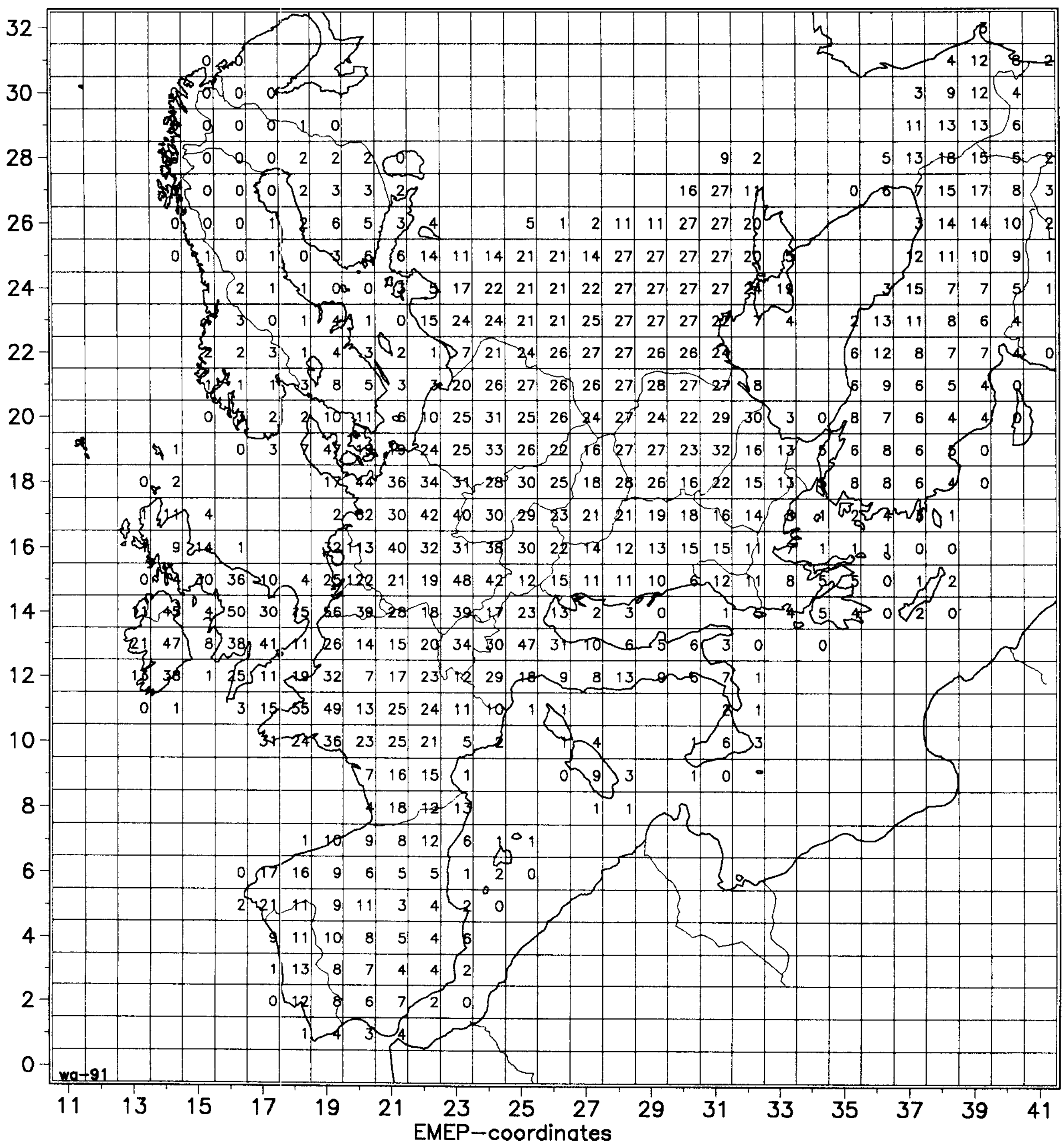

Fig. A3-6. NH_3 emission from livestock in Europe (1000 tonne NH_3 yr^{-1} per EMEP-grid element).

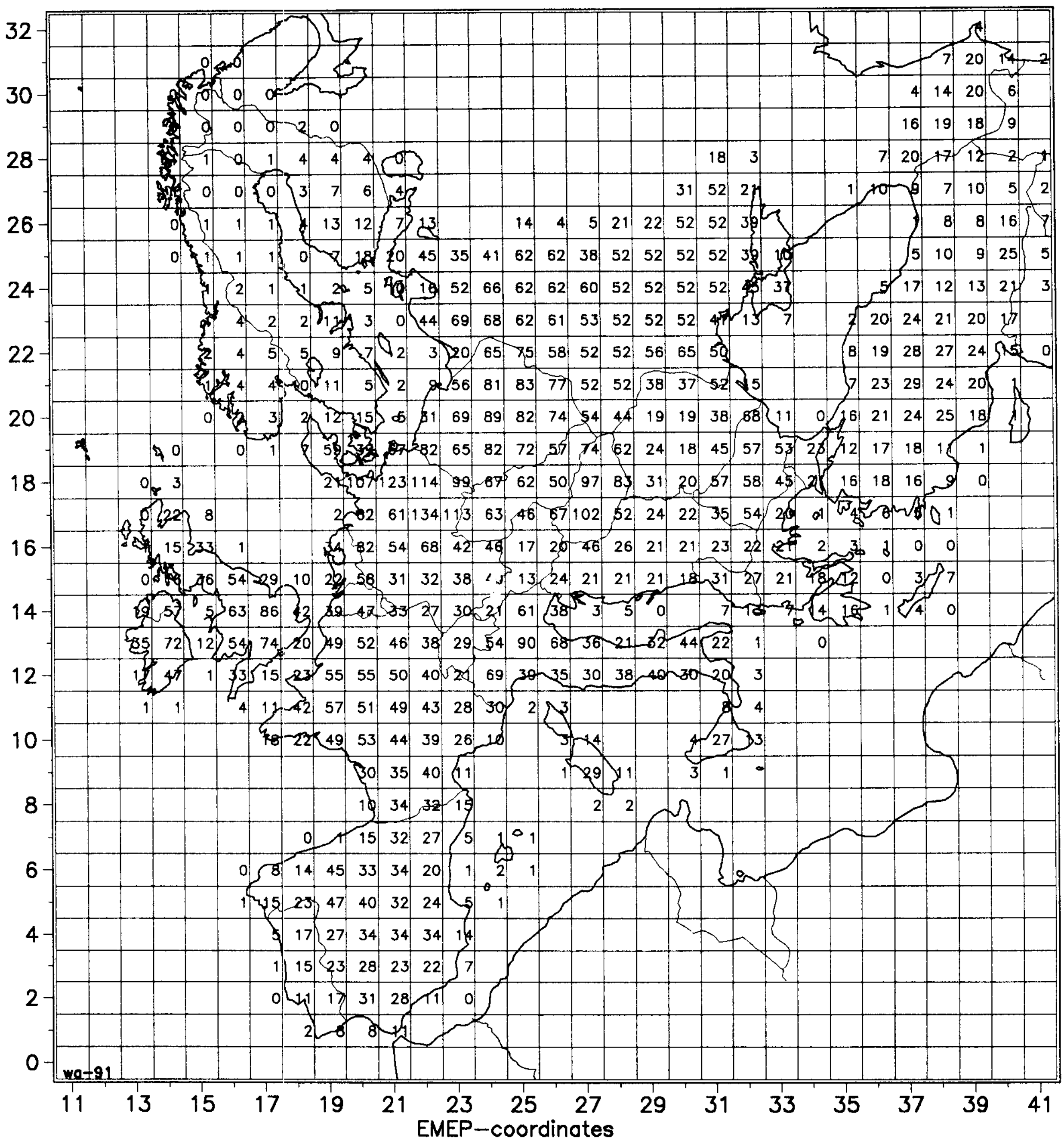

Fig. A3-7. NH_3 emission from the application of fertilizers in Europe (100 tonne NH_3 yr^{-1} per EMEP-grid element).

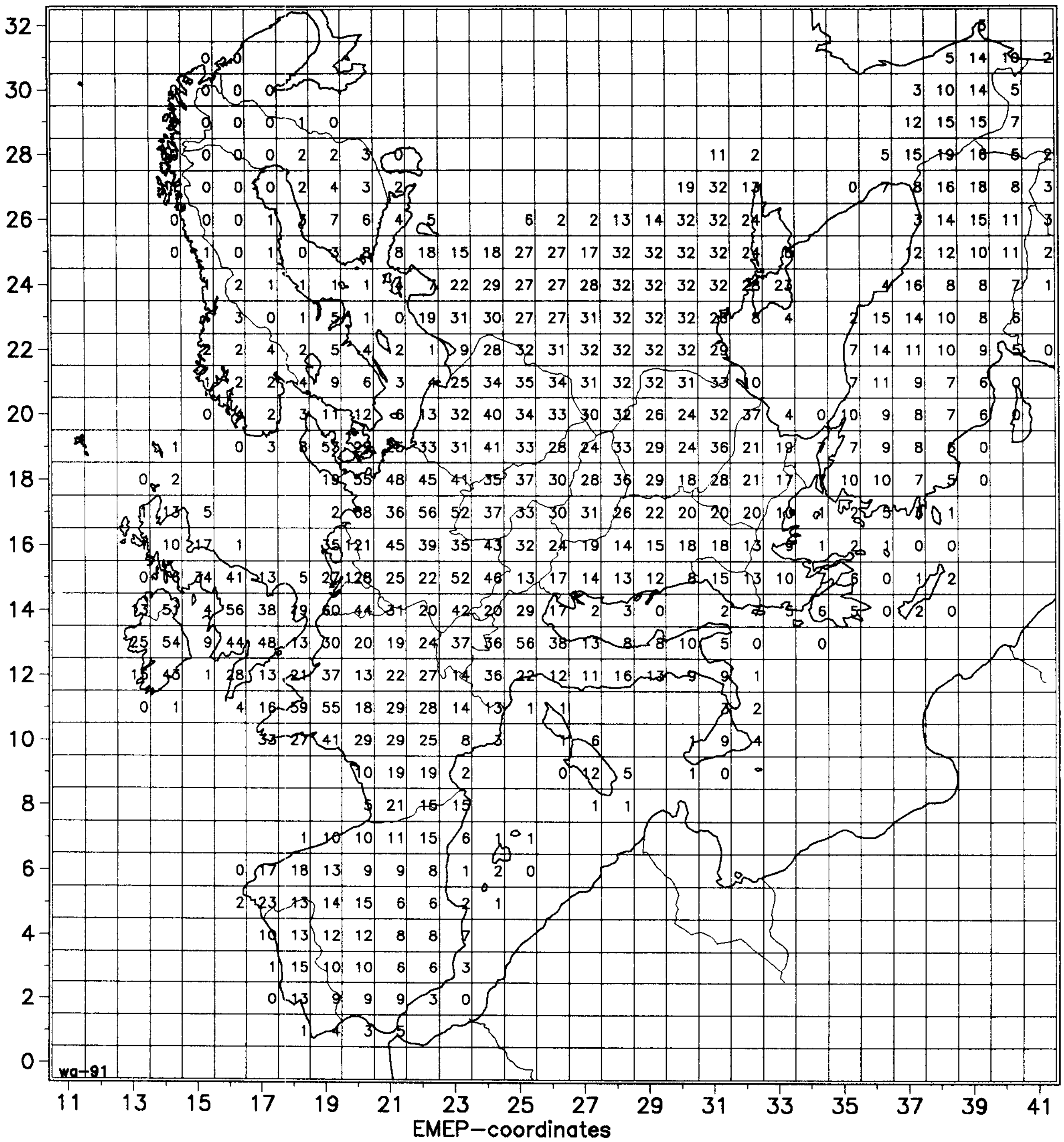

Fig. A3-8. Total NH_3 emission in Europe (1000 tonne NH_3 yr^{-1} per EMEP-grid element).

APPENDIX 4. COMPUTATION OF DETAILED EMISSIONS FOR BELGIUM AND THE WESTERN PART OF THE FRG

A4.1 Introduction

For Belgium and the western part of the F.R.G detailed emissions are computed for each municipality, but not on a regular grid (information on the emissions on a regular grid may be obtained from the author).
In addition to the emission the geographical coordinates of the centre of the municipality and a radius are given, so that these emissions can be used in an atmospheric transport model which is able to handle area sources of different sizes, which are not on a regular grid. The radius of the municipality is computed from two characteristic diameters of the municipality found from maps. It is taken care of that the sum of the products of the characteristic diameters of the municipalities is equal to the area of Belgium respectively the western part of the F.R.G.
Before updating these emissions it is necessary to **update the European emissions first**, because the programmes for the computation of the emissions here use the file with the total number of animals for Europe (IENR2B.DAT) to update for the number of animals and the file with European emissions (IEEMNEW2.DAT) to update the emission from fertilizers.
The information on the number of animals for each muncipality is for the year 1984. The number of animals for each municipality is updated by assuming the same relative change for the municipality as for the country as a whole.

The emission from fertilizers for the Belgian munipalities is found from the total emission for Belgium and the agricultural area within the municipalites, thereby assuming the same emission density in those areas for the whole country.

The emission for the F.R.G. is only computed for the following IE grid elements (x,y coordinates): (38,33), (39,33), (39,32), (40,32), (40,31) ,(40,30), and (40,29). For this part of the F.R.G.(consisting of parts of Nordrhein-Westfalen and Niedersachsen) the emission from fertilizer is read from the file IEEMNEW.DAT and distributed over the municipalities in such a way that the same emission density for fertilizers is obtained for every municipality. The emission computed for the western part of the F.R.G. is slightly different (1% for the total emission, up to 6% for a category) then for the sum of the IE emission grids. This is caused by the fact that whole municipalities are taken in this survey, whereas in the computation of the emission for the IE grids also parts of municipalities was taken into account by Buijsman *et al.* (1987).

A4.2 Belgium

The programme used to compute the detailed emission for Belgium is **BELEM2.FOR**.
Input files:

BELGEO.DAT : Gives for each municipality: number of municipality, name municipality, latitude and longitude of the centre (decimal degrees), two characteristic diameters (km), not yet used space for the official area of the municipality, agricultural area (km^2), not yet used space for number of inhabitants.
Format: I5, 1X, A30, 4F6.2, 10X, F10.4, 10X.

BELNR.DAT : Gives for each municipality: number of animals for different animal subcategories. See comment in BELEM2.FOR for details.

IEEMF2.DAT : Emission factors for animals, see Appendix 2.

IENR2B.DAT : Number of different animals for each country, see Appendix 2.

IEEMNEW2.DAT : New emission for Europe on IE grid, see Appendix 2.

Output file:

BELEM2.DAT : Contains for every municipality: Number of municipality, latitude and longitude of the centre (decimal degrees), radius (m), emissions for the following categories (tonne NH_3 yr^{-1}):

1. Cattle

2. Pigs
3. Poultry
4. Horses
5. Sheep
6. Total emission from livestock
7. Application of fertilizer
8. Total emission (sum of all categories)

Format: I8, 1X, A30, 2F6.2, F6.0, 8F7.2.

A4.3 Nordrhein-Westfalen

The programme used to compute the detailed emission for Nordrhein-Westfalen is **NRDEM2.FOR**.
Input files:

NRDGEO.DAT	: Gives for each municipality: number of municipality, name municipality, latitude and longitude of the centre (decimal degrees), two characteristic diameters (km). Format: I5, 1X, A30, 4F6.2.
NRDNR.DAT	: Gives for each municipality: number of animals for different animal subcategories. See comment in NRDEM2.FOR for details.
IEEMF2.DAT	: Emission factors for animals, see Appendix 2.
IENR1.DAT	: Number of different animals for each country used by Buijsman *et al.* (1987).
IENR2B.DAT	: Number of different animals for each country, see Appendix 2.
IEEMNEW2.DAT	: New emission for Europe on IE grid, see Appendix 2.

Output file:

NRDEM2.DAT	: the same as BELEM2.DAT.

A4.4 Niedersachsen

In parts of Niedersachsen larger municipalities were made out of smaller ones. The emission in the file NIEEM2.DAT is given for the old (smaller) municipalities, but the centre and radius is given for the new municipality of which they are now part. This means that there exist more than one source at the same location in the emission file. After the name of the old municipalities the number of the new municipality to which it belongs is given (as part of the name).

The programme used to compute the detailed emission for Niedersachsen is **NIEEM2.FOR**.
Input files:

NIEGEO.DAT	: Gives for each municipality: number of municipality, name municipality, latitude and longitude of the centre (decimal degrees), two characteristic diameters (km). Format: I5, 1X, A30, 4F6.2.
NIENR.DAT	: Gives for each municipality: number of animals for different animal subcategories. See comment in NIEEM2.FOR for details.
IEEMF2.DAT	: Emission factors for animals, see Appendix 2.
IENR1.DAT	: Number of different animals for each country used by Buijsman *et al.* (1987).
IENR2B.DAT	: Number of different animals for each country, see Appendix 2.
IEEMNEW2.DAT	: New emission for Europe on IE grid, see Appendix 2.

Output file:

NIEEM2.DAT	: the same as BELEM2.DAT.

A4.5 Combining the emissions of Belgium and the F.R.G. in one file

The programme to combine the emission files of Belgium and the parts of Nordrhein-Westfalen and Niedersachsen is **BOUNCOM2.FOR**.
Input files:
BELEM2.DAT : see above.
NRDEM2.DAT : see above.
NIEEM2.DAT : see above.
Output file:
BOUNEM2.DAT : the same as BELEM2.DAT, but then for the whole area.

APPENDIX 5. RATIO MEASURED/MODELLED WET DEPOSITION OF NHx IN THE NETHERLANDS

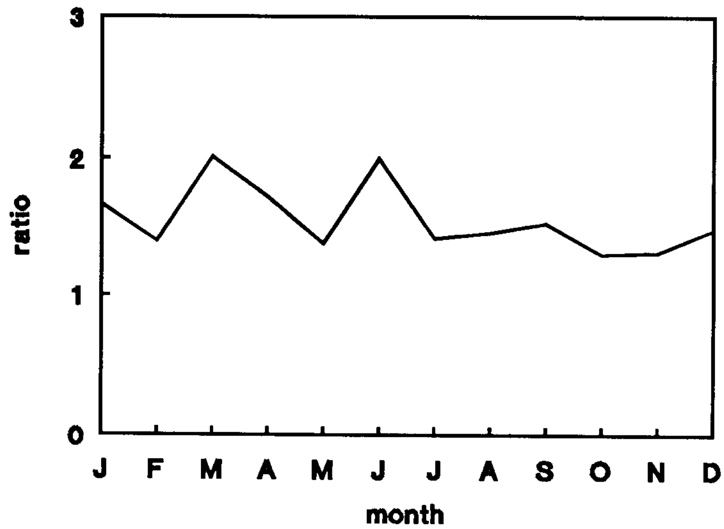

Fig. A5-1. Ratio measured/modelled wet deposition of NH_x De Kooy 1978-1986.

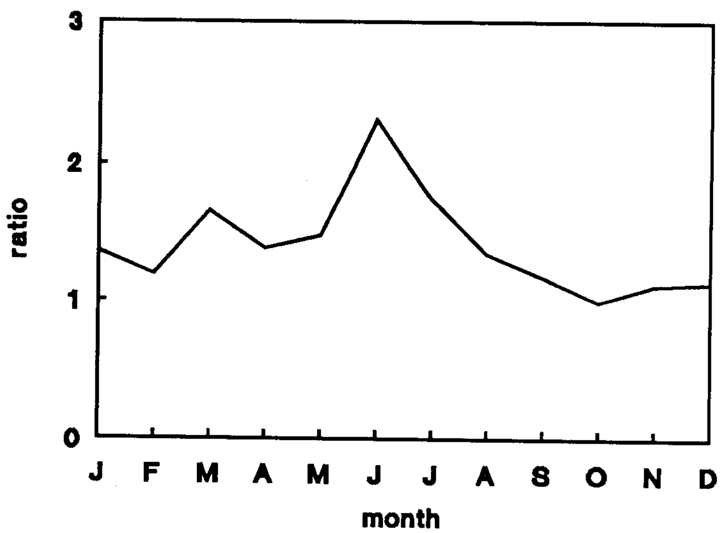

Fig. A5-2. Ratio measured/modelled wet deposition of NH_x Leeuwarden 1978-1986.

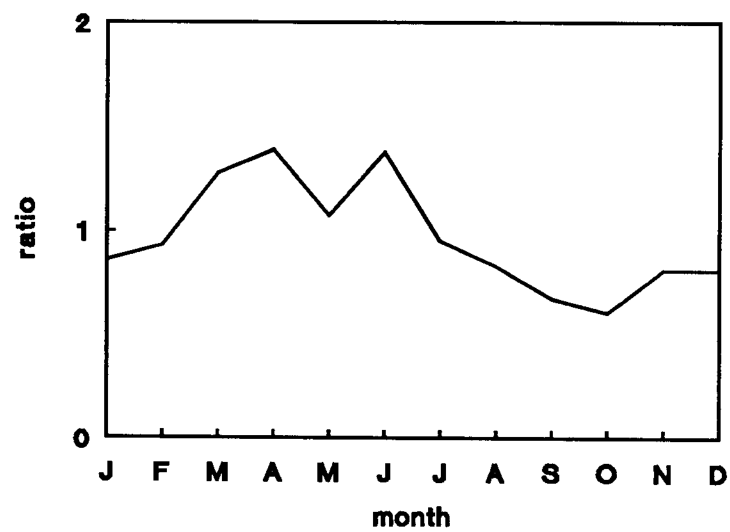

Fig. A5-3. Ratio measured/modelled wet deposition of NH_x Witteveen 1978-1986.

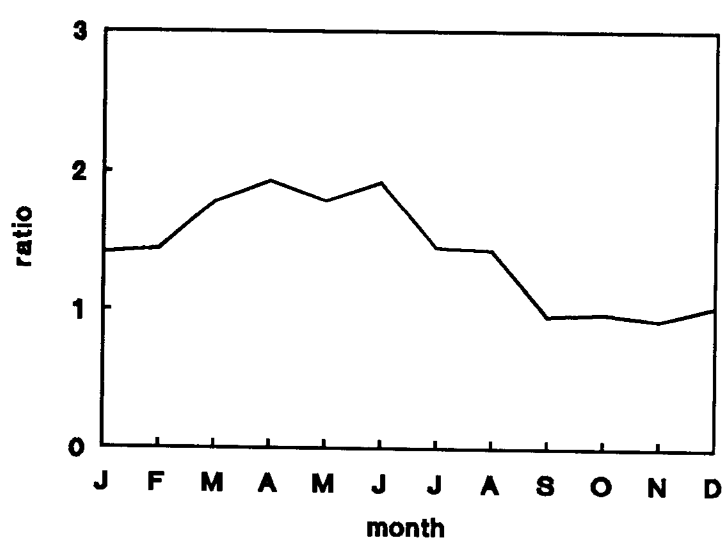

Fig. A5-4. Ratio measured/modelled wet deposition of NH_x Lelystad 1978-1986.

Fig. A5-5. Ratio measured/modelled wet deposition of NH_x Twente 1978-1986.

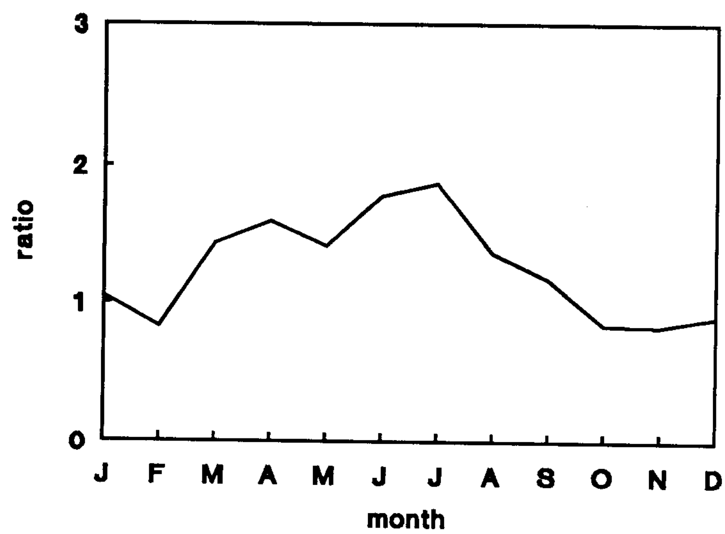

Fig. A5-6. Ratio measured/modelled wet deposition of NH_x Rotterdam 1978-1986.

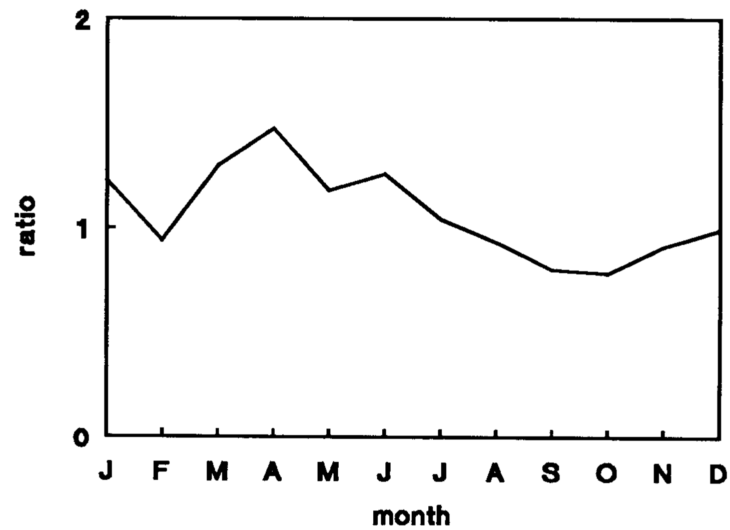

Fig. A5-7. Ratio measured/modelled wet deposition of NH_x De Bilt 1978-1986.

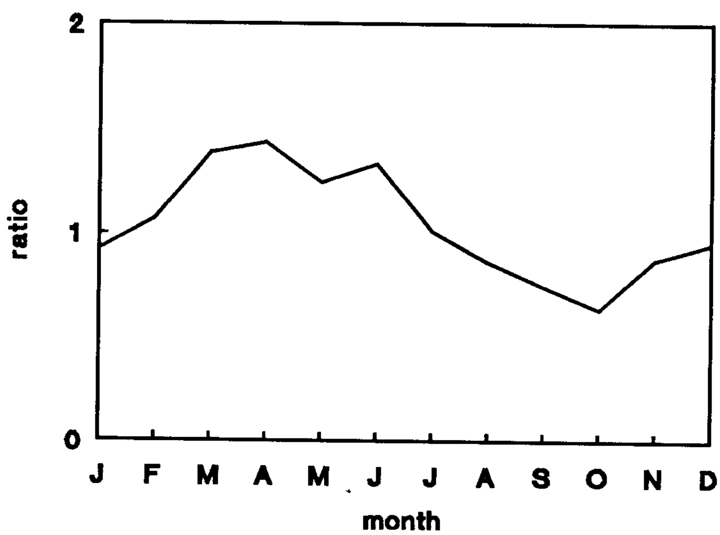

Fig. A5-8. Ratio measured/modelled wet deposition of NH_x Deelen 1978-1986.

Fig. A5-9. Ratio measured/modelled wet deposition of NH_x Vlaardingen 1978-1986.

Fig. A5-10. Ratio measured/modelled wet deposition of NH_x Gilze-Rijen 1978-1986.

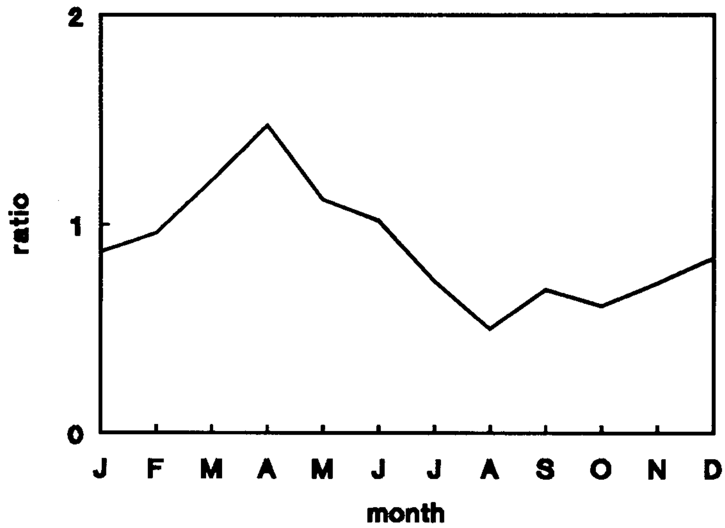

Fig. A5-11. Ratio measured/modelled wet deposition of NH_x Eindhoven 1978-1986.

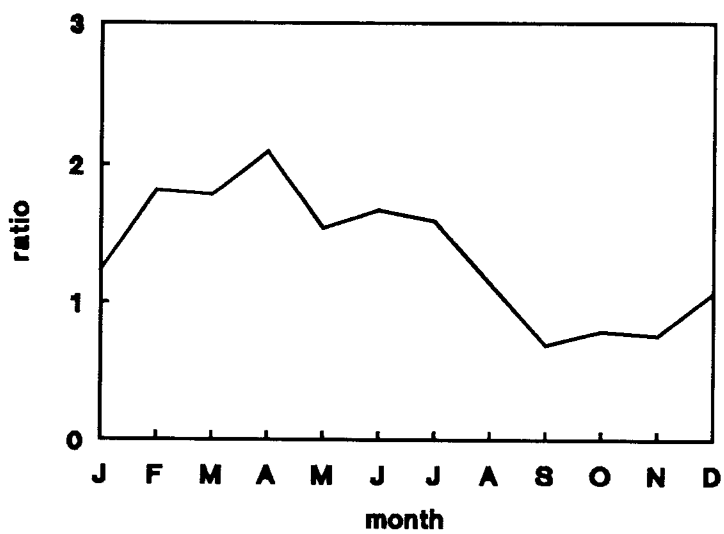

Fig. A5-12. Ratio measured/modelled wet deposition of NH_x Beek 1978-1986.