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THE DUTCH NITROGEN CASCADE IN THE EUROPEAN PERSPECTIVE

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Abstract
The Netherlands is 'well known' for its nitrogen problems; it has one of the highest reactive nitrogen (N_r) emission densities in the world. It is a small country at the delta of several large European rivers. Ever since the industrial revolution, there has been a growing excess of nutrients and related emissions into the atmosphere (ammonia, nitrogen oxides and nitrous oxide) and into groundwater and surface water (nitrate), leading to a large range of cascading environmental impacts. Vehicular traffic, sewage and animal husbandry are the main sources of oxidized and reduced forms of N_r. This report provides an overview of the origin and fate of nitrogen in the Netherlands, the various reported impacts of nitrogen and the Dutch and European policies to reduce nitrogen emissions and related impacts. In addition, ways are presented to go forward to potentially solve the problems in a European perspective. Solutions include the improvement of nitrogen efficiencies in different systems, technological options and education.

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SUMMARY

The two faces of nitrogen

Nitrogen (N) has a good and a bad side: it is necessary for all forms of life and a crucial component in the increased production of food to feed the world population. At the same time it threatens the environment because the N used to produce food cannot be utilized without losses to the environment and reactive nitrogen (N_r) is also formed when energy is produced from fossil fuels. This is the basic dilemma for nitrogen management policies. Furthermore, N is an important crosscutting theme over most of the key environmental problems for Europe such as climate change, biodiversity, ecosystem health, human health and groundwater pollution. Each of these N-related problems is addressed with a range of policy instruments and measures. There are obvious benefits if these problems could be considered in an integrated way and not as isolated phenomena. Such an approach would increase the possibility of keeping in pace with the necessity for food and energy production while finding more (cost) effective solutions for both the unavoidable use of N in agriculture and for the development of the abatement strategies in various sectors that leak N_r.

Adverse impacts of nitrogen

Reactive nitrogen, N_r, is defined here as all forms of nitrogen apart from N_2. Vehicular traffic, energy use, industry, sewage and animal husbandry are the principal sources of oxidized and reduced forms of N_r. The negative impacts of these emissions include eutrophication of nature areas and surface waters, soil acidification, and nitrate pollution of groundwater, particle formation leading to impacts on human health and influencing the earth's radiation balance, ozone formation leading to effects on humans and vegetation, and to climate change when it is transformed into nitrous oxide, one of the most important greenhouse gases. Although the effects of N inputs on the carbon cycle remain controversial, there are indications of a strong relationship both stimulating greenhouse gas emissions and carbon sequestration and plant/forest growth. Increased inputs of N to aquatic ecosystems from atmospheric deposition, sewage, and agricultural runoff can cause eutrophication, including damage to fisheries in coastal ecosystems. The formation of N_2O during nitrification and denitrification in all systems results in tropospheric warming and stratospheric ozone depletion. These undesirable "cascading effects" of N_r moving through aquatic and terrestrial ecosystems and the atmosphere do not stop until the N_r is eventually converted back to N_2 through the process of denitrification. One molecule of N_r can contribute therefore to a cascade of effects. The anthropogenic input has been steadily increasing and human activity now fixes more atmospheric N_2 into reactive forms than all terrestrial natural processes combined. A notable example of the effects on fauna is the disappearance of the red-backed shrike (*Lanius collurio*) in coastal dunes of the Netherlands and in other parts of Western Europe due to high N deposition inputs. The red-backed shrike is a good indicator of fauna diversity, since its breeding success highly depends on the availability of large insects and small vertebrates.

Evidence for serious adverse effects on faunal species diversity and marine systems exists, but the level of scientific understanding is rather low. In the Netherlands the main focus of effects related to nitrogen are currently on groundwater nitrate levels, the decrease in biodiversity and forest vitality, human health in relation to NO_x and algal blooms in the North Sea.

Nitrogen problems in the Netherlands

The Netherlands is 'well known' for its production and export of high quality agricultural products. It can also be characterised as a very small country with a high population density and large industries focussed on the added value of importing and exporting materials and goods. Since the industrial revolution, there has been a growing overload of nutrients and related emissions into the atmosphere (NH_3, NO_x and N_2O) and groundwater and surface water (NO_3).

After World War II agricultural production and industry/traffic increased enormously. Nitrogen has had a beneficial role in this process. It was imported through animal feed and at the same time relatively easily produced through the Haber-Bosch process in fertiliser plants. Hence, the increase in agricultural industry was facilitated partially by the cheap availability of N_r. The Netherlands has one of the highest N_r emission densities in the world. Other countries in Europe or parts in the world where N has just been recognised as a serious threat could benefit from this experience. This is also true for those areas that need to develop and increase their nitrogen use to feed the population.

N budget in the Netherlands

By 1910, the Netherlands housed nearly 6 million inhabitants, very little fertiliser entered the country, and feed imports were small. Nevertheless, the annual N cycle between soil, plants, and cattle based on the natural fertility of the soil amounted to 160 kton N. The food supply contained 30 and 15 kton N per year in plant and animal products, respectively. By 1950, the fertiliser industry had developed and its use had risen tenfold to 160 kton N. The feed imports had remained at previous levels. The N cycle increased with 30%. Soils were loosing 1/3 of the N supply by denitrification. Since 1950, fertiliser use has tripled, and feed imports have increased 16-fold. Hence, by 1999, the N cycle doubled and soil losses were estimated at half the N supply. Furthermore, gaseous losses from manure in the intensive husbandry upset the nutrition balance of surrounding ecosystems. Food supply contains 105 and 180 kton N per year in plant and animal products, respectively. The national food industry serves enough food for 32 million people, which is twice the current population of the Netherlands. The nitrogen efficiency decreased between 1910 and 1999 to a large extent, leading to more losses to the environment compared to the N increase in products.

Agricultural product value was small – about 200 million euro – in the early twentieth century. Cattle, pigs and poultry – estimated at respectively 2, 1.25, 10 million heads – produced about 170 kton N manure, while synthetic fertiliser use had yet to start. The introduction of synthetic fertiliser stimulated the economy until the World War II collapse. After the war the agricultural product value rose in forty years to 8000 million euro. By 1985 manure production peaked at some 600 kton N produced by 5 million heads of cattle, 12 million pigs, and 90 million heads of poultry. Synthetic fertiliser use had increased to 500 kton N or 250 kg N per hectare. Since 1985, Dutch agricultural policies were diverted from favouring agri-economic development to environmental protection. Policy focused on emission prevention, but also on the decrease of the animal stocks. Particularly, the number of pigs dropped with more than 30% during the last twenty years. Also the number of cattle dropped strongly as the result of the agricultural policies in the EU (milk quota). Dutch policies to reduce the agricultural pressure on air and soil have been successful. While the production volume of the agricultural sector increased since 1985 with some 25%, the excess N application shrunk with more than 50%.

N policies in the Netherlands in the European perspective

Several measures and policy options were evaluated and an overview of these is given in this report. Three categories are distinguished: (i) <u>legal and fiscal rules</u>: these measures cannot be avoided by those concerned and producers and/or consumers have a legal duty to obey them; (ii) <u>guidelines and incentives</u>: these measures aim at stimulating positive behaviour by providing (technical) information or a financial incentive; (iii) <u>(social) education</u>: trying to change consumer and producer behaviour through education, e.g. advertising campaigns, brochures etc. The policies and measures were evaluated on their effects to combat N pollution in the Netherlands and Europe. An analysis of the present extensive package of sectoral nitrogen measures shows that they have been effective in reducing individual flows and effects of N. This was also caused by the fact that the gap between the emissions and the targets was very large. However, additional measures will be required to attain the targets for nitrate, N deposition, surface water loading and NO_x emissions.

Successful policies: The most successful policies include e.g. the implementation of the wastewater treatment. The increase in the 1990s of the population connected to tertiary wastewater treatment, which removes nutrients and organic matter, has resulted in marked reductions in phosphorus and nitrogen discharges. Ammonia emissions were abated by the obligation to reduce the evaporation of manure and urea and as a side effect of quota that regulated the milk production. Since the introduction of the system of mineral bookkeeping in the Netherlands in 1998, there has been a significant reduction of the N surplus in the agricultural sector due to a reduction of the use of inorganic fertilisers. On the whole this has resulted in a reduction of the NO_3 concentration in ground and surface waters. The proportion of renewable energy has increased, supported by policy interventions aimed at stimulating the growth of new renewable technologies, to 2% (aim 10% in 2020). Quality standards for emissions and fuel have greatly contributed to reduction of air pollution from road vehicles through the introduction of the three-way catalytic converter. The voluntary agreement between car manufacturers and the European Commission has stimulated the energy efficiency of new cars in the EU. The different protocols under the UN/ECE Convention on Long Range Transboundary Air Pollution have resulted in decreases of especially SO_2, but also NO_x and NH_3 emissions in Europe. Currently a number of N_r problems related to air pollution are being tackled in an integrated manner in Europe. The reason for developing an integrated approach was mainly to reduce costs. The Gothenburg Protocol that was adopted and signed in 1999 set emission ceilings for SO_2, NO_x, NH_3 and VOC for 2010 in order to combat acid and N deposition on natural ecosystems and the effects of ozone on human health and natural ecosystems. Once the Protocol is fully implemented, Europe's sulfur emissions should be cut by at least 63%, its NO_x emissions by 41%, its VOC emissions by 40% and its ammonia emissions by 17% compared to 1990. During the preparation of this Protocol it was estimated that an integrated and cost-effective approach to acidification, eutrophication and ground-level ozone in Europe would halve the costs.

Less effective policies: Apart from the successes also examples of less effective measures can be given. The fact that agricultural policies for many decades have been directed exclusively towards production increase, without taking into account the environmental impacts, can be considered a policy failure. A clear example of this is the European agricultural subsidiary system, which is entirely focussed on socio-economic factors, farmers' employability and supporting and increasing production, without taking the environmental consequences into account. According to an evaluation by the European Environment Agency, EEA, in 2003 there was no evidence of a decrease (or increase) in levels of nitrate in Europe's groundwaters. It was found that nitrate drinking water limit values were exceeded in around one-third of the groundwater bodies for which information is currently available. Environmentally related taxes in the EU are levied almost exclusively on households and the transport sector. The polluter pays principle is undermined by the exemptions and rebates for the industrial sector and the abatement measures are not directed to the areas where they are likely to have the greatest overall effect. In the EU there has been an overall increase of emissions from transport, despite various measures to reduce emissions, due to growing transport. The EU Common Agricultural Policy (CAP) has stimulated intensification of agricultural production and contributed to environmental problems. The Agenda 2000 reform of the CAP has not addressed the serious nitrate pollution problem in regions of intensive pig and poultry production. The education program for farmers that was linked to the Dutch manure policy has reached 20-30 percent of the farmers. About 50 to 80 % of theses farmers have used the knowledge in their management. The aim of the educational program to reach all farmers was too ambitious. Other examples of less effective measures include:

- manure transfer agreements that result in a better distribution of manure, do not lead to a reduction of the total amount of manure produced and of the total potential losses,
- the Clean Development Mechanism as part of climate policies enables the Netherlands to invest in measures in other countries - often against lower cost. However, at a national level this does not result in a reduction of the emissions of NO_x, which would be attained if the CO_2 reduction would be realized by domestic measures,

- the promotion of organic food production failed in the Netherlands due to high prices that discouraged consumers.

In order to develop more effective policies it is useful to identify the reasons of ineffective policies. A general problem with the implementation of some of the policies is the lack of enforcement or of an inspection regime. There are many diffuse sources with a huge variation and with complex interactions. Furthermore, there are complex links between the different spatial scales (local, regional, national, global) and the involved governments and stakeholders. Other reasons for not being successful include the strong lobby of the farmers in politics up to the end of the last century and the strong juridical emphasis of the problems and solutions. Furthermore, the economics of measures have not been profitable enough to implement them, especially because of the low prices of products (local and global markets) and the cheap energy prices. If the cost of a measure cannot be paid off within a certain (short) time period it is impossible for individuals to invest in costly measures. Targets were to increase production (economic sustainability), which inevitably led to a decrease in efficiency of (cheap) N and other resources. Finally, consumers are accustomed to luxury food and energy use (transport, personal comfort, electricity, etc.).

New (innovative) measures

In the National Environmental Plan 4 of the Dutch government it was recognized that the current most challenging environmental issues need system innovations and the terms *Transitions* and *Transition management* were introduced. The basis of transitions is that the government chooses long-term targets and that through cooperation of the different stakeholders, supervised by the government, system innovations can be stimulated and introduced necessary to reach the long-term targets. Transition programmes have started for the four most challenging environmental problems: sustainable energy, sustainable mobility, sustainable agriculture and sustainable resources (including biodiversity).

In September 2004 a workshop was organised to bring the experience of the four transition programmes together with the aim of developing innovative strategies for the N issues, providing a cross-link over all four transitions. The workshop concluded that no innovative measures or policies could be defined that had not been identified earlier. This does not imply that everything has been tested in practice. The issue is very complex because of the involvement of different stakeholders, the many interactions and the complex nature of the problem (variation, scale, cascade, etc.). The general line of successful policies on reducing the cascade effect of N is well accepted and can be categorized as follows:
- limit N production or limit import of N through animal concentrates,
- increase N_r use efficiency and close nutrient cycles at different scales,
- more evenly distribute N production over the country or over the whole EU,
- convert N_r to N_2 catalytically or by stimulating denitrification.

For these options, measures are given in this report.

Final remarks

The Netherlands is a clear example of a country that profited from the cheap availability of N_r leading to the negative impacts of intensive agriculture, industrialization, urbanization and mobility. A strong tension exists between economical and societal interests and environmental effects, which poses quite a challenge. In this paper options are put forward that can substantially reduce the loads of N_r to the environment. We realize that the future policies should be focused on setting and meeting the targets through some freedom for the stakeholders and not, as has been done mostly up till now, by prescribing what the stakeholder should do! Targets should be based on all effects (no trade-offs), on sound science and a clear long-term vision, which takes into account the Dutch position in Europe. We should aim for the closing the nutrient cycles and minimizing resource use. Therefore, the scientific community should come up with simple, easy to determine indicators that can be used to implement, monitor, evaluate and maintain policies: e.g. N efficiency indicators and N rulers.

Some of the options should be agreed upon within the framework of the European Union, because it affects other countries or the competitiveness of Dutch entrepreneurs. Such measures include taxes or financial grants, and setting of targets for N losses. Furthermore, the closing of cycles should be tackled at different scales at the same time. We are accustomed to seek our improvements in technological options. There are potential technologies that might lead to substantial emission reduction (catalytic converters, hydrogen economy, nitrification inhibitors, fermentation of manure, etc.). These are important, but the reduction in environmental load they cause should not lead to increased import of raw materials, leading to changes in cycles at supranational scales. Furthermore, other components (such as carbon) and issues (access to freshwater) should be taken into account to prevent trade-offs. If financial incentives are given, it is important to secure the period that these incentives will last, in order to guarantee a return on investment.

To stimulate innovation we suggest the creation of an experimental region within the Netherlands where viable options that do not fit within current regulations can be tested.

1. INTRODUCTION

1.1 Rationale

The Netherlands is 'well known' for its production and export of high quality agricultural products. It is also known as a very small country with a high population density and large industries focussed on the added value of importing and exporting materials and goods. After World War II there has been an enormous increase in agricultural production and industry/traffic. Nitrogen (N) has had a beneficial role in this process. It was imported through animal feed from developing countries and at the same time relatively easily produced through the Haber-Bosch process in fertiliser plants. The increase in agricultural industry was facilitated a.o. by the cheap availability of N. Now the country is also known for its N problems in terrestrial ecosystems (van Breemen et al., 1982; Heij and Erisman, 1997; Erisman et al., 1998; 2001; 2003; de Vries et al., 2003), aquatic ecosystems (Roelofs et al., 1996), groundwater (Oenema et al., 1998) and marine ecosystems (Skogen et al., 2004). The Netherlands is also known as a forerunner in the development of knowledge of the N cycle and the relevant processes, their technological innovations and the ways to combat N pollution. This leading role can be made an advantage to other countries in Europe or parts of the world where N has only just been recognised as a serious threat or for those areas that need to develop and increase their N use to feed the population. It is therefore considered very relevant to share the knowledge and make it useful to others. The current Dutch situation, its knowledge, data and assessments provide a good example for other areas in the world. In this paper it is used to put the Dutch N cascade in a European perspective. This provides insights in the N issues and possible solutions relevant for similar areas of the world. New in this respect is (i) quantification of cascade and (ii) estimation of the influence of EU policies on the Dutch N situation and (iii) identification of measures and policies to most effectively abate N.

1.2 Background

The Netherlands is a small country at the delta of two large European rivers: the Rhine and the Meuse. The Netherlands has always been a country that imported raw materials to be manufactured into added value products for export. In addition, agriculture has always been an important economic factor, especially in the last decades, where intensive livestock breeding increased to a large extent. All these activities have lead to increased imports of raw materials and concentrates and export of products and goods, accompanied with the remaining of waste materials in the country. Table 1.1 gives some pertinent numbers for the Netherlands (CBS, 2001). Since the industrial revolution, there has been a growing overload of nutrients and related emissions into the atmosphere (NH_3, NO_x and N_2O) and groundwater and surface water (NO_3). The Netherlands is known for having one of the highest reactive nitrogen (N_r) emissions densities in the world[1]. Vehicular traffic and animal husbandry are the principal sources of oxidized and reduced forms of N_r. The impacts of these emissions in the Netherlands (and many other countries) include eutrophication of nature areas and surface waters, soil acidification, and nitrate pollution of groundwater, particle formation leading to impacts on human health and influencing the earth’s radiation balance, ozone formation leading to effects on humans and vegetation, and to climate change when it is transformed into nitrous oxide, one of the most important greenhouse gases (e.g. Galloway, 1998; Galloway and Cowling, 2002; Galloway et al., 2003; Matson et al., 2002). Although the effects of N inputs on the carbon cycle remain

[1] The term reactive nitrogen (N_r) as used in this paper includes all biologically active, photochemically reactive, and radiatively active N compounds in the atmosphere and biosphere of the Earth. Thus N_r includes all nitrogen compounds except N_2: inorganic reduced forms of N (e.g., NH_3, NH_4^+), inorganic oxidized forms (e.g., NO_x, HNO_3, N_2O, NO_3^-), and organic compounds (e.g., urea, amines, proteins).

controversial (Houghton et al., 1998; Nadelhoffer et al., 1999), there are indications that there is a strong relationship both stimulating greenhouse gas emissions and carbon sequestration and plant/forest growth. Increased inputs of N to aquatic ecosystems from atmospheric deposition, sewage, and agricultural runoff can cause eutrophication, including damage to fisheries in coastal ecosystems (Rabalais, 2002). The formation of N_2O during nitrification and denitrification in all systems results in tropospheric warming and stratospheric ozone depletion (Prather et al., 2002). These undesirable "cascading effects" (see Box), as Galloway et al. (2003) call them, of N_r moving through aquatic and terrestrial ecosystems and the atmosphere do not stop until the N_r is eventually converted back to N_2 through the process of denitrification (Figure 1.1). One molecule of N_r can contribute therefore to a cascade of effects (see box on the nitrogen cascade). The anthropogenic input has been steadily increasing and human activity now fixes more atmospheric N_2 into reactive forms than all terrestrial natural processes combined (see also Galloway et al., 1995; Vitousek et al., 1997). Figure 1.2 presents the effects and fluxes in the N cascade as described, analysed and evaluated in this report.

Table 1.1 *Illustrative numbers related to nitrogen problems in the Netherlands*

Some important numbers	Environmental factors
16 million inhabitants	362 kton N input by forage
100 million poultry	396 kton N input by fertilisers
15 million pigs	90 kton N input by deposition and biological fixation
4 million cattle	180 kton NH_3 emissions
6 million cars	490 Kton NO_x emissions
454 people per km^2 of land	72 kton N_2O emissions
60% agricultural area of the total land area	GDP = 25 thousand $ per inhabitant
Rotterdam, the largest port of the world	Annual GDP growth ~ 3.9%
Industrial Rijnmond area with refineries, fertiliser plants, etc.	Unemployment ~ 5 %
Ecological Main Structure, a zone of connected nature areas through the country	

The nitrogen cascade. Human activities have increased the conversion of N_2 to reactive forms of N and, as a consequence, N is accumulating in the environment locally, regionally, and globally. The bulk of the atmosphere is N_2 gas, yet this form of N is not available to most of earth's biota. Thus, the rate at which N_2 is "fixed" into biologically available forms is vital in determining the structure and function of terrestrial, freshwater and marine ecosystems (Delwiche, 1970; Vitousek and Howarth, 1991). Humans are dramatically changing the rate of N_2 fixation, largely via fertiliser production, fossil fuel combustion, and widespread cultivation of N_2-fixing crop species (Galloway et al., 1995; Vitousek et al., 1997). These activities lead to an increase in multiple forms of N that are available to the biota, can move readily among terrestrial, aquatic and atmospheric realms, and that can alter the chemistry and/or radiative balance of the atmosphere. Galloway et al. (1995) labelled this diverse pool of N as "reactive N", and defined the term to include all biologically, radiatively, and/or photochemically active forms of the element. Examples include, but are not limited to: NO_3^- and NH_4^+, the predominant forms of N taken up by organisms, NO_x and NH_3, which are chemically important in the troposphere, and N_2O, which is an important greenhouse gas in the troposphere and can catalyse ozone destruction in the stratosphere. See Galloway et al. (1995), Vitousek et al. (1997) and Galloway and Cowling (2002) for additional details on the forms and consequences of increasing reactive N in the environment.

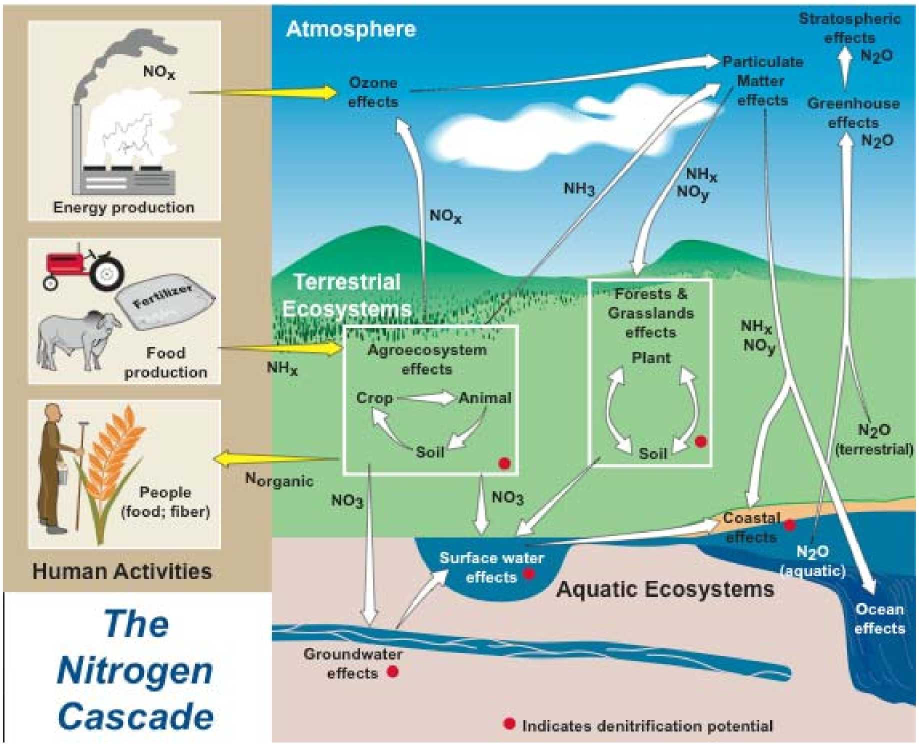

Figure 1.1 *The N cascade from Galloway et al. (2003)*

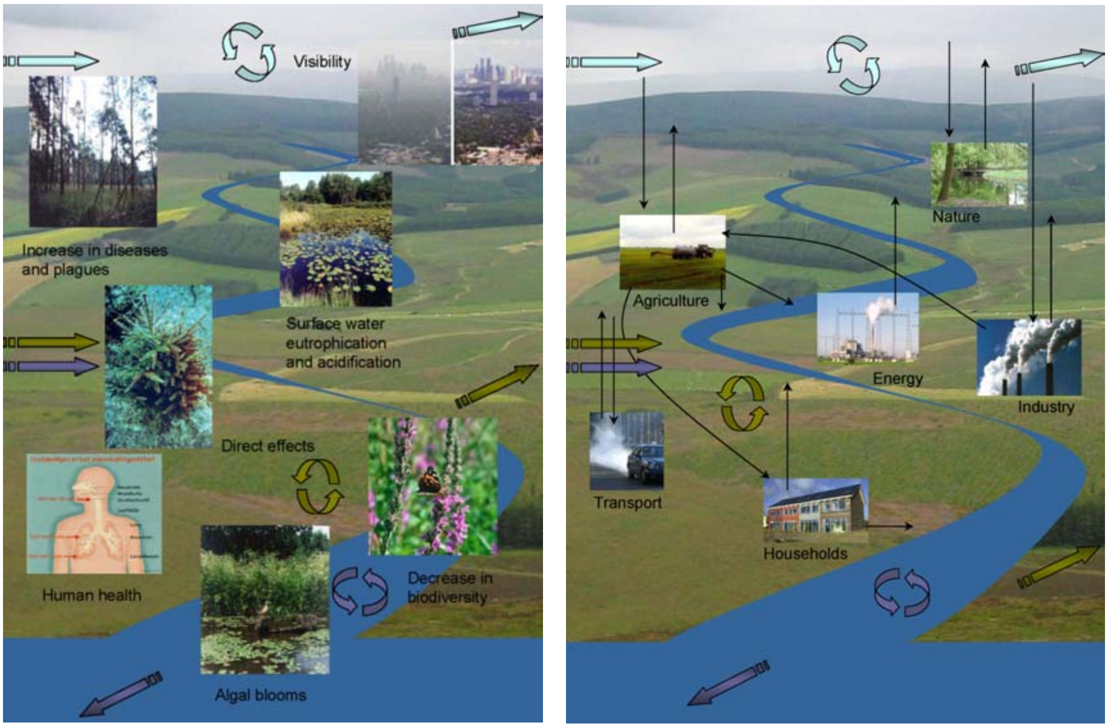

Figure 1.2 *Effects (left) and fluxes (right) in relation to the N cascade*

1.3 Nitrogen fluxes

During the last few decades, the introduction of N_r into the biosphere by food and energy production has been greater than rates of N fixation in native terrestrial ecosystems (Galloway and Cowling, 2002). Table 1.2 provides an overview of the global, European and Dutch N_r production. It is clear from this table that whereas on the global level the natural fixation is dominant (including the oceans), in Europe and especially in the Netherlands the human controlled inputs dominate. In the Netherlands only 3% of the total input is from natural sources. Even though these numbers cannot be compared as such, it is illustrative for the Dutch situation and the European situation in the world. The Netherlands is a very intensive Nr producing country. Integrated assessment models, such as NitroGenius (Erisman et al., 2002), and state of the environment reports (e.g. van Grinsven et al., 2003) use databases and process parameterisations to describe the entire system of N flows in the Netherlands. In Chapter 2 the Dutch N fluxes will be further explained and the budgets between 1910 and 1999 will be given to show and discuss the changes. Also in this chapter the Dutch fluxes will be compared to the European fluxes and it will be shown how the European fluxes influence the Dutch fluxes and vice versa.

Table 1.2 *Global, European and Dutch reactive nitrogen production in Tg N of current inputs of N to the biosphere. (In brackets: the percentage of the total budget)*

	Global	Europe	Netherlands
Natural terrestrial ecosystems			
• biological N fixation	90 (24)	14.8 (28)	0.025 (3)
• lightning	5 (1)	0.1 (0)	-
Total	*95 (25)*	*14.9 (28)*	*0.025 (3)*
Human-controlled inputs			
• Haber-Bosch N fertiliser and industry	85 (23)	21.6 (41)	0.4 (49)
• biological N fixation in agriculture	33 (9)	3.9 (7)	-
• animal feed imports	-	7.6 (14)	0.48 (59)
• combustion in industry and transportation	21 (6)	6.1 (11)	0.09 (1)
Total	*140 (37)*	*39.2 (74)*	*0.79 (97)*
Natural N fixation in oceans	**140 (37)**	**-**	**-**
Total	*375*	*53.2*	*0.815*

1.4 Adverse impacts of elevated nitrogen use in the Netherlands

There is a long history of N related problems and research in the Netherlands. The first N research in the Netherlands dates from the nineteenth century in the area of agriculture (Erisman, 2000). In the eighties of the last century the coordinated Acidification Research Program was executed, where the causal chain of a.o. N compounds was extensively studied (Heij and Schneider, 1991; Heij and Erisman, 1997). As a follow up the Nitrogen Research Program was executed in the nineties (Erisman and van Eerden, 2001). This research has shown that N has a large impact on air quality and climate, human health, terrestrial and aquatic ecosystems, groundwater quality and the marine biosphere. For some of these effects, such as marine eutrophication, it is obvious what the role of N is, however, for other effects it is much harder to quantify this role, e.g. in the case of human health in relation to particulate matter. In the Netherlands the main focus of effects related to N are currently on groundwater nitrate levels, the decrease in biodiversity and forest vitality, human health in relation to NO_x and algal blooms in the North Sea. Chapter 3 provides an overview of our current understanding of adverse effects from N_r. It provides an overview of all effects, but focuses on the Dutch and European situation. It also gives an indication of the knowledge level and the level of evidence for these effects.

1.5 Nitrogen policies in the Netherlands and Europe

The extensive research in the Netherlands has resulted in integrated models, databases and a science basis (a.o. de Vries et al., 2002; Erisman, 2000; Erisman et al., 2001; van Grinsven et al., 2003). Furthermore, several measures and policy options were developed, implemented and evaluated (e.g. van Grinsven et al., 2003). This forms the basis of Chapter 4. In this chapter an overview of all the policies and measures is given. Three categories are distinguished: (i) legal and fiscal rules: these measures cannot be avoided by those concerned and producers and/or consumers have a legal duty to obey them; (ii) guidelines and incentives: these measures aim at stimulating positive behaviour by providing (technical) information or a financial incentive; (iii) (social) education: trying to change consumer and producer behaviour through education, e.g. advertising campaigns, brochures etc. The policies and measures are evaluated on their effects to combat N pollution in the Netherlands and Europe. The effectivity of measures is assessed and a scheme is presented for selection of the most effective measures for the future abatement of N_r. This also forms the basis to identify new, more effective measures for the future.

1.6 Outline of this report

Aim of this paper is to describe the Dutch cascade in the EU perspective, show what the effect of the Dutch and EU policies are and identify the most effective policies to reduce the cascade. The report is structured to provide the background and quantification of N fluxes in Chapter 2 and an overview of the effects in Chapter 3. These form the basis for the assessment of policies and measures in Chapter 4. In this chapter also new, promising and integral approaches are suggested based on the studies done.

2. DUTCH REACTIVE NITROGEN FLUXES IN A EUROPEAN PERSPECTIVE

The Netherlands houses some 16 million inhabitants. Most of the working population is involved in the services industry, while only 2.1% is employed in the agricultural sector. The Dutch territory comprises 60% of agricultural land, 15% forests, nature and recreational areas, 10% water, and 15% cities, roads and industry. The 2 million hectares of agricultural area are used for grassland (54%), arable land including maize (40%) and horticulture (6%) (RIVM/CBS, 1999). Due to the N intensity of the economy people and terrestrial and aquatic nature are exposed to a severe N load (see Figure 2.1). In comparison, in Europe live 540 million, 46% of its area is suitable for agriculture. These decided differences lead to a different pattern in the N fluxes - and losses - associated with the economic development. As a consequence of its N intensity, the Netherlands early developed policy responses to abate N pollution (see also Chapter 4).

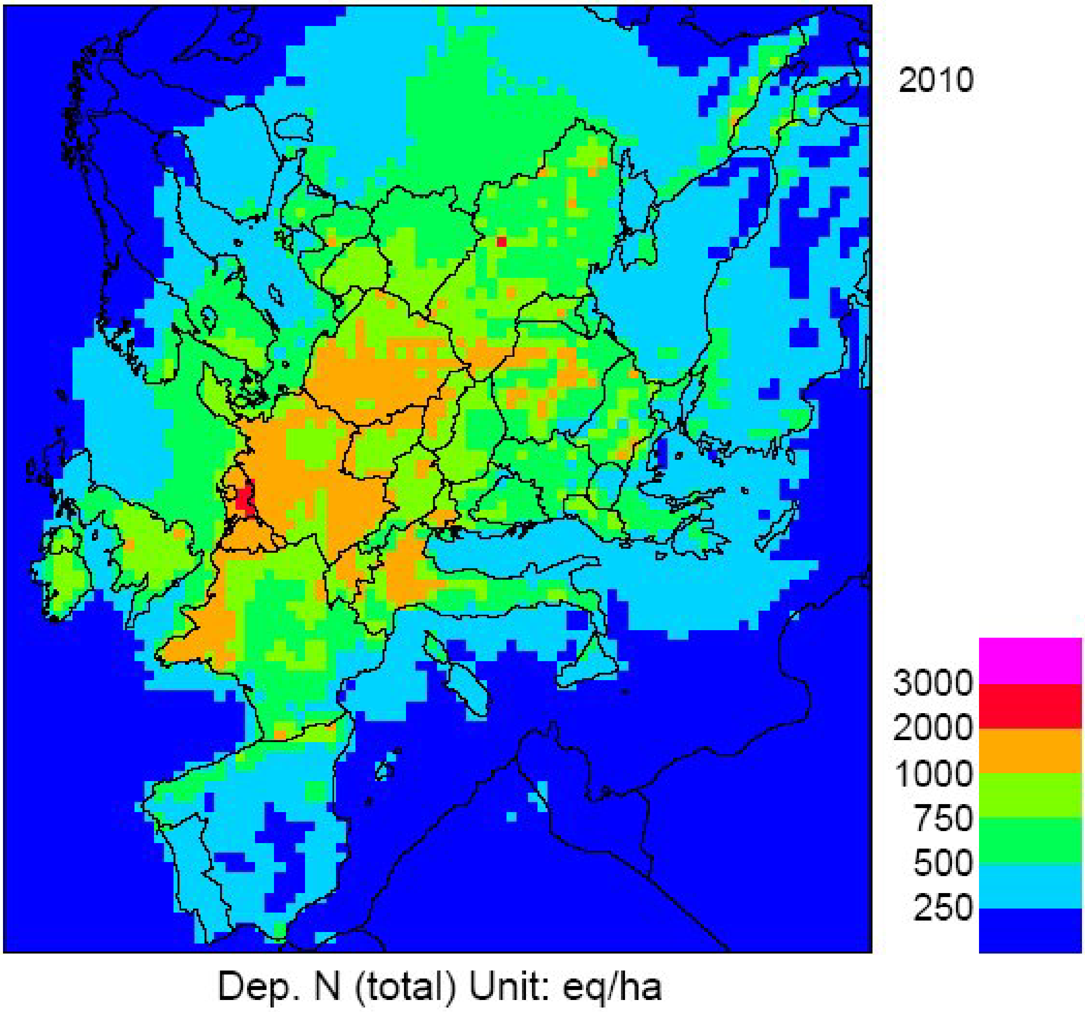

Figure 2.1 *Deposition of N (acid equivalent per ha) after implementing National Emission Ceilings for 2010 in Europe. The southeast of the Netherlands still receives more than 2000 acid equivalents per ha, which is the largest load in Europe. (EMEP, 2003)*

This chapter presents the N budget for the Netherlands (Section 2.1), and for Europe (Section 2.2). The chapter ends with a quantified review of the trends and environmental impacts related to agricultural and environmental policies (Section 2.3).

2.1 Nitrogen budget for the Netherlands

Table 2.1 presents a N budget for the Netherlands, based on best available estimates. N inputs into the Netherlands include import of N in products, by rivers, by the atmosphere, and fixation of N_2 by fertiliser production, combustion and bacteria. Of the 4000 kton N annually added to the Netherlands' economy 2720 kton N are exported in products. What happens to the remainder is less clear. Some of it is transported out of the country by rivers (about 400 kton N per year) or atmospheric transport (about 210 kton N per year). Most of the remaining 950 kton N is likely to be lost during denitrification, or accumulated in soils, sub-aqueous sediments and aquifers. Agriculture and food processing cycle a large amount of N through the economy. Some 400 kton N per year of synthetic fertiliser and 460 kton N per year of imported fodder fuel this cycle.

The intensity of the Dutch N cycle and its driving forces can be demonstrated by reviewing its historical development – farm scale - as illustrated in Figure 2.2 and Table 2.2. By 1910, the Netherlands housed nearly 6 million inhabitants, very little fertiliser entered the country, and feed imports were small. Nevertheless, the N-cycle between soil, plants, and cattle based on the natural fertility of the soil amounted to 160 kton N per year. The food supply contained 30 and 15 kton N per year in plant and animal products, respectively. Figure 2.3 displays the economic development and fertiliser use since 1900. During the early twentieth century agricultural product value remained small: estimated at about 200 million euro. Cattle, pigs and poultry – estimated at respectively 2, 1¼, 10 million heads – produced about 170 kton N in manure, while synthetic fertiliser use had yet to start.

Table 2.1 *The annual N budget of the Dutch arable and dairy economy (kton N per year) in 1910, 1950 and 1999 explaining the terms shown in Figure 2.2*

Source	**The Netherlands**		
	1910	**1950**	**1999**
Throughput	kton N	kton N	kton N
Plant uptake	154	346	405
Manure application/production	130	212	500
Feed (grass, hay, maize)	174	326	340
Input			
Biological fixation	50	50	25
Feed imports (hay, concentrates)	23	30	480
Synthetic fertiliser	13	160	400
Atmospheric deposition	20	45	80
Output			
Domestic plant products	30	70	105
Domestic animal products	15	20	180
Air emissions (animals)	40	105	95
Denitrification (in soil)	9	71	400
Air emissions (from soil)			175
Water pollution, errors, etc.	12	19	45

Source: C.S.M. Olsthoorn, pers. Communication.

Table 2.2 *The 1995-2000 annual N budget of the Netherlands'economy (kton N per year). Internal flow in the N budget consists of fertiliser (398) between industry and agriculture, plant and animal products (50+147) between agriculture and food processing, food and pet food (95+24) between food processing and consumers, and industrial products (300) between industry and consumers*
(Note: in- and output totals do not necessarily balance due to uncertainties in data from various – inconsistent – sources).

Consumers		Food processing		Agriculture		Chemical industry and refineries		Traffic	
Input						**Input**			
Fixation fossil fuel	6					Fixation	2594	Fixation fossil fuel	88
		Food import	465	Synthetic fertiliser	*398*	Import	300		
Food	*95*	Plant products	*50*	Import feed	483				
Pet food	*24*	Animal products	*147*	Accumulation	29				
Industrial products	300			Deposition	37				
Total	425		662		947		2894		88
Output						**Output**			
		Food	*95*			Synthetic fertiliser	*398*		
		Pet food	*24*			Industrial products	300		
				Plant products	*50*				
				Animal products	*147*				
		Food export	530	Feed export	53	Industrial exports	2127		
				Manure export	14				
Loss to air									
NH_3	6	NH_3		NH_3	137	NH_3	3	NH_3	
NO_2	6	NO_2		NO_2	27	NO_2	15	NO_2	87
N_2O		N_2O		N_2O	16	N_2O	18	N_2O	1
Loss to water									
Direct	1	Direct	4	Direct	6				
Wwtp[1]	53	Wwtp[1]	9	Indirect	66				
Loss to soil									
Products	300			Direct (accumulation and denitrification)	423				
Compost	3								
Disposal	20								
Total	389		662		939		2861		88

[1] wwtp= wastewater treatment plants
Source: Van Grinsven et al., 2003.

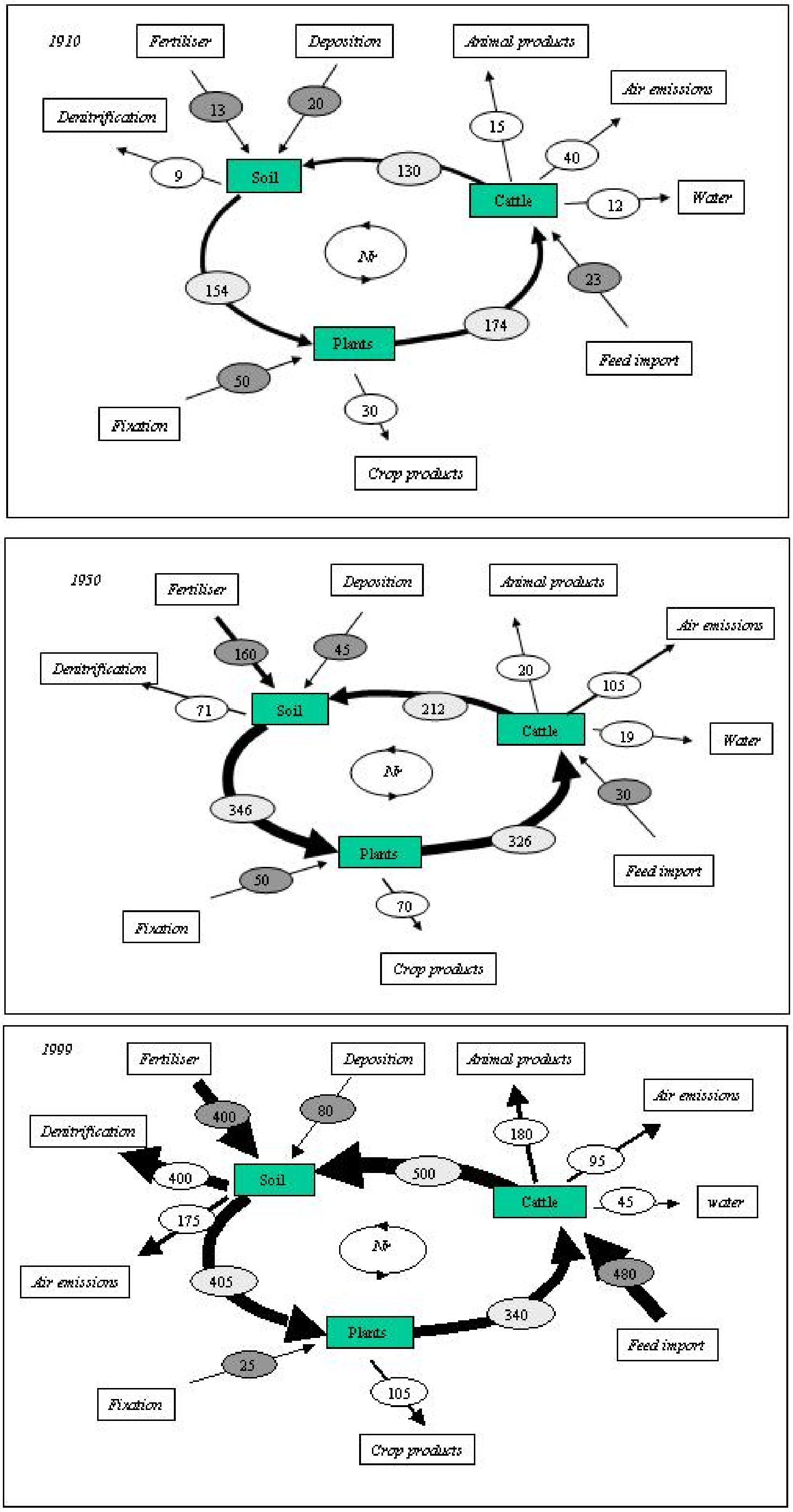

Figure 2.2 *The annual N budget of the Netherlands' arable and diary economy (kton N per year) in 1910, 1950 and 1999. The driving forces of the throughput – exchange between soil, plants and cattle – are synthetic fertilisers – rising from 13 to 160 and 400 kton N – and feed imports – rising from 23 to 30 and 480 kton N. By 1999, N-loss terms in air and soil oversize the N content of plant and animal products.*

The advent of synthetic fertiliser stimulated the economy until the World War II collapse. After the war the agricultural product value rose in forty years to 8000 million euro. By 1985 manure production peaked at some 600 kton N produced by 5¼ million heads of cattle, 12½ million pigs, and 90 million heads of poultry. Synthetic fertiliser use had increased to 500 kton N or 250 kg N per hectare.

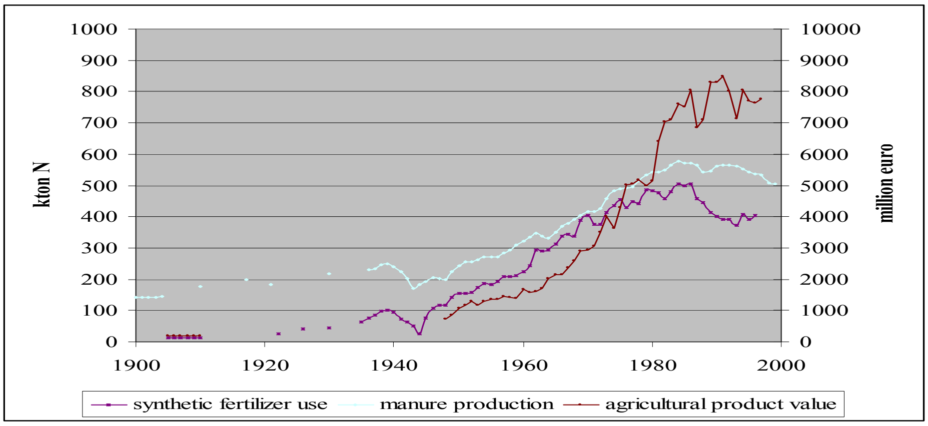

Figure 2.3 *Development of manure production, synthetic N-fertiliser use and agricultural product value in the Netherlands in the twentieth century (adapted from Statistics Netherlands (CBS), at http://statline.cbs.nl/StatWeb/historische reeksen)*

Since 1985, Dutch agricultural policies diverted from favouring agri-economic development to environmental protection. An up to date and complete review of recent agricultural policies with regard to nutrient flows has been presented at the 3rd International Nitrogen Conference in Nanjing in 2004 (van Eerdt et al., 2004). Policy focused on emission prevention, but also on the decrease of the animal stocks. Particularly, the number of pigs dropped with more than 30% during the last twenty years.

Dutch policies to reduce the agricultural pressure on air and soil have been successful. While the production volume of the agricultural sector increased since 1985 with some 25%, the excess N application shrunk with more than 50%. In recent years, this separation between economic development and environmental pressure seems to have entered a new stage as the agri-economic development stagnates, while the pressure still declines (RIVM, 2004).

By 1950, the fertiliser industry had developed and fertiliser use had risen tenfold to 160 kton N. The feed imports had remained at previous levels. The N cycle increased with 30%. Soils were losing 1/3 of the N supply by denitrification. Since 1950, fertiliser use has tripled, and feed imports have increased 16-fold. Hence, by 1999, the N cycle doubled and soil losses were estimated at ½ of the N supply. Furthermore, gaseous losses from manure in the intensive husbandry upset the nutrition balance of surrounding ecosystems. Food supply contains 105 and 180 kton N per year in plant and animal products, respectively. The national food industry serves enough food for 32 million people, which is twice the current population of the Netherlands.

An overview of the 1995-2000 annual N budget in the Netherlands for different ecosystems (atmospheric, agricultural, natural terrestrial, aquatic and marine) is given in Table 2.3 and discussed below.

Table 2.3 *The 1995-2000 annual N budget of the Netherlands subdivided over agricultural and natural soils, atmospheric and aquatic systems (kton N per year)*

Terrestrial System				Atmospheric system		Aquatic System			
Agricultural soils		Natural soils				Inland waters		Marine (North Sea)	
Inputs		**Inputs**		**Inputs**		**Inputs**		**Inputs**	
- fertiliser	398	- point sources	29	- consumers	12	- import by rivers	356	- import by rivers	*378*
- manure	496	- atmospheric	62	- industry	36				
- atmospheric	78	deposition		- energy	19	- point sources		- point sources	
deposition		- other	18	- traffic	88	- leaching	44		
- other	10			- agriculture	164	- atmospheric	90	- atmospheric	
						deposition	12	deposition	34
				- import	43				
Total	1010	*Total*	108	*Total*	362	*Total*	501	*Total*	412
Outputs		**Outputs**		**Outputs**		**Outputs**		**Outputs**	
- crops and grass	444	- leaching to		- atmospheric		- export by rivers	*378*	- export to Atlantic	?
- ammonia emissions	60	surface waters	4	deposition:		- other	3	ocean	
- leaching to surface				agricultural soils	78				
waters	86			natural soils	62	- accumulation and			
- accumulation and		- accumulation and	104	water	12	denitrification	121	- accumulation and	
denitrification	420	denitrification						denitrification	?
				- export	210				
Total	1010	*Total*	108	*Total*	362	*Total*	501	*Total*	412

Source: van Grinsven et al., 2003

Agricultural soils
The annual N input in Dutch agricultural soils by fertilisers, manure, atmospheric deposition and biological N_2 fixation was about 1000 kton N in the late twenty century (Tables 2.1 and 2.3). About 450 kton N was recovered in agricultural products. The remaining 550 kton N either stays in the agricultural system, or is lost to the environment. By introducing MINAS, the Dutch administration set levies on farms with high N surpluses. Full application of the scheme would decrease the N surplus in agriculture with about 400 kton by the year 2003 (e.g. Oenema et al., 1998; Oenema and Roest, 1998). Current knowledge about N and P cycling and losses from agriculture in the Netherlands, environmental targets and governmental policies and measures has been reviewed briefly by Schröder and Corré (2000) and Van Grinsven et al. (2003).

Non-agricultural soils
Non-agricultural soils receive 108 kton N per year by atmospheric deposition, local pollution, and biological N_2 fixation. Atmospheric deposition of nitrogen oxide (NO_x) and ammonium (NH_x) make up about 60% of total N inputs to non-agricultural soils. Most of the atmospheric deposition is anthropogenic and must therefore be considered as additional N input into these systems. N outputs are mainly denitrification and accumulation, with some leaching and runoff. A considerable part of the N from deposition is retained in the soil (e.g. Koopmans et al., 1996), but uncertainties in these estimates are considerable.

Atmospheric system
By examining model results, N deposition can be attributed to its sources. Such an attribution is especially helpful to target policy responses. In the Netherlands, ½ of the N deposition originates from its own agricultural sector, $^1/_3$ originates from abroad, and $^1/_6$ originates from its consumers, their pets and traffic. The emission caused by manure application has been reduced by prescribing the injection of manure into the soil to prevent the evaporation of ammonia. The single largest source now consists of the stables of the intensive animal husbandry, estimated at $^1/_6$ of the total deposition. This sector is currently under pressure, both because of its low economic returns and because of the aftermath of mass animal epidemics. The most effective policy measure is the improvement of the housings. Unfortunately, low emission housings – for laying hens – are not the best with regard to animal welfare.

Aquatic system
The Dutch aquatic system (defined as the aquatic system within the Dutch territory) includes lakes, large rivers such as the Rhine and the Meuse, many smaller streams, and numerous ditches that are part of the Dutch drainage system. The N inputs into aquatic systems within the Dutch territory amount to about 500 kton N per year, about 70% of which is imported by large rivers (Table 2.3). Leaching and runoff of N from Dutch soils, and industrial or urban point sources add to these inputs.

Rivers flowing through the Netherlands transport about 400 kton N to the North Sea. Most of this N entered the rivers through leaching and runoff from surrounding soils outside the Netherlands. The input to the North Sea comprises only a moderate part of the total N input to the watersheds of these rivers, which are much larger than the Dutch territory (Seitzinger and Kroeze, 1998). The remainder is lost somewhere between the soil and the mouth of the river, most likely through denitrification in small streams or accumulation in sediments.

OSPAR (2000) estimated that through rivers, atmospheric deposition and direct inputs respectively 700, 350, 100 kton N per year entered the Greater North Sea area in 1995. This contribution accounts already for half the estimated natural biological N fixation. It should be noted that these estimates are surrounded by large uncertainties. Concentrations of N and P in the Dutch coastal waters exceed natural values by a factor 5 to 10 since 1990. The extra input reveals itself in frequent algal (Phæocystis) blooms, which incidentally cover the North Sea beaches with a thick spume layer.

Uncertainties in N flows through various systems

The analysis of the N flows is hampered by uncertainties about the emission coefficients and the penetration of abatement techniques. De Vries et al. (2002) quantified the uncertainty by means of a Monte Carlo analysis. The 90% confidence interval for the fluxes of N compounds to air, groundwater and surface water (in kton N per year) ranged between 102 and 194 for ammonia emissions, between 18 and 51 for N_2O emissions, between 32 and 108 for NO_3 inflow to groundwater and between 2 and 38 for N inflow to surface water. The uncertainties are mainly due to the lack of knowledge about the process of denitrification in the soil and upper groundwater.

Denitrification is controlled by many factors, such as contents of nitrate, oxygen and degradable organic carbon and the temperature. Hence, the spatial and temporal variability of denitrification in soils is very high. Furthermore, no accurate method to measure denitrification on field (and larger) scale is available, which hampers an accurate quantification of denitrification in top and subsoil and in ground and surface waters. Therefore, the uncertainties in the estimation of N losses via denitrification are very high.

Using the IPCC error propagation calculation technique Van Gijlswijk et al. (2004) assessed the uncertainty of NO_x, SO_2 and NH_3 emissions in the Netherlands. They used a Monte Carlo technique, where the probability density functions of the parameters of the emission model were estimated by expert judgement. They estimated the 95%-uncertainty interval of ammonia emissions between –13% and +19% (which is between 131 and 180 kton NH_3). The estimated uncertainty in NO_x emissions was somewhat smaller and ranged between –11% and +18% (which is between 380 and 502 kton NO_2). The application of dairy cow manure contributed more than any other source-activity combinations to the overall uncertainty in acidification equivalents. It was also biased to higher values, as ‘it is questionable whether farmers work as accurate in practice as during the field laboratory experiments’. Better estimates for this emission source are clearly welcome.

2.2 Nitrogen budget for Europe

At the second International Nitrogen Conference held in Potomac (USA), Van Egmond et al. (2003) presented the estimated input and output flows for Europe as summarised in Figure 2.4 and Table 2.4. Internal flow between soil, plants and animals was not considered though important N loss terms are involved. Based on a 60% estimate of the N efficiency, an internal flow of 22,000 kton N per year was estimated. Figure 2.4 combines all estimates in the same format as used in the previous section. It appears that Europe depends more on synthetic fertilisers, while the Netherlands relies on import of animal feed concentrates.

The agricultural sector in the Netherlands produces more than average quantities of animal and plant products. This production depends on the imports of feed (particularly soy concentrates) and synthetic fertilisers. While air emissions by industry compare well with European standards, agricultural activities go together with high losses to the environment. Hence, atmospheric deposition is high as was demonstrated in Figure 2.1.

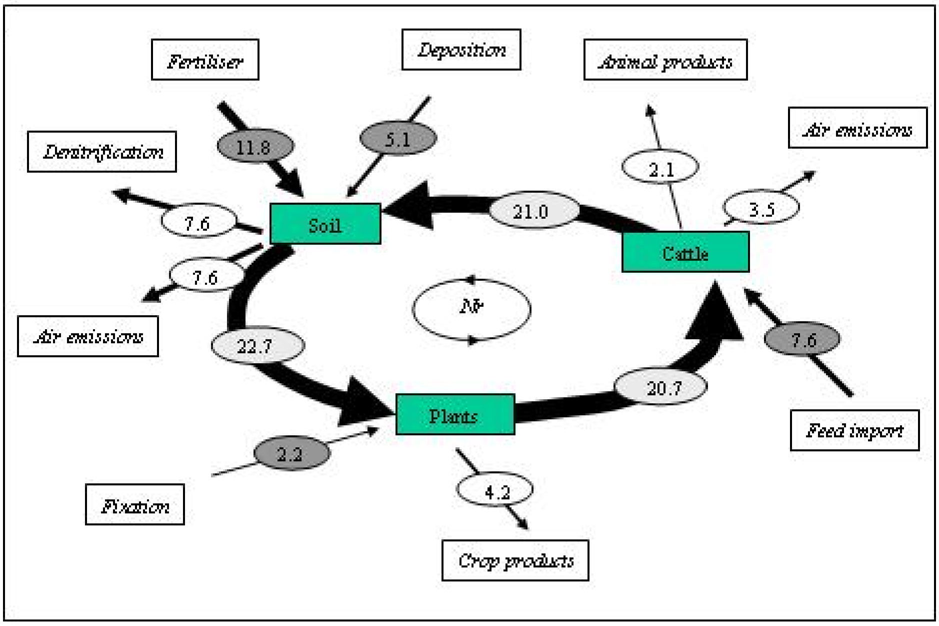

Figure 2.4 *The annual N budget of the aggregated European agricultural economy (Mton N per year) in 2000. See Table 2.4 for an explanation of the various entries. The use of synthetic fertiliser – 11,8 Mton N – is the main driving force.*

Table 2.4 *The annual N budget of the agricultural economy in the Netherlands (kton N per year) in 1999 and in Europe (Mton N per year) in 2000 explaining the terms shown in Figure 2.4.*

Source	The Netherlands	Europe	%
	1999	2000	
Inhabitants [million]	16	540	3,1
Land Area [thousands sq km2]	33,8	4733,3	0,7
Agricultural area %	59	46	0,9
Throughput	kton N per year	Mton N per year	
Plant uptake	405	22,7	1,8
Manure application/production	500	21,0	2,4
Feed (grass, hay, maize)	340	22,8	1,5
Input	kton N per year	Mton N per year	
Biological fixation	25	2,2	1,1
Feed imports (hay, concentrates)	480	7,6	6,3
Synthetic fertiliser	400	11,8	3,4
Atmospheric deposition	80	5,1	1,6
Output	kton N per year	Mton N per year	
Plant products	105	4,2	2,5
Animal products	180	2,1	8,6
Air emissions (animals)	95	3,5	2,7
Denitrification (in soil)	400	7,6	5,3
Air emissions (from soil)	175	7,6	2,3
Water emissions, errors, etc.	45	1,7	2,6
Air emissions Industry and traffic	134	3,6	3,7

2.3 Trends and environmental assessment

While some environmental problems are strictly local, like soil pollution, the N-related problems are as a rule regional to global. The emissions of N_2O will readily spread across the atmosphere. NO_x has a continental character; NH_3 is also continental but less than NO_x. The scale of N problems in estuaries and coastal seas depends on the extent of the river basin feeding them. The scales are important for the abatement strategy. Continental problems demand a continental perspective for a successful approach. This section analyses the appropriate scale of policy intervention. A comprehensive overview of N-related policies in the Netherlands and in Europe is given in Chapter 4.

Soil and groundwater

Human use places severe pressure on Europe's water resources. Water quality is a major concern throughout Europe. N pollution of groundwater mitigates its use for drinking water, while eutrophication of surface water due to excessive nutrient loads can lead to algal growth, oxygen deficiencies, and fish kills (see Chapter 3).

Agriculture puts the largest pressure on groundwater and also on surface water pollution. The EC Nitrates Directive aims to control N pollution and requires Member States to identify areas under threat of eutrophication of groundwater, surface water, and marine waters. In these areas agriculture is restricted. In particular, the application of fertilisers should balance the needs of the crops, and the application of manure should not exceed 170 kg N per ha. Consequently, livestock numbers have decreased and the overall consumption of fertilisers has stabilised in recent years at the level of some 120 kg N per hectare. Nevertheless, more progress by European Union Member States is required before this policy response can be considered fully satisfactory (EEA, 2003).

Nitrate concentrations in drinking water should not exceed 50 mg l^{-1} (EC Drinking Water Directive). However, exceedances are a common problem across Europe, particularly from shallow wells. It is often a problem in rural water supplies. For example, in Belgium 29% of 5000 wells examined had concentrations in excess of the limit value (OECD, 1997) and in Bulgaria it was estimated that, in the early 1990s, up to 80% of the population was exposed to nitrate concentrations that exceeded the limit value (OECD, 1995). In about a third of the groundwater bodies for which information was available nitrate concentrations exceeded the limit value. In general, there has been no substantial improvement in the nitrate situation in European groundwater and hence nitrate pollution remains a significant problem (EEA, 2003).

Wastewater discharge to surface water

In surface waters, the overall trend is that N concentrations have remained relatively stable throughout the 1990s and are highest in those Western European countries where agriculture is most intensive. Also in Europe's seas the nitrate concentrations have generally remained stable. A few stations in the Baltic, Black and North Sea, though, have demonstrated a slight decrease in nitrate concentrations (EEA, 2003).

The EU makes progress in controlling point sources of pollution from industry and households through wastewater treatment. The Urban Waste Water Treatment directive aims at 75% removal of the N load to the treatment plants in sensitive areas. However, by the end of 1998, still some 37 out of 527 cities had no treatment at all, including Brussels, Milan and Porto, while 57 others including Aberdeen, Athens, Barcelona, Dublin, Florence, Liège and Marseille were discharging a large part of their effluents untreated. The situation is generally improving and some of these cities made the necessary investments (EC, 2002).

In the Netherlands the European standard of 75% treatment (N and P influent) of wastewater is expected to be met by 2008.

Eutrophication of terrestrial ecosystems

The emissions of SO_2 and NO_x originate principally in transport (road and off-road, international shipping and air craft), the energy sector (fuel combustion from power plants), and the services sector. NH_3 emissions originate mainly from agricultural livestock. By 1995 in Europe 15.5 million tonnes of NO_x and 4.5 million tonnes of NH_3 were emitted. The transport sector had become the largest source of emissions of nitrogen oxides, accounting for 60% of the total. The agricultural sector emitted 93% of the ammonium.

By the year 2000 the Netherlands received 34 and 52 kton N by deposition of NO_x and NH_3 respectively. These depositions are of the same order of magnitude. However, the sources are quite different. Only 8% of the NO_x deposition is domestic, while 58% of the NH_3 deposition is emitted by agriculture. This gives the Dutch government an obvious incentive to abate NH_3 emissions, while negotiating EU measures against NO_x emissions.

The EU15 were responsible for 63% of the NO_x that the member states received by deposition. The accession of the 10 new member states made the NO_x problem even more domestic: 68%. The same holds for ammonia. The deposition in the EU15 and the EU25, 60% and 66% respectively, is predominantly domestic.

The issues of acidification and eutrophication have been effectively tackled by policy measures in the EU since the 1980s. Several international agreements under the Convention on Long-Range Transboundary Air Pollution (LRTAP) have been reached to reduce emissions in a harmonised fashion. With respect to air pollution control, the EU has adopted emission and fuel quality standards for its Member States. In addition, many European countries have adopted national standards and other types of regulation reflecting the seriousness of pollution and national environmental quality priorities.

The impact indicators used to assess the policy responses relate to the proportion of ecosystems where "critical loads" of acidity and eutrophication are exceeded, i.e. the maximum input to an ecosystem that is believed not to cause harmful effects as it matches the self-generating N flux of the soil. Current policies will substantially improve the environmental conditions for Europe's nature. The area affected by acidification decreases from 25% in 1990 to less than 5% in 2010. The eutrophication indicator shows the percentage of unprotected ecosystems improving from 55% to 41%. This underlines that eutrophication is a far larger problem in Europe than acidification.

The ambition to further reduce the emission of eutrophying substances has been laid down in the Gothenburg Protocol by the Member States of the UNECE and in the directive on National Emission Ceilings (NEC) for certain atmospheric pollutants by the Member States of the EU (directive 2001/81/EC). In general, the emission of NO_2 will be halved by 2010, while the emission of NH_3 will reduce by 15%. Table 2.5 shows the ambition by comparing the annual emission per inhabitant (census 2000) and the annual emission per € GDP (Gross Domestic Product) (in 2000 source: Eurostat) in 2010 according to the NEC directive. In comparison with the Gothenburg Protocol the EU Member States reduce an extra 1,2% of NO_2 emissions. With regard to NH_3, only for Portugal has reduced its ceiling.

Table 2.5 *Comparing the ambition of the EU to reduce NO_2 and NH_3 emissions. National Emission Ceilings for 2010 and population and economic statistics for 2000 (kg NO_x and NH_3).*

	% Emission Reduction 1990-2010		Emission per inhabitant 2010		Emission per € GDP 2010	
	NO_x	NH_3	NO_x	NH_3	NO_x	NH_3
Austria	-47	-19	13	8	498	319
Belgium	-48	-31	17	7	710	299
Denmark	-55	-43	24	13	740	402
Finland	-43	-11	33	6	1306	238
France	-57	-4	14	13	570	549
Germany	-61	-28	13	7	518	271
Greece	0	-9	33	7	2794	593
Ireland	-43	-8	17	31	632	1128
Italy	-49	-10	17	7	849	359
Luxembourg	-52	0				
Netherlands	-55	-43	16	8	646	318
Portugal	-28	-8	25	9	2164	779
Spain	-24	1	21	9	1389	579
Sweden	-56	-7	17	6	569	219
UK	-56	-11	20	5	748	190
EC 15	-50	-15	17	8	763	364

Source: Eurostat

Eutrophication of marine ecosystems

Pollution of coastal seas occurs by the influx of nitrates through – often international – rivers. For the protection of the North Sea, countries draining and discharging into these rivers agreed in 1988 to:

- Take effective national steps to reduce nutrient inputs.
- Aim to achieve a substantial reduction (of the order of 50%) in inputs of N and P into these areas between 1985 and 1995, or earlier if possible.

These commitments were reiterated at the Oslo and Paris Commission's Ministerial meeting (OSPAR) in 1992. Later, the deadline was postponed from 1995 to 'as soon as possible'. Based on data from 1985 and 2000, no OSPAR Contracting Party - committed to the 50% reduction in nutrient inputs – has reached this 50% reduction target on N losses/discharges from sources in areas draining into the defined problem areas (Table 2.6). Germany and Denmark reached a reduction of 38-43% respectively. The Netherlands has indicated that the target will be met by 2010 (OSPAR, 2003).

Table 2.6 *Discharges of N (tonnes) from anthropogenic sources in 1985 and 2000 and the reductions achieved*

North Sea State	Number of catchments	Catchment area (km^2)	Discharges/losses of N 1985	Discharges/losses of N 2000	Reduction of N since 1985 (%)
Belgium	4	30518	100820	81902	19
Denmark	12	27763	75151	42991	43
France	8	64741			
Germany	246	264112	763700	469800	38
Netherlands	4	37181	165800	114414	31
Norway	5	98990	35077	23152	34
Sweden	41	76495	31410	22770	28
Switzerland	1	9500	34490	25111	27

Source: OSPAR, 2003

The contribution from the Netherlands to the N load to the North Sea is difficult to estimate. Annual transboundary river transport – estimated at 349 kton N – will flow readily through the country and enter the North Sea unaffected. The emissions by domestic wastewater treatment plants – 31 kton - will have the same fate as they can be considered as point sources to open water. Agriculture emits annually 92 kton through run-off and seepage. Another 11 kton is added by air deposition. Most of these emissions from diffuse sources will pass through the extended web of waterways before they reach the North Sea. Hence, it may be expected that some if not all of it accumulates or denitrifies. Eventually, 330 kton N enters the North Sea. This implies that in the Dutch waterways the nitrogen load actually decreases due to denitrification.

The contribution from the Netherlands to the N load can be estimated between 27 kton and 86 kton N per year. The low estimate assumes that diffuse sources do not contribute at all, while foreign and point sources denitrify at a rate of 87%. The high estimate assumes conversely that all sources denitrify alike at a rate of 68%. OSPAR estimated the total river load on the (Greater) North Sea at 700 kton. Hence, the contribution from the Netherlands is about (or less than) 10%, although about half the total river load passes through the country. N deposition on the North Sea amounts 350 kton N, of which 10% originates from the Netherlands (EMEP, 2003). Obviously, the protection of the North Sea lies in the European perspective.

Global warming

Total denitrification of nitrates by organic materials in soils, groundwater and surface water is considerable. Particularly when nitrate concentrations are comparatively high, denitrification is incomplete and small quantities of N_2O are released in the process. N_2O is also a by-product in the Haber-Bosch process of synthetic fertiliser production. However although the absolute quantities are small, since N_2O is a powerful greenhouse gas, the increasing N_2O production plays an important role in the global warming issue.

The Netherlands is estimated to emit 48 kton N_2O – half of which due to incomplete denitrification processes. Europe’s emission is estimated at 0,8 Mton N_2O-N – 65% of which is due to denitrification. The targets for the Netherlands and Europe defined in the Kyoto Protocol are -6% and -8% compared to 1990. These targets have to be met during the period 2008-2012.

3. ADVERSE IMPACTS OF ELEVATED NITROGEN USE

The significance of the N cascade comes into focus with the realisation that it is linked to so many of the major global and regional environmental challenges that policymakers face at these levels today: ozone layer depletion, acidification of soils, global warming, surface and groundwater pollution, biodiversity loss, and human vulnerability. While the extent of its contribution to these problems is still unclear, addressing the issue of excess N_r is one of the critical challenges for policymakers (UNEP, 2003).

Therefore, UNEP Executive Director Klaus Töpfer made the following statement in the Global Environment Outlook Year Book 2003, released at the opening of the agency's 8th summit for the world's environment ministers: "Human kind is engaged in a gigantic, global, experiment as a result of inefficient and often overuse of fertilisers, the discharge of untreated sewage and the ever rising emissions from vehicles and factories". He posed this statement in view of the occurrence of algal blooms and its impact on marine life, while concluding "Hundreds of millions of people depend on the marine environment for food, for their livelihoods and for their cultural fulfilment. Unless urgent action is taken to tackle the sources of the problem, it is likely to escalate rapidly." This example is one of many (see Figure 3.1) why excessive N use is seen as a problem that has to be tackled.

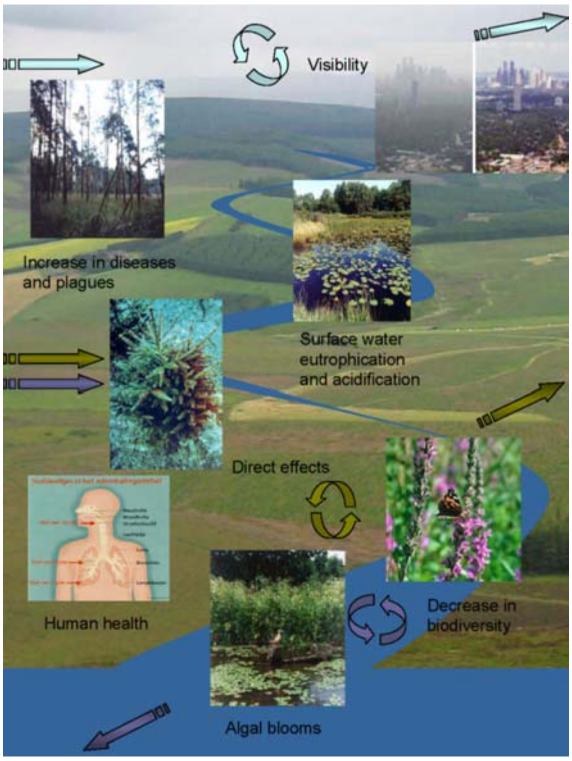

Figure 3.1 *Adverse impacts of elevated N*

Elevated N use does cause various widespread and well-documented environmental effects (Vitousek et al., 1997), but there are also diverse consequences for human health (Wolfe and Patz, 2002) and even for materials. In this chapter an overview of the adverse effects is presented. It focuses on the adverse impacts of elevated inputs of N_r in the environment in terms of impacts on (i) species diversity of terrestrial ecosystems (Section 3.1), (ii) forest vitality (Section 3.2), (iii) water quality and species diversity of aquatic ecosystems (Section 3.3), (iv) human health (Section 3.4), (v) climate (Section 3.5), (vi) visibility (Section 3.6) and (vii) materials (Section 3.7).

3.1 Species diversity of terrestrial ecosystems

Adverse impacts of elevated inputs of N_r on terrestrial ecosystems include (i) decreased plant species diversity of terrestrial ecosystems and (ii) decreased faunal species diversity, as discussed below.

3.1.1 Plant species diversity

Nitrogen deposition and biodiversity loss

In Europe the effect of N deposition is now considered as the most relevant effect of air pollution on plant diversity. During the past two decades the general attention shifted from effects of S deposition and acidification towards effects of N deposition and eutrophication. There are three main reasons for this: (i) the atmospheric concentration of SO_2 dramatically decreased over this period in most parts of Europe, (ii) the expected large-scale forest die-back did not yet occur, and (iii) the effects of N deposition and resulting eutrophication appeared to be much more widespread than effects of S deposition and resulting acidification. Evidence suggests that increasing N availability often causes overall declines in plant species diversity (Tilman, 1987; Aerts and Berendse, 1988). In the Netherlands, such species diversity changes do occur mainly due to nitrogen deposition, related to ammonia and nitrogen oxide emissions, because of eutrophication and acidification of non-agricultural soils, as discussed below.

Effects of N deposition are now recognised in nearly all oligotrophic natural ecosystems; these include aquatic habitats, forests, grasslands (including tundra and Mediterranean grasslands), oligotrophic wetlands (mire, bog and fen), heathland, and coastal and marine habitats (Achermann and Bobbink, 2003). In such oligotrophic systems, N is generally the most important growth-limiting element, and their species are adapted to a N-deficient environment. If the availability of N increases, other species that use the available nitrogen more efficiently will out-compete the unproductive species adapted to N deficiency. This effect may occur at low deposition rates, and is probably most determinative for the lower end of the critical load range (Heij and Erisman, 1997). At higher deposition levels, N saturation will occur when the deposited N is no longer completely taken up by the vegetation or immobilised in the soil, and leaching may occur (Tamm et al., 1999). Increased levels of N in foliage, which in turn may increase susceptibility of plants to frost or diseases, accompany N saturation. This is effect well documented for forest trees (e.g. Aronsson, 1980; Balsberg-Påhlsson, 1992), but also occurs in natural vegetation, e.g. in Calluna vulgaris (Berdowski, 1987).

Impacts of nitrogen deposition on grasslands and heath lands

In Dutch calcareous grassland massive expansion of *Brachypodium* and drastic reduction in species diversity has been observed due to N addition (Willems et al., 1993). In many Dutch dune grasslands with relatively high N deposition (about 25 kg N $ha^{-1}.y^{-1}$) many grasses have increased, whereas in coastal areas of Western England with relatively low deposition (about 10 kg N $ha^{-1}.y^{-1}$) dune grasslands are still species-rich (Bobbink et al., 1998). In the Netherlands more than 35% of the heathland has been altered into grassland. Even in southwest Norway, the area with the highest N deposition in Norway, similar changes have been observed (see e.g. Bobbink et al., 1998). The importance of N deposition, especially in the early phase of heathland development is also confirmed by field experiments (Aerts et al., 1990). A recent nation wide inventory in the UK also showed that increased N deposition results in a decrease of floristic diversity, at least in grassland and heath land communities (Stevens et al., 2004). Specifically in wet-heathlands in the Netherlands, which are generally richer in plant species compared to dry-heathlands, a drastic change in species composition has been observed. Most wet-heathlands in the Netherlands are now mainly dominated by *Molinia* in stead of *Erica* (e.g. Bobbink et al., 1998). Some authors also ascribe the decline of the diversity of grasslands on poor, sandy soil to acidification (De Graaf et al., 1997). However, in many of these cases also other factors besides acidification seem to be responsible for the reported decline. The decline of acid grassland species is probably caused by a combination of acidification and eutrophication, where toxicity of Al ions and a shift in the NH_4 / NO_3 ratio are the triggers (De Graaf et al., 1998).

Critical nitrogen loads

Since the recognition of N deposition as one of the main drivers behind the general loss of biodiversity in Europe, a number of expert workshops have taken place in order to reach agreement among specialist on the critical loads of N for various ecosystems (Nilsson and Grennfelt, 1988; Bobbink et al., 1992; Hornung et al., 1995; Bobbink et al., 1996b; Achermann and Bobbink, 2003). In this context, critical loads are defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt, 1988).

Empirical critical loads for ecosystems are extensively treated by Bobbink et al. (2003). In their approach, long-term (> 1 year) effects of N addition to existing vegetation play a central role. Such addition experiments may be carried out either in the field, or in the laboratory in so-called mesocosms (i.e., pieces of vegetation directly taken from the field). Because of the time and labour-intensive nature of such studies, results are only available for a limited number of broadly defined ecosystems. In some cases, experimental results are supplemented by observational studies e.g. time series under a known increase in deposition. In this approach, the critical load is the highest addition of N that does not lead to adverse physiological changes (on the individual level) or loss in biodiversity (on the ecosystem level).

Table 3.1 gives a comparison of empirical critical loads (Achermann and Bobbink, 2003) and simulated critical loads (van Dobben et al., 2004) for major ecosystems in Europe, that do occur in the Netherlands. Table 3.1, which also includes forest ecosystems that are discussed below, shows that there is a fair agreement between the empirical and the modelling approach. In general, the empirical critical loads tend to be somewhat lower and have narrower ranges than the simulated ones. In interpreting the differences it should be noted that the empirical ranges are the result of an interpretation of a large number of studies, and that this interpretation is usually based on a precautionary principle, i.e. it tends to search the lower end of all reported no-effect levels.

As a result, the empirical critical load ranges usually pertain to the more sensitive forms of a given ecosystem. On the other hand, the simulated critical loads are determined as an average over all vegetation structure belonging to a given ecosystem, under average environmental conditions for that ecosystem.

Forested ecosystems

Circumstantial evidence is available for large changes in the forest ground vegetation in the Netherlands from 1950 to 1990. A pilot study carried out by De Vries (1982) in an area of pine forests on dry, sandy soil, where vegetation maps from 1957 were available showed a complete change in ground vegetation, from a moss and lichen dominated type to a grass dominated type. Changes in the species composition of the ground vegetation of Dutch pine forests in a more recent period were studied by comparing vegetation descriptions made in 177 permanent plots in 1984 and in 1993 (van Dobben et al., 1994). This study showed a significant decrease in the cover of heathland species (*Erica tetralix* and *Calluna vulgaris*) and a strong increase of many nitrophilous species.

Species changes in the ground vegetation of forests towards nitrophilic species have also been recorded in other parts of Europe. These changes entail: (i) a decline of terrestrial lichens (‘reindeer lichens’) and of ectomycorrhiza mushrooms, (ii) an increase of grasses, notably Deschampsia flexuosa and (iii) a general increase of mosses and vascular plants that typically occur on N rich soils (Bobbink et al., 1998). In a recent review, Flückiger and Braun in Achermann and Bobbink (2003) concluded that these changes occur at N loads above 10-15 kg

N ha-1.y^{-1}(see also Table 3.1). Inversely, tree growth may be hampered by limited N availability below this N deposition level.

Table 3.1 *Comparison of simulated and empirical critical loads (kg N ha^{-1}.y^{-1}). ## = reliable, # = quite reliable, (#) is expert judgement. * = EUNIS class does not occur in the Netherlands. Correspondence between simulated and empirical critical loads is given in the last column*

Ecosystem type (EUNIS class)	Empirical critical load	Reliability	Simulated critical load	Simulated compared to empirical
Grasslands and tall forb habitats (E)				
Sub-atlantic semi-dry calcareous grassland	15-25	##	15-31	=
Non-mediterranean dry acid and neutral closed grassland	10-20	#	10-31	=
Inland dune grasslands	10-20	(#)	10-21	=
Low and medium altitude hay meadows	20-30	(#)	10-31	=
Heathland habitats (F)				
Dry heaths	10-20	##	4-31	=
Mire, bog and fen habitats (D)				
Raised and blanket bogs	5-10	##	26-33	>
Poor fens	10-20	#	5-30	=
Rich fens	15-35	(#)	5-30	=
Coastal habitat (B)				
Shifting coastal dunes	10-20	(#)	15-24	=
Coastal stable dune grasslands	10-20	#	15-24	=
Coastal dune heaths	10-20	(#)	33-34	>
Moist to wet dune slacks	10-25	(#)	10-24	=
Marine habitats (A)				
Pioneer and low-mid salt marshes	30-40	(#)	21-24	<
Forest habitats (G)				
Ground vegetation (Temperate and boreal forests)	10-15	#	8-41	=
Lichens and algae (Temperate and boreal forests)	10-15	(#)	8-9	<

Empirical data are taken from Achermann and Bobbink (2003); calculated values are from Van Dobben et al. (2004).

3.1.2 Faunal species diversity

Research on acidification, eutrophication, as well as restoration management has mainly focussed on vegetation and abiotic processes. Plants are sessile organisms, greatly facilitating research possibilities. Research on fauna is complicated, as different species use the landscape at different spatial scales and animal species outnumber plant species by about 25 to 1. Consequently, research on the effects of N deposition on fauna is largely lacking. In the last years, research on faunal diversity gained more attention. In nature management it is noticed that a selection of fauna species has benefited from restoration projects, but other target species show a further decline in abundance or even disappear from nature reserves. Therefore, the Dutch ministry of Agriculture, Nature and Food Quality decided to start several research projects on the effects of eutrophication, acidification and desiccation on fauna diversity as well as on possibilities to rehabilitate fauna diversity by means of restoration measures in nature reserves (cf. van Turnhout et al., 2003; Stuijfzand et al., 2004).

To complete their life-cycles, all animal species need suitable food and suitable environmental conditions, including e.g. specific vegetation structures and micro-climate. N deposition affects the species composition and nutrient content of plant organic matter. Thus, increased N deposition has consequences for herbivorous animals like caterpillars, as their host plants may decrease or increase in abundance, or because of changes in food quality (Bink, 1992; Soontiëns and Bink, 1997; Kerslake et al., 1998). N deposition causes changes in plant species composition and vegetation structure and thereby alters the micro-climate (temperature and moisture regimes) experienced by animals. Changes in nutrient content of dead organic matter has consequences for detritivores, as e.g. Vos et al. (2000; 2002) showed for aquatic invertebrates.

Ground beetles in dry coastal dune grasslands

The ground beetle (*Carabidae*) assemblages of dry open sandy coastal dune grasslands is characterised by species preferring drought and higher temperatures. N deposition, however, results in grass encroachment. Consequently, the characteristic micro-climate of coastal dune grasslands (very warm during day time, but fairly cold at night and continuously dry) changes to a buffered micro-climate (continuously cool and moist). Comparison of the ground beetle assemblage between 15 coastal dune grasslands on the Waddensea isles Ameland and Terschelling showed that encroachment with the grasses *Calamagrostis epigejos* and, to a lesser extent, *Ammophila arenaria* results in a change in the relative numbers of drought vs. moisture preferring species. Grazing by sheep is one of the nature management measures used to combat grass encroachment. Grazing results in a strong decrease of tall grasses, but the ground beetle assemblage remains dominated by moisture preferring species, instead of the warmth and drought preferring species dominating in more intact dune grasslands (Nijssen et al., 2001, Figure 3.2).

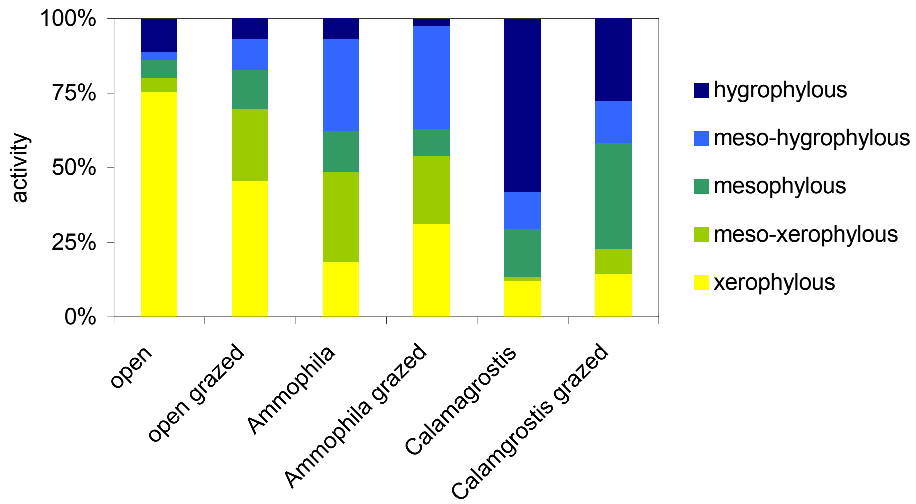

Figure 3.2 *Relative activity of ground beetles classified according to their preference for moist (hygrophylous) to dry (xerophilous) conditions in different coastal dune grasslands on the Dutch Waddensea isles Ameland and Terschelling (Nijssen et al., 2001).*

Changes in heterogeneity

Next to (a)biotic conditions at a spot, variation in these conditions at a higher spatial scale are important in the occurrence of animal species. Animals differ fundamentally with plants in their mobility. Heterogeneity in the landscape can be used by mobile animals and the presence of variation in (a)biotic conditions in the landscape can be a prerequisite for the occurrence of many species. The importance of landscape heterogeneity in facilitating fauna diversity was shown in a case study aimed at elucidating the mechanisms between aquatic invertebrate diversity and landscape heterogeneity. This case study is conducted in the heterogeneous bog landscape of the Korenburgerveen reserve in the eastern part of the Netherlands. The occurrence of animal species can be related to heterogeneity by -at least- three mechanisms. (i) Species may depend on specific conditions, which are only present in transitions between different biotopes.

(ii) Many animal species require different parts (biotopes) of the landscape for reproduction, resting, foraging, hibernation, etc. Their mobility is a necessity to complete their life cycle and the required parts of the landscape have to be available within the home range of an individual animal. (iii) Heterogeneity creates the possibility of risk spreading, leading to a higher persistence of species (Verberk et al., 2002). Evidence for each of these mechanisms was found in this case study. Rare species were found to occur mainly in the transition between seepage and infiltration. Invertebrates were found to selectively use different water types during their larval and adult stages. In addition, evidence for risk spreading mechanisms was found. Species were shown to be less selective with respect to water type during autumn. This is an adaptive response to spread the considerable mortality risk of the winter period (Verberk and Esselink, 2004). Changes in the landscape heterogeneity will affect species diversity. Heterogeneity is declining due to the chronic and large scaled nature of N deposition. Differences in vegetation structure disappear due to extensive grass encroachment. Therefore, N deposition affects fauna diversity not only directly (e.g., changes in food quality and micro-climate), but also indirectly through changes in landscape configuration and heterogeneity.

Decline of red-backed shrike

The decline of the red-backed shrike (*Lanius collurio*) illustrates how the effects of elevated N deposition have repercussions across the entire food web (Beusink et al., 2003). This bird species strongly declined from 1900 onwards throughout Western Europe. It has currently disappeared from the coastal dunes of the Netherlands and it is disappearing from the coastal dunes of northern Germany and southern Denmark. Only in the coastal dunes of northern Denmark the population of red-backed shrikes is still stable (Figure 3.3). This pattern in population trends is clearly correlated to atmospheric N deposition levels, although the occurrence of this bird species can of course not directly be related to higher N availability. Red-backed shrikes feed on large insects and small vertebrates (e.g. lizards) and carry only a single prey item to the nest at a time. Prey demands of the nestlings have to be met during the day under different weather conditions and also during the whole breeding period. To ensure a constant and sufficient energy supply, the red-backed shrikes require a high diversity of large prey species which in turn depends on landscape heterogeneity (Esselink et al., 1994).

In coastal dunes increased N deposition led to the encroachment by tall grasses and bushes, a decrease of open sandy areas and a loss of succession stages rich in species. In addition, N deposition has, together with acidification and active stabilisation, led to a strong decrease of the natural dynamics of coastal dune systems. This has led to a loss of landscape heterogeneity. The lack of heterogeneity in the deteriorated Dutch dune landscape has serious negative consequences for the resident fauna. In northern Denmark, where N deposition is significantly lower and red-backed shrikes are still abundant, the coastal dunes are still much more dynamic. Sand blow-outs and sand deposition zones are still present, creating a range of different successional stages.

The decline in landscape heterogeneity seriously affected the prey availability for red-backed shrikes. Especially the lack of sufficient large prey species in the Netherlands is considered as an important factor. Especially larger species are declining due to the degradation. Comparison of the sizes of prey items caught by red-backed shrikes in northern Denmark in 2001 and 2002, on Ameland and Terschelling around 1990, and on Ameland in 1997 and 1998 shows a considerable decline in the amount of larger prey items from the most intact to the most degraded situation. As shrikes carry only one prey item at a time to their nestlings, a decline in prey size means an increase in the number of flights adults have to make to provide sufficient food to their nestlings (Beusink et al., 2003).

The main prey species in northern Denmark are large, such as the scarabid beetle *Anomala dubia*, the grasshopper *Decticus verrucivorus* and the sandlizard (*Lacerta agilis*). All three of these species have strongly declined in the Netherlands during the 1980s and 1990s. Investigations into the lifecycle of these species show that they depend directly or indirectly on the dynamics of an intact dune system. For example, the larval stage of the scarabid beetle *Anomala dubia* feeds on vital roots of *Ammophila arrenaria* which only occur in those parts of the dunes where sand is regularly deposited. Thus, changes in the coastal dune landscape, in which increased atmospheric N deposition is a main factor, affect invertebrate diversity and the species at higher trophic levels, as well.

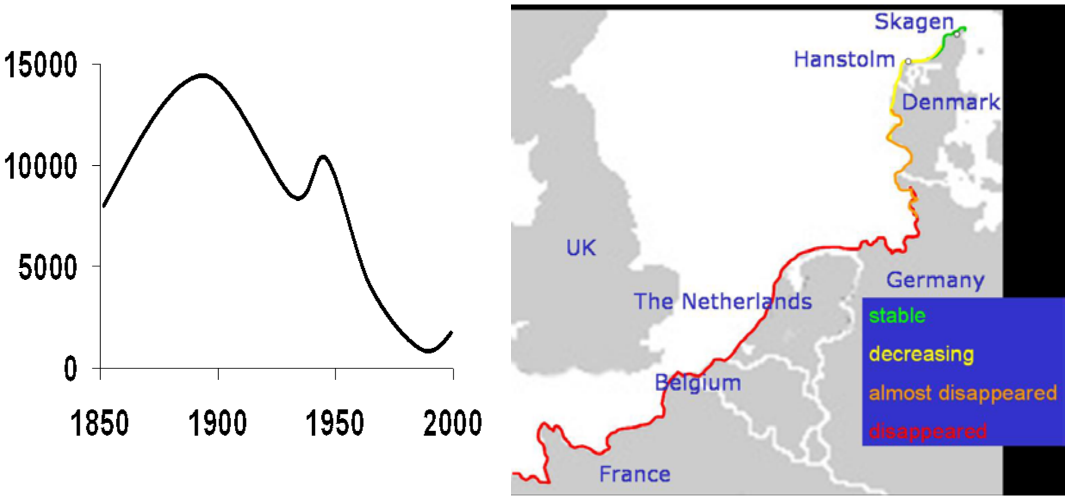

Figure 3.3 *The change in the number of breeding pairs of the red-backed shrike in the Netherlands (right) and population trends in coastal dunes of Western Europe (left)*

3.2 Forest vitality

Impacts of nitrogen on forest ecosystems

Until a certain threshold level is reached, forests will react to additional N inputs by an increased biomass production, but above that, production stays constant or even decreases. Below the threshold level, however, changes in the ecosystem are observed, especially the forest biodiversity may gradually change towards more nitrophilic species (Ellenberg, 1985; Bobbink et al., 1996a; Bobbink et al., 1998). In forested plots with a continuous high N input, the ecosystem may approach "N saturation" (Aber et al., 1989). At the stage of "N saturation" or "N excess", the ecosystem may be destabilised by the interaction of a number of factors. Strong accumulation of N in foliage (e.g. as amino acids) may affect frost hardiness and the intensity and frequency of insect and pathogenic pests. It may also cause water stress as a result of increased canopy size, increased shoot/root ratio, and loss of mycorrhizal infection. Furthermore, release of aluminium by soil acidification and imbalances of ammonium to base cations may cause absolute or relative nutrient deficiencies, which may be aggravated by a loss of mycorrhiza or root damage. A detailed overview of possible effects on forests as a result of increased atmospheric acid and N deposition and/or exposure to air pollutants is presented by Erisman and de Vries (2000), as summarised in Table 3.2.

Table 3.2 *Possible effects of increased atmospheric N loading and exposure to NO_x and NH_3 on forest ecosystems*

Forest compartment	Effects	
	Chemistry	Ecosystem
Trees (foliage)	- elevated N concentrations in foliage	- increased biomass production/ water demand
		- increased ratio of foliage to roots (risk of drought and nutrient deficiency)
		- increased frost sensitivity
		- increased parasite injury (insects, fungi, virus)
		- nutrient deficiency absolute or relative (to N) / discoloration
	- elevated arginine concentrations in foliage	- growth reduction
Soil (solution)	- elevated N concentrations in soil (solution)	- increase in nitrophilous species/ decrease in biodiversity
		- increase in NO_3 leaching
	- elevated ratios of NH_4^+ and Al^{3+} to base cations	- inhibition of uptake (nutrient imbalances)
		- root damage and mycorrhiza decline

After: Erisman and de Vries, 2000

Nutritional imbalance due to elevated N concentrations in foliage

An important impact of the high N concentrations in foliage is nutritional imbalance, i.e. absolute deficiencies or deficiencies relative to N in needles of the macronutrients K, P, Mg and Ca, and possibly of micronutrients, B, Mn and Mo. Elevated atmospheric deposition of N and S compounds in the Netherlands during the period 1960-1990 has led to an increase in the N content and a decrease in the P, K and Ca content in foliage. This can be derived from a study by Van den Burg and Kiewiet (1989), who compared the foliar composition of stands of Scots pine, black pine and Douglas fir in 1956 and 1988 in the 'Peel' area with intensive animal husbandry. Surprisingly, the Mg content did not decrease during that period. However, even in 1956, the Mg content was already low. Furthermore, as with P, K and Ca, the Mg supply relative to N decreased (Table 3.3).

Table 3.3 *Average N content and ratios between K^+, Mg^{2+} and N concentrations in half-year-old needles in 1956 and 1988*

Tree species	N content (% dry weight)		Nutrient ratio x 100 (g g-1)			
			K/N		Mg/N	
	1956	1988	1956	1988	1956	1988
Scots pine	1.5	2.3	34	27	3.0	2.7
Corsican pine	1.2	1.7	58	35	4.0	3.8
Douglas fir	1.4	2.2	68	24	6.1	5.0

Source: van den Burg and Kiewiet, 1989

Increased growth rate and elevated N concentrations in foliage may dilute the pool of other nutrients in absolute and/or relative terms. Insight in the possible impact of N deposition on a nutritional imbalance in foliage has been derived for more than 100 intensive monitoring plots in European forest with information on both the chemical composition of the foliage and total N deposition (de Vries et al., 2003). Ranges in N deposition at plots with a balanced and unbalanced ratio of the base cations K, Ca or Mg to N are given in Table 3.4. More information on the criteria related to balanced and unbalanced ratios is given in Flückiger and Braun (2003).

Table 3.4 *Ranges in N deposition at 109 intensive monitoring plots in Europe with a balanced and unbalanced ratio of the base cations K, Ca or Mg to N*

Element	N deposition kg.ha^{-1}. y^{-1}							
	Unbalanced				Balanced			
	Number of plots	50%	5%	95%	Number of plots	50%	5%	95%
P	46	21	6.9	34	63	11	1.5	34
K	15	23	14	37	94	14	1.7	33
Ca	4	28	20	35	105	16	1.9	34
Mg	24	22	11	35	85	13	1.7	33
All	57	21	7.8	34	52	9.6	1.4	32

The number of plots with a clearly unbalanced nutrition is approximately 50%, with relative P deficiencies being the most important reason for an imbalance, followed by relative Mg deficiencies. When considering all elements P, K, Ca, Mg, there was an unbalanced ratio of one or more of those elements at 57 of the 109 plots. The results clearly indicate a larger N deposition at the plots with an unbalanced ratio. Considering all base cations, the median N deposition is 10 kg.ha^{-1}. y^{-1} (range of 2-32 kg. ha^{-1}. y^{-1}) at the plots with a balanced nutrition and 21 kg.ha^{-1}. y^{-1} (range of 8-34 kg.ha^{-1}. y^{-1}) at the plots with an unbalanced nutrition. These results do at least suggest that an unbalanced nutrition hardly ever occurs at an N deposition of 10 kg.ha^{-1}. y^{-1}, thus suggesting a critical load of approximately 10-15 kg.ha^{-1}. y^{-1} in view of tree nutrition.

For most coniferous tree species, an N concentration in the needles of 16 to 20 g.kg^{-1} is considered optimal for growth (e.g. McNulty et al., 1991). Considering an empirical relationship between N deposition and foliar N content and applying a critical N concentration of 1.8% for pine would lead to a critical load (in throughfall) of approximately 20-25 kg.ha^{-1}. y^{-1}as shown in Figure 3.4. This coincides with the empirical range of 10-30 kg.ha^{-1}. y^{-1} reported by Bobbink et al. (1998). These values are exceeded in high N deposition areas located in (parts of) the Netherlands, Belgium, Denmark and Germany.

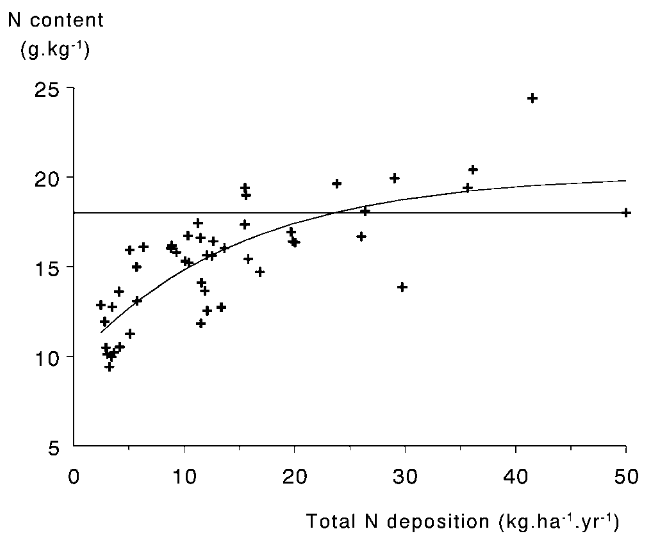

Figure 3.4 *Relationship between N contents in first year needles of Scots pine and total N deposition at 68 plots in Europe*

Nutrient imbalances induced by N can be aggravated by the acidifying impact of both N and S compounds. In soils with a low-base saturation (most sandy forest soils in Europe) an elevated input of acidity by S and N compounds, will cause the release of toxic Al that may reduce the availability of nutrients by affecting both root growth and root uptake (e.g. Sverdrup and Warfvinge, 1993).

Nitrogen leaching and soil acidification
A first indication of adverse impacts of N inputs in forest ecosystems is elevated leaching of N (NO_3) that may cause acidification of ground and surface water. At more than 100 intensive monitoring plots in Europe, the input and output of different N compounds (total N, NH_4 and NO_3) has been derived, using methods described in detail in De Vries et al. (2001). Results of the leaching of total N and NO_3 against the total N deposition show that the leaching of N is generally negligible below a total N input of 10 $kg.ha^{-1}. y^{-1}$ (Figure 3.5A). The same is true for NO_3, that dominated the N leaching (Figure 3.5B). These results are in accordance with those found by e.g. Dise et al. (1998a; 1998b) and Gundersen et al. (1998). At N inputs between 10 and 20 $kg.ha^{-1}. y^{-1}$, leaching of N is generally elevated, although lower than the input indicating N retention at the plots. At N inputs above 20 $kg.ha^{-1}. y^{-1}$, N leaching is also mostly elevated and in several cases (seven plots), it is near or even above (for two plots) the N deposition (Figure 3.5 A, B).

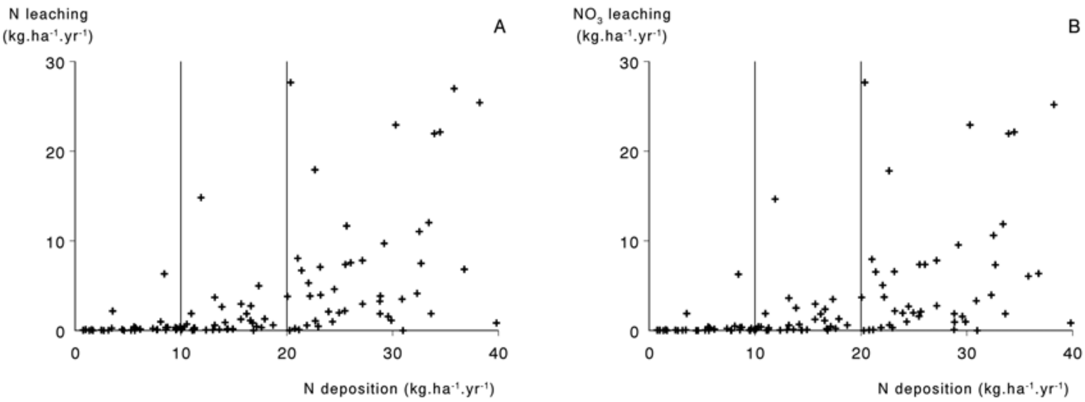

Figure 3.5 *Scatter plots of the leaching of total N (A) and NO_3 (B) against the total N deposition*

There appears to be a clear distinction between N leaching from coniferous stands in response to N deposition as compared to leaching from deciduous stands. First of all, N deposition is generally lower on coniferous trees, which often occur in the north with a relatively low N load. Furthermore, the increase in N leaching in response to elevated N loads (above 20 $kg.ha^{-1}. y^{-1}$) appears to be larger for deciduous trees than for conifers

In acidic soils, atmospheric deposition of S and N compounds does lead to elevated Al concentrations, in response to elevated concentrations of sulphate (SO_4) and nitrate (NO_3), and also to accumulation of NH_4 in situations where nitrification is (strongly) inhibited. This may cause nutrient imbalances, since the uptake of base cation nutrients (Ca, Mg, K) is reduced by increased levels of dissolved Al and NH_4 (Boxman et al., 1988). This effect may be aggravated in systems of low N status, where an elevated input of N will increase forest growth, thus causing an increased demand for base cations. Observations of increased tree growth of European forests (Spiecker et al., 1996) may be the effect of increased N inputs. The effect of increased N inputs in combination with soil acidification has been emphasised in several studies (Schulze et al., 1989; Huttl, 1990; Olsthoorn and Tiktak, 1991). Nitrogen may stimulate tree growth and increase the demand of, for example, Mg, which has to be taken up (i) from a decreasing soil pool, (ii) by a root system which may be damaged by Al toxicity or be less effective due to a decline of mycorrhiza, and (iii) possibly in competition with NH_4 in elevated concentrations (Schulze, 1989). From several of the N saturated sites, deficiencies of elements such as Mg (Kazda, 1990; Probst et al., 1990) and K (Roelofs et al., 1988) are observed. These deficiencies may limit the capacity of the vegetation to retain N inputs hereby causing NO_3 leaching.

The possible impact of acid deposition on Al release and of N deposition on NH_4 accumulation is given in Figure 3.6. The release of Al in response to elevated SO_4 and NO_3 concentrations in subsoils with a low pH (below 4.5) is shown in Figure 3.6A. In those soils, more than 80% of the variation in Al concentration could be explained by a variation in SO_4 and NO_3 concentrations, which in turn were strongly related to the deposition of S and N, respectively. Although SO_4 is important in releasing Al, results showed that NO_3 concentrations were mostly higher, reflecting the increasing role of N in soil acidification. The NH_4/K ratio in the mineral topsoil in response to elevated N deposition is shown in Figure 3.6B. Results do indicate that below an N deposition of approximately 10 $kg.ha^{-1}. y^{-1}$, the NH_4/K ratios are hardly elevated, whereas they do increase above this value. The critical NH_4/K ratio of 5 is only exceeded once in the topsoil at an N input near 30 $kg.ha^{-1}. y^{-1}$. The results hardly indicate a clear critical load for N in relation to N accumulation, but one could use 25 $kg.ha^{-1}. y^{-1}$ as a reasonable precautionary value (de Vries et al., 2003).

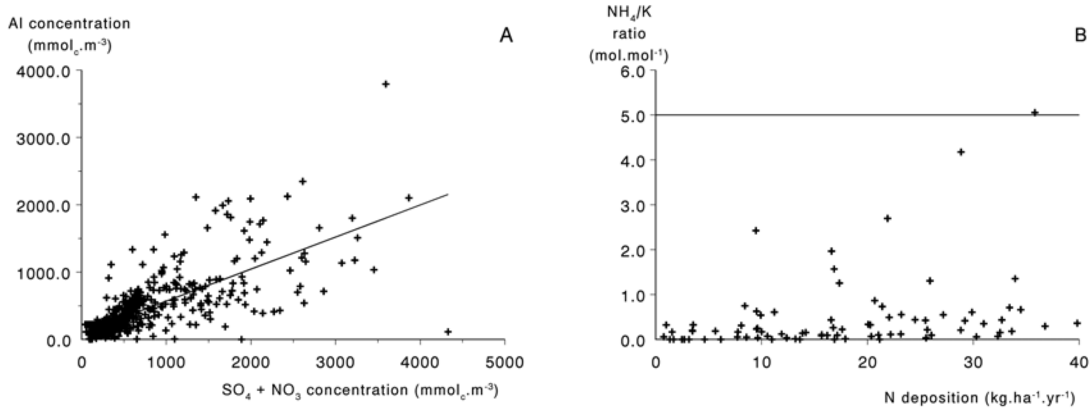

Figure 3.6 *Scatter plots of the concentration of total Al against total SO_4+NO_3 in the subsoil of intensive monitoring plots with a pH < 4.5 (A), and of the NH4/Mg ratio in the mineral topsoil against the total N deposition (B). The solid line in A represents a regression line being equal to: $Al = -95 + 0.74 (SO_4 + NO_3)$ ($R^2 = 0.86$)*

Increased sensitivity to frost, drought and fungal diseases

An increased N content in foliage, due to excess input of N, may also cause an increased sensitivity to climatic factors, such as frost and drought (Aronsson, 1980; De Visser, 1994) and diseases and plagues, such as attacks by fungi on (Roelofs et al., 1985; van Dijk et al., 1992; Flückiger and Braun, 1998). In a fertilisation experiment in Sweden, it was found that frost damage to the needles of Scots pine strongly increased above an N concentration of 18 $g.kg^{-1}$ (Aronsson, 1980). At this N level, the occurrence of fungal diseases such as Sphaeropsis sapinea and *Brunchorstia pinea* also appears to increase (van Dijk et al., 1992). The relation between N contents in first year needles of Scots pine and total N deposition at 68 intensive monitoring plots in Europe (Figure 3.6), applying a critical N concentration of 1.8% for pine would lead to a critical load (in throughfall) of approximately 20-25 $kg.ha^{-1}. y^{-1}$ in view of this effect, comparable to nutrient imbalances.

Direct effects of NOx, NH3 and ozone

Impacts of NO_x, NH_3: At low NO_x concentrations, NO_x may enhance the growth both for agricultural crops and natural vegetation. Adverse impacts of NO_x and NH_3, such as growth reduction, are however known at elevated concentrations for both (semi)natural vegetation and agricultural crops (cf. van der Eerden et al., 1998). In the Netherlands crop damage due to elevated atmospheric NO_x concentrations does occur, and may lead to a considerable reduction in yield (van der Eerden and Duym, 1988). Furthermore, it may result in forest damage. High

NH_3 concentrations may cause discolouration (from green to brown) of crops and tree foliage (van der Eerden and Pérez-Soba, 1992). Natural vegetation is more sensitive than agricultural crops to both NO_x and NH_3. However, due to a lack of sufficient experimental data, it is not possible to derive different values for crops and natural vegetation (cf. WHO, 2001). Pearson and Stewart (1993) hypothesized that species that are part of a climax vegetation on nutrient-poor acidic soils are often relatively sensitive to NO_x and NH_3. It is not clear whether this may lead to loss of plant diversity.

A summary of critical levels of N compounds related to acute effects by short-term exposures and to chronic effects by long-term exposures is given in Table 3.5. The critical values are related to adverse effects on all vegetation types.

Table 3.5 *Critical levels ($\mu g.m^{-3}$) used for short-term and long-term exposures to NO_x and NH_3*

Exposure	NO_x	NH_3
Short term (1 day; for NO_x 4 hours)	95	270
Long term (1 year)	30	8

Based upon UN/ECE (1990) and Ashmore and Wilson (1994); for a summary see also UN/ECE, 1996.

For NO_x and NH_3, separate critical levels have not been set for different vegetation classes because of a lack of information. The sensitivity is, however, thought to decrease from (semi)natural vegetation > forests > crops. Critical levels are related to both growth stimulation in response to the fertiliser effect of N, and adverse physiological effects at toxic levels. The critical level for NO_x is based on the sum of NO and NO_2 concentrations. The knowledge to establish separate critical levels for the two gases is still lacking, even though there is evidence that NO is more phytotoxic than NO_2 (UN/ECE and EC, 1996).

Impacts of ozone: In the literature, several ozone impact studies have been made varying in the quantification of: (i) effects of ozone on (semi)natural vegetation, (ii) uptake of ozone by plants in connection with biotic and abiotic variables to determine 'stocks at risk' and (iii) economic consequences of effects of ozone on crop production (Bunte et al., 1998; van der Eerden et al., 1998). Apart from the ozone concentration in the atmosphere, the sensitivity of the crop to ozone is determined by meteorological factors such as relative humidity and temperature, which vary strongly in space and time.

Monitoring of ozone impacts does occur within the context of the ICP on vegetation and the ICP on forests. Monitoring of sensitive crops, including bean (*Phaseolus vulgaris*) and underground clover (*Trifolium subterraneum*) and natural vegetation, including brown knapweed (*Centaurea jacea*), which are exposed to the air in a standardised way, is a central issues in ICP on vegetation. Results show that adverse impacts of ozone on ozone-sensitive crops and natural vegetation do occur throughout the whole of Europe and North-America. Critical levels for ozone are regularly exceeded at more than ¾ of the measuring points.

In the context of the biomonitoring programme of ICP Vegetation (cf. Buse et al., 2003), the impacts of ozone on bean (*Phaseolus vulgaris*) and underground clover (*Trifolium subterraneum*) was investigated at four locations (Westmaas, Schipluiden, Zegveld and Wageningen) in the period 1994-1996. Most important results were that observed effect intensities significantly differed between the four locations and that plants were not protected against ozone according to the present "critical levels" (Tonneijck and van Dijk, 1997).

Critical levels for ozone have been defined by the sum of the hourly ozone concentrations during daylight hours (defined as the time with global radiation > 50 $W.m^{-2}$) above a threshold value of 40 parts per billion (ppb) during the growing season. The threshold of 40 ppb is based on a reduction in annual biomass increment. The use of daylight hours only is based on the observation that ozone uptake during night time is negligible due to the closure of stomatal pores (Ashmore and Wilson, 1994). This accumulated ozone exposure over a threshold of 40 ppb, called AOT40, is expressed in ppb hours or ppm hours. For crops a critical AOT40 of 3000 ppb h (3 ppm h) is used. For forests, a critical AOT40 of 10 000 ppb h (10 ppm h) accumulated over a six-month growing season (April-September) has been adopted, independent of tree species (Kärenlampi and Skärby, 1996). More information on critical levels for ozone in comparison to those set for human health are given in Table 3.6 (Section 3.4).

3.3 Water quality and species diversity of aquatic ecosystems

Adverse impacts of elevated inputs of N_r on aquatic ecosystems can be divided in eutrophication and decreased species diversity of (i) oligotrophic small-scale soft water ecosystems (focus on N deposition) and (ii) marine areas/coastal systems and large surface waters, including excess algal growth (focus on runoff of nitrogen from agricultural and non –agricultural soils).

3.3.1 Soft water ecosystems

Water quality

Soft-water ecosystems are common in the boreal and temperate zones of the northern hemisphere. Typically for these ecosystems is that they have a low bicarbonate concentration and generally a low nutrient availability. Most of these ecosystems are mainly fed by rainwater, which partly explains their oligotrophic status. Their diversity in plant species is high, but very vulnerable to environmental changes (Roelofs, 2002).

Most important water quality parameters in view of impacts on the aquatic plant species diversity (see further) are alkalinity (bicarbonate), pH and concentrations and form (NH_4/NO_3 ratio) of inorganic N (the latter as a result of atmospheric N deposition). The negative impact of N is partly induced by shading, by algae and other macrophytes that are favoured by increased N concentrations. The International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters) is designed to assess the degree and geographical extent of acidification of surface waters. Trends in water chemistry indicate that sulphate concentrations decreased tremendously during the last two decades (Lükewille et al., 1997). Decreasing sulphate concentrations emphasise the importance of nitrate as the second important acidifying anion.

In an analysis on regional trends in surface-water chemistry in North and Central Europe and North America, Stoddard et al. (1999) found that lake and stream sulphate concentrations decreased throughout the 1980s and the 1990s, with generally a stronger decrease in 1980s than in the 1990s. Surface waters in Europe also showed an increase in alkalinity, especially in North/Central Europe. Stoddard et al. (1999), however, hardly found regions with a decline in nitrate. In the 1980s, they found a serious increase in North and Central Europe, whereas in the 1990s a decline was found in Central Europe. Based on an inventory in the period 1990-2000, Arts et al. (2002) found that about 70% of the moorland pools in the Netherlands exhibit NH_4 concentrations and sulphate concentrations that exceed the EC Water Framework Directive for good water quality. Most of these fens are located in southern part of the country.

Besides N deposition, the overall N status of ecosystems, changes in climate extremes and hydrology can have strong influences on leaching of excess nitrate from a watershed. Increased carbon dioxide levels, due to acidification of the sediment, in combination with strongly increased ammonium levels in the systems, due to an increased ammonium input and a decreased nitrification in the acidic water layer, may benefit the growth of Sphagnum species considerably (see above).

Plant species diversity
The highest plant diversity in soft-water lakes can be found in the atlantic regions of Europe and North America. Decreased plant species diversity of oligotrophic small-scale soft-water ecosystems is mainly due to direct N deposition on those waters. Generally recognised effects of acidification are confined to lakes and streams in areas with acidic bedrock (Bronmark and Hansson, 2002) and to moorland pools on sandy soils (Roelofs et al., 1996). Such effects are well described and generally entail a loss of species, sometimes accompanied by a strong dominance of one or a few acid-resistant species (see above). The reduction in plant diversity in soft-water lakes in the Netherlands has been ascribed to acidification and eutrophication due the deposition of N and S compounds (Brouwer et al., 1997; Smolders et al., 2002), but also to drought (Lamers et al., 1998a; Lamers et al., 1998b). The previously mentioned inventory on the quality of moorland pools in the Netherlands in the period 1990-2000 (Arts et al., 2002) shows that 44% of the pools suffers from a lack of characteristic plant species. The most serious deteriorated pools occurred in the southern part of the country, being the area with the highest N deposition.

Characteristic soft-water plant communities like *Isoetes*, *Lobelia* and *Littorella* are very sensitive to water quality. These slow-growing plants require a pH > 5.5 and preferably grow in systems with low N availability and NO_3 as the dominant N source (Schuurkes et al., 1986). The latter is demonstrated in Figure 3.7. As ammonium is more easily assimilated than nitrate, most aquatic plants generally prefer ammonium. As *isoetid* species are able to utilise nitrate, they will have an advantage over species that use ammonium as a nitrogen source in sediments with a high redox potential. In acidified waters, N is largely available as ammonium and nitrate may be limiting. Due to enhanced N deposition and/or acidification, these systems will be dominated by *Spagnum* and *Juncus*. This is not only caused by a disruption of the NH_4/NO_3 ratio but also the reduced resistance to infections (Smolders et al., 2000).

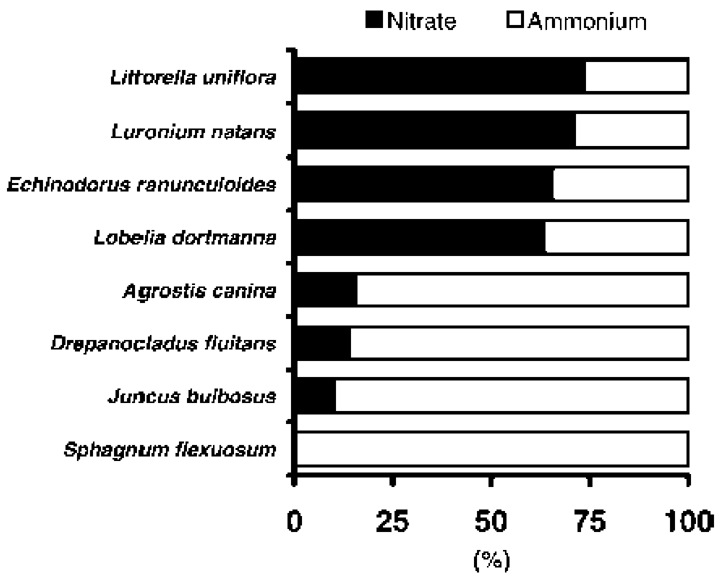

Figure 3.7 *Relative contribution of ammonium and nitrate in the N uptake of different aquatic macrophyte species (from Smolders et al., 2002, adapted from Schuurkes et al., 1986)*

According to Arts (2002), the observed differences in vegetation changes between soft waters in distinct geographical areas can be attributed to differences in the characteristics of the soft water systems. Acidification of the original, non-calcareous sediments in the southern Norwegian lakes for example did not lead to a decrease in plant diversity (Roelofs et al., 1996) but in southern Swedish lakes with more calcareous sediments, a transition to a system dominated by *Spagnum* and *Juncus* takes place (Lükewille et al., 1997). The main reason for this is that the acidification in the calcareous sediments leads to an increase in bicarbonate levels supporting the development of submerged *Spagnum* and *Juncus* in southern Swedish waters.

Besides C, N is also involved in triggering successional changes. The Netherlands is the only country where originally soft water sites have ammonium as the main form of inorganic N today (Lükewille et al., 1997). Nitrate is the dominant inorganic form of N in soft waters in other countries in Europe. If ammonium/nitrate ratios and nitrate concentrations are low, conditions may remain more favourable to *Isoetids* than to *Sphagnum* and *Juncus*. However, nitrate concentrations are enhanced in many waters in Europe, indicating a high degree of N saturation, resulting from high N deposition loads. In some softwaters in Norway and Sweden, a high degree of N saturation has also been found (Lükewille et al., 1997). So, even though ammonium/nitrate ratios are still low in waters outside the Netherlands, nitrate concentrations may be enhanced, resulting in potentially negative effects on *isoetids*. In an overview on deterioration of atlantic soft water lakes, Arts (2002) shows that in at least three European countries (the Netherlands, Germany and Poland) *isoetids* disappeared, whereas, in Belgium hardly any soft water ecosystems are left. In Denmark, widespread eutrophication is reported, leaving only few oligotrophic *Lobelia* lakes. At this time no loss of *isoetids* from Scandinavian countries are reported, but changing vegetation as well as suboptimal growth and fertility of i*soetids* have become distinct recently (see also above). In contrast to western and central European waters, isoetids are still very abundant (Roelofs et al., 1996).

Fauna species diversity

Aquatic invertebrates in raised bogs: Studies in lakes and ditches have shown that increased nutrient availability affects the aquatic invertebrate assemblages (e.g. Verdonschot, 1996; Lang, 1999). In these aquatic systems, eutrophication can mainly be due to run-off water from agricultural or urban areas. In raised bogs, however, nutrient enrichment is generally due to increased atmospheric deposition only. In northwest European raised bogs the increased nutrient deposition has resulted in the invasion of birch (*Betula* spp.) and purple moor grass (*Molinia caerulea*) (Risager, 1998; Limpens et al., 2003a; Tomassen et al., 2003; Tomassen et al., 2004). These changes in the vegetation composition and its structure will have affected the fauna species assemblages, e.g. spiders and beetles living in the originally open bog vegetation and ground breeding birds. The increased nutrient availability has resulted in increase of the nutrient content of plant material (Limpens et al., 2003a; Tomassen et al., 2004). Also the growth of algae might be stimulated by an increase of N and P availability (Gulati and DeMott, 1997; Limpens et al., 2003b). These changes have consequences for the herbivorous and detritivorous invertebrates that eat this material. Also carnivorous invertebrate species, like aquatic beetles (Dytiscidae) are affected (van Duinen et al., 2004a).

A comparative study between pristine raised bogs in Estonia (low N deposition level) and degraded and rewetted raised bog remnants in the Netherlands (high N deposition level) showed that the aquatic macro-invertebrate assemblages of pristine ombrotrophic sites (nutrient poor central raised bog pools) are absent in Dutch bog remnants (van Duinen et al., 2002; see Figure 3.8). This study also showed that the variation in species assemblage is low in water bodies created by rewetting measures, compared to pristine raised bog systems in Estonia and compared to Dutch degraded bog remnants not influenced by rewetting measures, as well (van Duinen et al., 2002; van Duinen et al., 2003). Until now restoration measures resulted in restoration of a limited part of the species spectrum of pristine raised bogs.

Compared to pristine ombrotrophic sites, the relative abundance of species preferring ombrotrophic conditions is generally low in both the degraded and rewetted bog sites in the Netherlands, whereas species preferring situations with a higher nutrient availability within pristine bogs (transitional mire or lagg) are dominant in Dutch bogs (van Duinen et al., 2004a; see Figure 3.9). Regarding the oligochaetes, in the Estonian ombrotrophic water bodies only the enchytraeid *Cognettia sphagnetorum* was present. The species *Nais variabilis* is in pristine Estonian raised bogs limited to water bodies influenced by minerotrophic, alkaline water where the decomposition rate of organic matter is higher and consequently the nutrient availability is higher. In Dutch bog remnants, however, *N. variabilis* is also frequently found in water bodies that are not influenced by minerotrophic, alkaline water. This difference in species assemblage between Estonian and Dutch bog water bodies can well be attributed to the higher atmospheric N (and sulfur) loads in the Netherlands (van Duinen et al., submitted).

For dragonflies the same kind of changes in species dominance was found. In Estonian bogs *Leucorrhinia dubia* is the most abundant species in the ombrotrophic sites, whereas *Leucorrhinia rubicunda* shows preference for the transitional mire. In the Netherlands, however, *L. rubicunda* is the most abundant species found in both degraded and rewetted sites, whereas *L. dubia* is fairly rare. This kind of shifts in species dominance was found for bugs, beetles, and chironomids as well (van Duinen et al., 2004a). To understand the mechanisms behind these shifts, differences in species traits and demands have to be elucidated. Nutritional requirements of species, or -in other words- species ability to build up biomass using decomposing organic matter, bacteria, fungi, algae, or micro-invertebrates with a relatively low vs. high nutrient content (Elser et al., 2000; Elser et al., 2001) will play an important role in the species composition of the invertebrate assemblage.

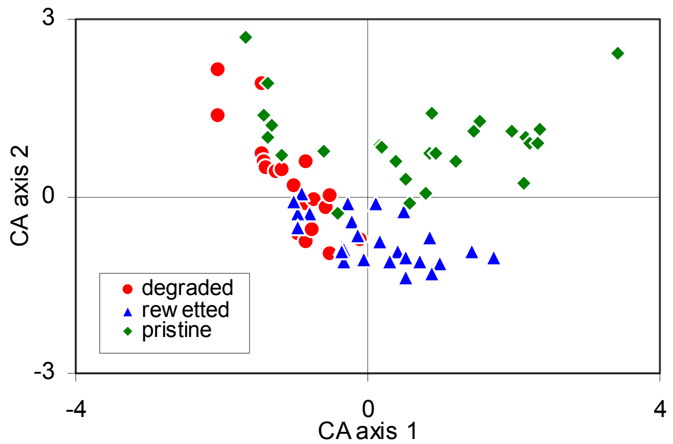

Figure 3.8 *Plot of a Correspondence Analyses of species presence data of Odonata, Trichoptera, adult Coleoptera, Chaoboridae and Heteroptera collected in spring in water bodies in pristine bogs in Estonia and in degraded and rewetted bog remnants in the Netherlands. The species assemblages of pristine ombrotrophic bog pools (plotted in upper right quadrant) is absent in Dutch bog remnants (van Duinen et al., 2002)*

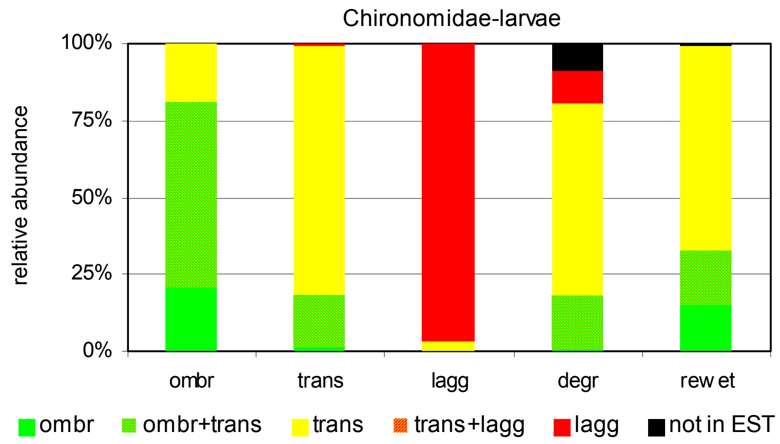

Figure 3.9 *Relative abundance of larvae of Chironomidae species classified in six species groups based on their preference for the ombrotrophic bog, transitional mire, and lagg in the pristine Estonian bogs. Sampling sites are grouped into ombrotrophic water bodies, water bodies in transitional mires, and laggs in pristine raised bogs and water bodies in degraded and rewetted bogs in the Netherlands. The species preferring transitional mires are dominant in Dutch raised bog remnants (van Duinen et al., 2004a).*

Aquatic invertebrates in soft-water lakes: In soft-water lakes, probably the same kind of changes in species assemblages occur due to increased atmospheric N deposition. From an inventory of soft-water lakes Van Kleef and Esselink (2004) found a clear relation between high ammonium concentrations and low pH at one hand and a decline of macro-invertebrate species at the other hand. Reconstruction of the chironomid species assemblage in the soft-water lake Beuven in the southern part of the Netherlands since 1900 shows that species preferring oligotrophic and mesotrophic water declined until 1985, whereas species indicating eutrophic conditions increased in this period of degradation by acidification and eutrophication. After restoration of this lake in 1985 the species preferring oligotrophic and mesotrophic conditions increased, whereas species indicating eutrophic conditions declined (unpublished data from Klink, Buskens and van Kleef; van Duinen et al., 2004b). Yet, the causal role and importance of N in the invertebrate assemblages of soft-water lake still have to be elucidated.

3.3.2 Coastal and marine ecosystems

One clear and widespread effect of an accelerated N cycle is the eutrophication of coastal and marine eco-systems (NRC, 2000). In marine ecosystems, excess nitrogen run-off from farm fertilisers, sewage and industrial pollutants does cause blooms of microscopic algae known as phytoplankton, which sink to the seabed and decompose, using oxygen, thereby suffocating other marine life.

Impacts in the Netherlands

At the 2nd International Conference on the Protection of the North Sea (London 1987), all countries around the North Sea agreed on reducing the input of nutrients by 50% between 1985 and 1995 in those areas where nutrients (are likely to) cause pollution. This decision was based on the fact that the loads in many European rivers were extremely high. This was considered the cause for the increasing frequency of harmful algal blooms and the significant oxygen reductions that were occasionally observed in the bottom water in some areas (Anonymous, 1993). However, very little quantitative information was available at that time on the possible effects of the management decision, which was seen as a first step for later management actions based on thorough ecosystem understanding and an approach towards a sustainable North Sea with clear ecological quality objectives.

Basically, the goal for phosphorus (P) has been achieved by the improvement of municipal wastewater treatment plants and the reduction of P as detergent in washing powder by a factor ten, while N loads have not been reduced by the same amounts (Behrendt et al., 2000). This has probably led to reduced primary production in areas being typically P limited. However, in these areas, the reduction of just P has probably led to increased imbalance between the two nutrients, an imbalance which may increase the possibility of certain algae being toxic (Anonymous, 1993).

Skogen et al. (2004), showed that due to a reduction in the P values only, the production regime in the southern North Sea is P limited, while N is the limiting nutrient in the northern North Sea. Focusing on the N/P ratio as a possible proxy for eutrophication, a reduction in the N and P loads reduces this ratio by a similar factor, while a reduction in the P loads only increases it.

Impacts in Europe and the World

Excess N run-off may cause so-called "dead zones," oxygen-starved (hypoxia) areas of the world's oceans that are devoid of fish (cf. Diaz and Rosenberg, 1995; Boesch, 2002; Rabalais, 2002). As a result of the inefficient and often overuse of fertilisers, the discharge of untreated sewage and the ever-rising emissions from vehicles and factories, N and P from these sources are being discharged into rivers and the coastal environment or being deposited from the atmosphere, triggering these alarming and sometimes irreversible effects. Oxygen-starved areas in bays and coastal waters have been expanding since the 1960s (UNEP, 2003). The number of known locations around the world, nearly 150, has doubled since 1990. While many of these sites are small coastal bays and estuaries, seabed areas in marginal seas of up to 70 000 km^2 are also affected. Not all are permanent: some appear annually or only intermittently.

Notable dead zones in Europe are the Baltic Sea, Black Sea and the Adriatic Sea. Increased flows of N from agricultural run-off and the deposition in coastal areas of air-borne N compounds from fossil-fuel burning stimulate blooms of algae in these waters. The algae sink to the bottom where they are decomposed by micro-organisms that use most of the oxygen in the system. Because very few organisms can tolerate the lack of oxygen in these areas, they can destroy the habitat for fish, shellfish, and most other forms of life. In recent decades, large areas of coastal waters with harmful algal blooms, severely depleted oxygen levels, and disappearing seagrass beds have been identified and clearly linked with increased inputs from the N cascade. Figure 3.10 illustrates the relationship between N loads to the northwestern shelf of the Black Sea and the size of bottom-water hypoxic zone in the Black Sea.

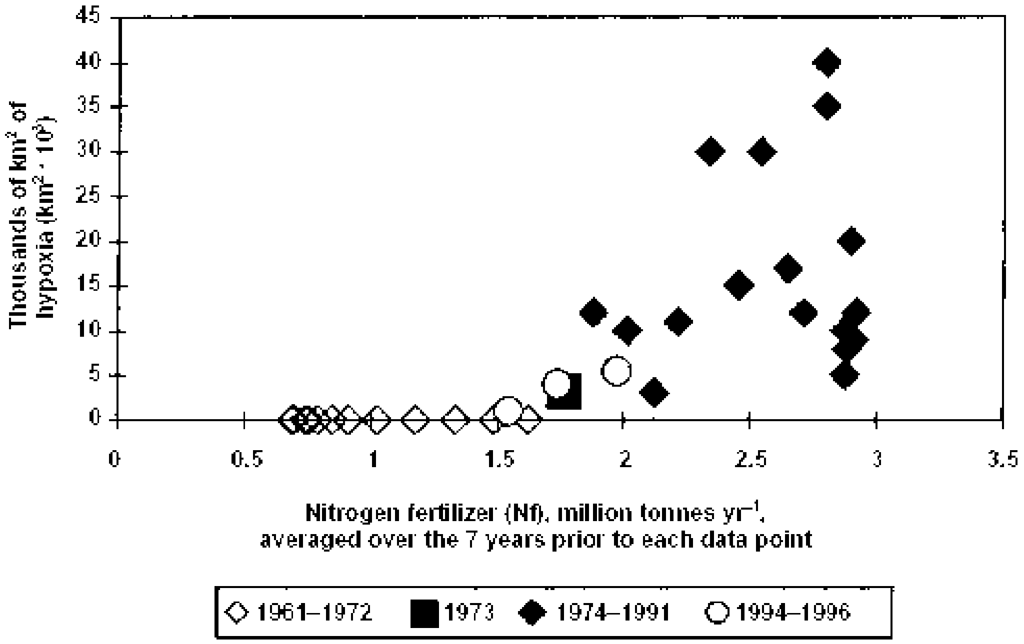

Figure 3.10 *The relationship of N loads to the northwestern shelf of the Black Sea vs. the size of the bottom-water hypoxic zone for the periods indicated (Mee, 2001)*

Even though 75% of the world's fish stocks are already being overexploited, UNEP states that the dead zones pose as big a threat to fish stocks. Over fishing and nutrient pollution of coastal zones often coincide and contribute synergistically to degradation. This requires a multi-prong approach to restore coastal ecosystems (Boesch et al., 2001). Reduction of external nutrient loads, however, does not lead to an immediate shift in the eutrophic condition of the system (cf. Rabalais, 2002, for an overview). As a result of the decline in fertiliser use, due to the collapse of the Soviet Union in the 1990s, nutrient input in the Black Sea decreased dramatically. For the first time in several decades hypoxia did not occur in the northwestern shelf of the Black Sea in 1996 (Figure 3.10). However, four years later, fish stocks are still depleted (Mee, 2001). Now the policy goal is to maintain this situation as the economy of the region redevelops.

In general reducing N discharges can restore the seas' health: an agreement by states along the River Rhine has for example cut the amount of N entering the North Sea by 37%. Other remedies include wasting less fertiliser, cleaning vehicle exhausts, and using forests to soak up excess N. UNEP thus urged nations to cooperate in reducing the amount of N discharged into their coastal waters, in part by cutting back on fertiliser use or planting more forests and grasslands along feeder rivers to soak up the excess N.

3.4 Human health

Changes in the N cycle also clearly have both negative and positive implications for human health. The most important effect of N use on human health is beneficial as it increases food production. This section, however focuses on the adverse health effects. This overview includes general information and where possible also specific information for the Netherlands. Adverse health impacts include direct effects due to the ingestion of N-containing compounds in water or air and indirect effects such as diseases related to ozone and primary particles. The health effects are mainly based on an overview paper on N and health by Townsend et al. (2003) and range from well-documented to largely theoretical. Below we discuss the various effects in terms of (i) their causes and related health effects and (ii) available critical limits and data on exceedances of those limits.

3.4.1 Water

Water quality is a major concern throughout Europe. N pollution of groundwater mitigates its use for drinking water, while eutrophication in surface and marine waters due to excessive nutrient loads can lead to algal growth, oxygen deficiencies, and fish kills. Nitrate concentrations in drinking water should not exceed 50 $mg.l^{-1}$ (EC Drinking Water Directive). Exceedances of this limit value are still a problem throughout the EU (EEA, 2003). The EU makes progress in controlling point sources of pollution from industry and households through wastewater treatment.

Groundwater nitrate contamination associated with fertiliser use is common in both developed and developing regions (Oenema et al., 1998; Agrawal et al., 1999). Severe instances of groundwater contamination are, however, often associated with intensive livestock production, particularly swine and poultry (Mallin, 2000). The potential health effects of high nitrate levels are diverse, including reproductive problems (Kramer et al., 1996), methemoglobinemia, and cancer. Infants are especially at risk for methemoglobinemia ("blue-baby" syndrome). In this context, groundwater nitrate contamination is a serious problem due to its poor reversibility (van Lanen and Dijksma, 1999).

While little conclusive evidence exists for this disorder at levels below 10 ppm, higher values found throughout the world can significantly elevate the risk (Gupta et al., 2000). The World Heath Organisation thus adopted a 10 $mg.l^{-1}$ NO_3-N standard for safe drinking water, being close to the EU standard 11.3 $mg.l^{-1}$ NO_3-N (NO_3 is 50 $mg.l^{-1}$). Recent evidence suggests that nitrate levels even below the WHO standard of 10 ppm may stimulate formation of N nitrosoamines (van Maanen et al., 1996), compounds strongly implicated in cancer risks. In Iowa, rising nitrate levels well below the WHO standard were associated with an increased risk of bladder and ovarian cancers (Weyer et al., 2001). Long-term consumption of water with nitrate-N concentrations above 6.3 $mg.l^{-1}$ NO_3-N has been linked to a higher risk for Non-Hodgkin's lymphoma (NHL), a cancer disease that has increased dramatically in the US (Ward et al., 1996).

In the Netherlands, the EU standard 11.3 $mg.l^{-1}$ NO_3-N is often exceeded in upper groundwater and this is especially the case with the target value of 5.6 mg l^{-1} NO_3-N (NO_3 is 25 $mg.l^{-1}$). High nitrate concentrations in drinking water wells, due to elevated nitrate leaching to groundwater, occur specifically in well drained sandy soils below intensive agricultural areas (Fraters et al., 2004, Figure 3.11A). Apart from agricultural soils, high concentrations also occur below non-agricultural (specifically forest) soils in the Netherlands, because of high N deposition, low denitrification rates and low precipitation surpluses (de Vries et al., 1995, Figure 3.11B).

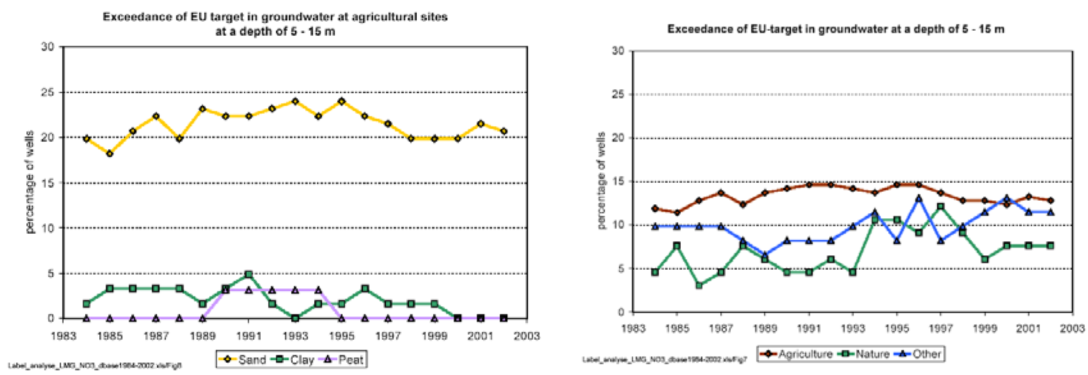

Figure 3.11 *Exceedance of the EU target value of 50 $mg.l^{-1}$ for nitrate in groundwater within the agricultural areas of the Netherlands (left, A) and for all type of landuse (right, B) at a depth of 5-15 m below the surface level for the 1984-2002 period (Fraters et al., 2004).*

Even worldwide, the 11.3 $mg.l^{-1}$ NO_3-N standard is often exceeded. In the US regional studies suggest that 10–20% of groundwater sources may exceed 10 $mg.l^{-1}$ NO_3-N (is 10 ppm), the standard of the Safe Drinking Water Act in the US, being close to 11.3 $mg.l^{-1}$ NO_3-N.

3.4.2 Air pollution

Air pollution is a widely recognised public health issue. In the developing world, indoor air pollution may account for nearly 2 million deaths per year (Wolfe and Patz, 2002). The relative importance of N-containing species in this disease burden is not well quantified, but could potentially be substantial (Wolfe and Patz, 2002). A changing N cycle plays an important role in several ways. It may cause high local concentrations of NO_x, ozone, fine particulates and pollen, which are all partly related to NO_x, NH_3 and/or N_2O emissions.

Nitrogen oxides

Elevated emissions of nitrogen oxides (NO_x) from fossil fuel combustion, biomass burning and fertiliser use all contribute to high atmospheric NO_x levels, especially in urban areas. Urban levels of NO_x can lengthen and worsen common viral infections, significantly elevating the risks to asthmatics (Spannhake et al., 2002). NO is not irritant itself but it does react with hemoglobin giving meta-hemoglobin which can be lethal.

Toxicity experiments conducted on animals proved that although a spot exposition to NO very seldom leaves permanent effects, a continuous and prolonged exposition for some weeks to some months to NO_2 concentrations even lower than 1880 $\mu g.m^{-3}$ (1 ppm) can have severe consequences, mainly for the lungs, but also for other parts op the body such as liver and blood (WHO, 2003).

NO_2 is an irritant gas and if breathed can cause severe damage to the lungs. High indoor NO_2 levels can also induce a variety of respiratory illnesses. The lethal concentration is about 200 ppm. Due to its high solubility in fat, NO_2 can penetrate deep into the lungs where it does damage capillaries and generate spread inflammation of tissues. Concentrations higher than 60-150 ppm can cause cough and burning sensation deep inside the lungs. Damage to the lungs can be visible after 2 to 24 hours. Continuous exposition to low concentrations of NO_2 can cause cough, headache, loss of appetite and stomach problems. Environmental studies have proved that children that have to sustain a continuous exposition to NO_2 end up with an increase of breathing disease and a reduced breathing efficiency (WHO, 2003).

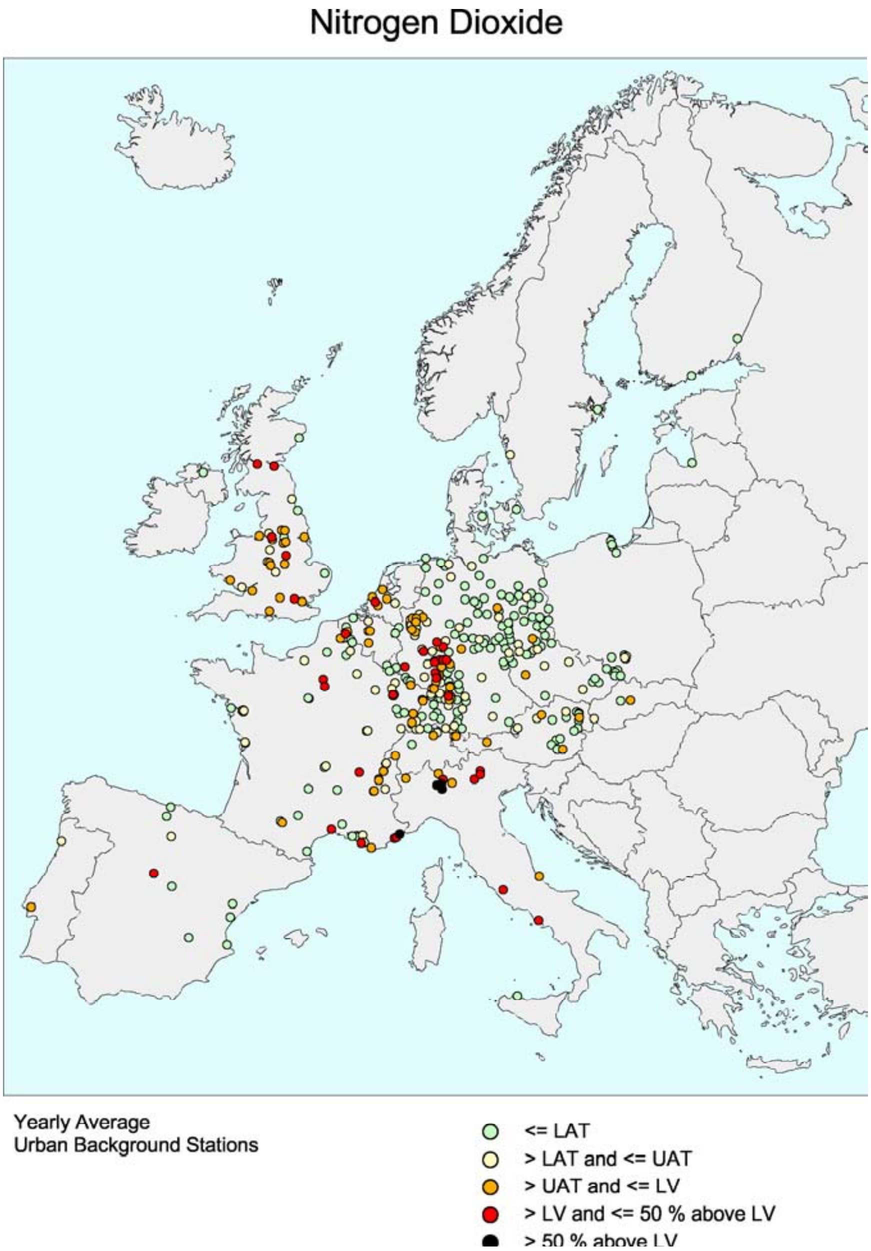

Figure 3.12 *Annual average NO_2 concentrations at urban background stations and the exceedances of EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT). LV: 40 µg.m^{-3}, UAT: 32 µg.m^{-3}, LAT: 26 µg.m^{-3} (EEA, 2003)*

NO_x interacts in the atmosphere to form fine nitrate particles that can be transported over long distances by wind and inhaled deep into people's lungs (see *Fine Particles*).

The current WHO guideline values for NO_2 are a 1-hour level of 200 µg.m^{-3} and an annual average of 40 µg.m^{-3}. Figure 3.12 shows annual average NO_2 concentrations at urban background stations. The maximum urban background station in each city with data is shown, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT). LV: 40 µg.m^{-3}, UAT: 32 µg.m^{-3}, LAT: 26 µg.m^{-3} (EEA, 2003).

The most stringent of the EU limit values for NO_2 proves to be the annual average concentration of 40 µg.m^{-3}. Its attainment generally also implies achievement of short-term limits. Concentrations at urban street hot spots have declined since the end of the 1980s as a result of the growing penetration of catalysts in the car fleet. Exposure to NO_2 has decreased and may now be stable. Nevertheless, at present the annual limit is exceeded in about 30 European cities, which report data, and substantial numbers of people are exposed to NO_2 concentrations above health protection-based limit values (Figure 3.13).

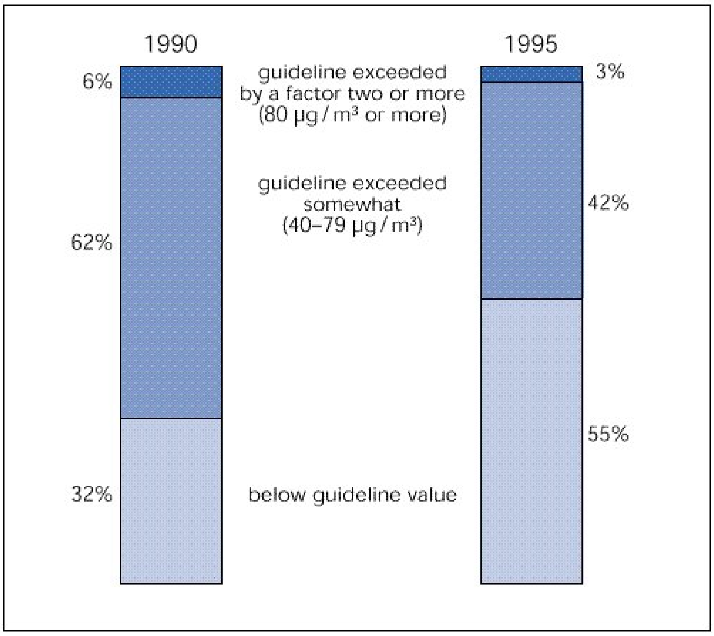

Figure 3.13 *Percentage of population exposed to NO_2 concentrations above health protection-based limit values in about 30 European cities in 1990 and 1995 (EEA, 2004)*

The EU-limit of 40 $\mu g.m^{-3}$ has not been exceeded in the Netherlands in 2002 (Buijsman, 2004). The annual average NO_2 concentration decreased these past years with 3% per year to 31 $\mu g.m^{-3}$ averaged over the country. The annual average NO_2 concentrations in the Netherlands exceed the limit values on a large scale near roads (Buijsman, 2004). Expressed in kilometre road length the exceedance dropped from 3500 km in 1990 to 1800 km in 2002. More than 70% of these kilometres are located in the four largest cities. In recent years no further improvement in NO_2 concentrations is observed.

Ozone

High atmospheric NO_x levels lead to the elevated production of tropospheric O_3 (Chameides et al., 1994). Adverse health impacts that can be initiated and exacerbated by O_3 exposure include coughs and asthma (reactive airways diseases, RAD), short-term reductions in lung function, and chronic respiratory disease (von Mutius, 2000; WHO, 2003). Children who exercise in environments high in O_3 are 40% more likely to develop asthma (McConnell et al., 2002), a disease that is increasing in many parts of the world, despite advances in treatment (Beasley et al., 1998).

The number of days with elevated O_3 concentrations, expressed as a highest 8 hourly average ozone concentration above 120 $\mu g.m^{-3}$, was reduced in 2002 to 5 days (Buijsman, 2004). The maximum was 9 days. The limit of 25 days has not been exceeded for several years, with the exception of 2003. The O_3 peak levels decreased in the Netherlands. The annual differences in O_3 concentrations are caused by differences in weather from year to year. Figure 3.14 shows the trend in the number of 8 hour averages above 120 $\mu g.m^{-3}$. Ozone and PM were responsible for 1-3% of the additional deaths in 2001.

Table 3.6 *Ozone critical levels and guideline values that apply in the European region for human health and health of terrestrial ecosystems, including agricultural crops*

Description	**Set by**	**Criteria**	**Value**
Human health			
Population information threshold	European Council Directive 92/72/EEC	1 hour average	180 $\mu g.m^{-3} \approx$ 90 ppb
Population warning threshold	European Council Directive 92/72/EEC	1 hour average	360 $\mu g.m^{-3} \approx$ 180 ppb
Health protection threshold	European Council Directive 92/72/EEC	fixed 8 hour means (0:00-8:00, 8:00-16:00,16:00-24:00,12:00-20:00)	110 $\mu g.m^{-3} \approx$ 55 ppb
Guideline for the protection of human health	WHO	running 8 hour maximum	
Provisional objective to be met by 2005 for the protection of human health	UK Government - Air Quality Strategy Jan. 2000	daily maximum of 8 hour running means to be exceeded no more than 10 times per year	100 $\mu g.m^{-3} \approx$ 50 ppb
Crop and vegetation health			
Critical level for crops and semi-natural vegetation	UNECE-CLRTAP	AOT40[i] daylight[ii] hours May to July	3,000 ppb.h
Critical level for forests	UNECE-CLRTAP	AOT40[i] daylight[ii] hours April to September	10,000 ppb.h
Critical level for agricultural crops	WHO	AOT40[i] daylight hours over 3 months	5,300 ppb.h
Critical level for forests	WHO	AOT40[i] all hours over 6 months	10,000 ppb.h

[i] AOT40 is the accumulated concentration over a threshold of 40 ppb
[ii] daylight hours are defined as when solar radiation exceeds 50 Wm^{-2}

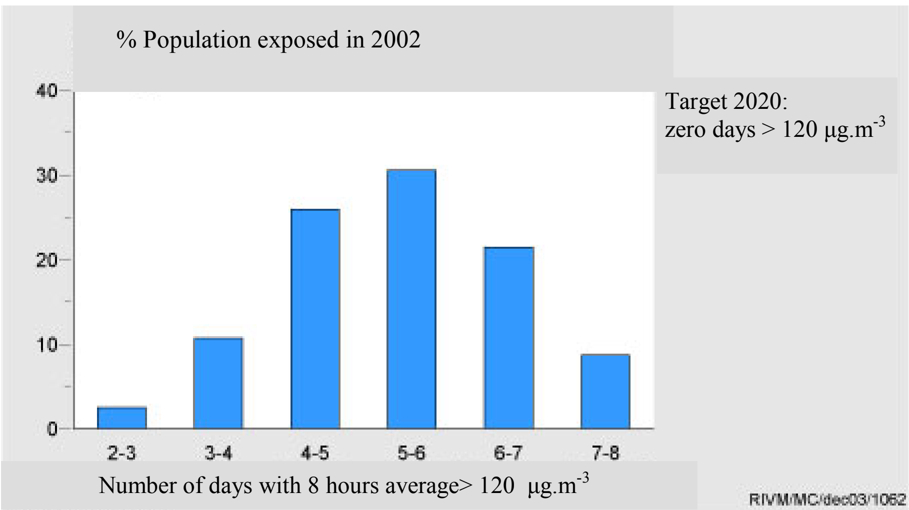

Figure 3.14 *Percentage of population exposed to the number of days with O_3 concentrations above 120 $\mu g.m^{-3}$ in the Netherlands (Buijsman, 2004)*

The new EU target of 120 $\mu g.m^{-3}$ (8-hour average to be exceeded on no more than 25 days per year; Directive 2002/3/EC) has seldom been exceeded in Europe in recent years. In 1999, a third of the urban population was exposed to over 30 exceedances a year, and about 30% of cities exceeded the target (rural concentrations are generally higher than urban). Most exceedances are in Central and Southern European countries. There appear to be decreasing short-term peak concentrations across Western Europe but increasing long-term averages. This would reduce the effects of acute ozone exposure, which the limit values address, but increase low-level chronic exposure.

Figure 3.15 shows the urban population fraction in Western Europe and Central and Eastern Europe exposed to short period air quality above limit values.

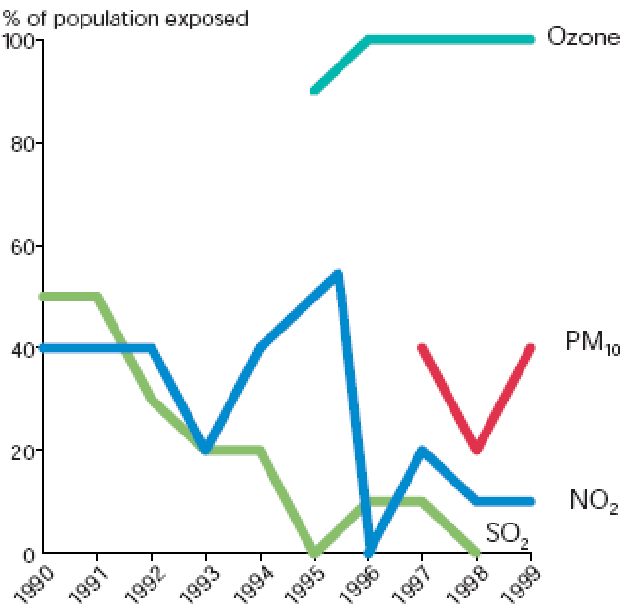

Figure 3.15 *Urban population fraction in Western Europe and Central and Eastern Europe exposed to short period air quality above limit values*

A map of predicted ozone concentrations in 2030 exceeding WHO air quality standards for both humans and vegetation is shown in Figure 3.16. Results show that exceedances of ozone quality standards occur in large parts of Europe.

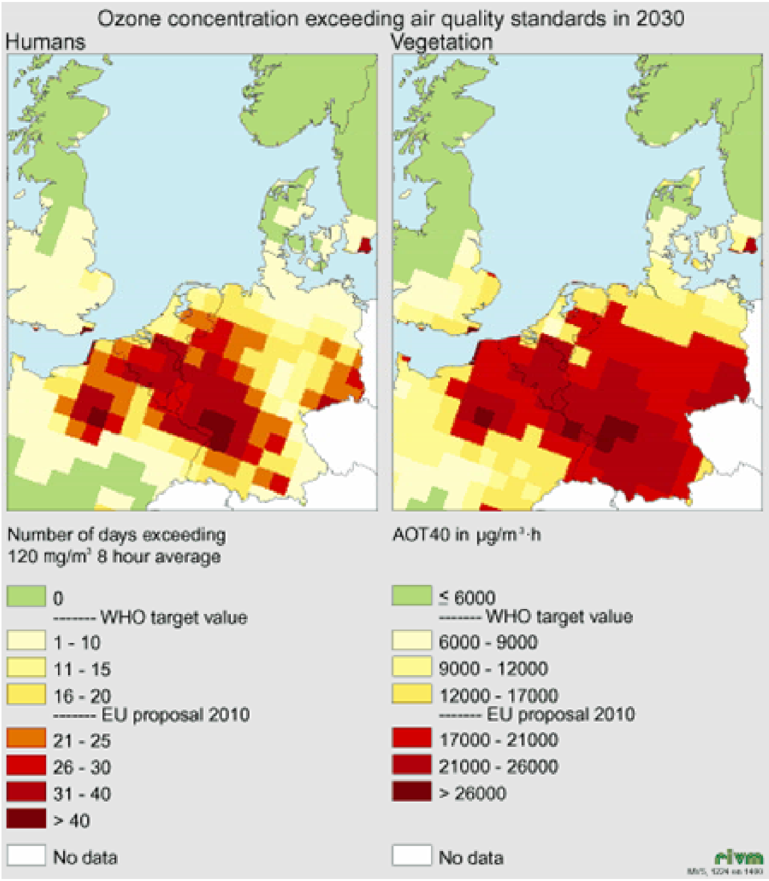

Figure 3.16 *Maps of predicted ozone concentrations in 2030 in north Western Europe exceeding WHO air quality standards for both humans and vegetation*

Fine particles

Aerosol particles are present in a variety of sizes, with different shape and composition. These physico-chemical parameters determine their atmospheric behaviour. Characterisation of so many parameters is virtually impossible and asks for simplification. The simplest approach is to consider the particles as a single atmospheric entity, aerosol or "particulate matter" (PM), characterised by a mass (concentration) that is the sum of the masses of the individual particles, and an overall composition. NO_x and NH_3 interact in the atmosphere to form fine nitrate particles that can be transported long distances. Multiple studies have shown positive correlations between fine particulate air pollution and cardiovascular diseases, respiratory diseases, asthma, reduced lung function, and overall mortality (Pope et al., 2002).

Airborne particulate matter represents a complex mixture of organic and inorganic substances. Mass and composition in urban environments tend to be divided into two principal groups: coarse particles and fine particles. The barrier between these two fractions of particles usually lies between 1 µm and 2.5 µm. However, the limit between coarse and fine particles is sometimes fixed by convention at 2.5 µm in aerodynamic diameter ($PM_{2.5}$) for measurement purposes. The smaller particles contain the secondarily formed aerosols (gas-to-particle conversion), combustion particles and recondensed organic and metal vapours. The larger particles usually contain earth crust materials and fugitive dust from roads and industries.

The fine fraction contains most of the acidity (hydrogen ion) and mutagenic activity of particulate matter, although in fog some coarse acid droplets are also present. Whereas most of the mass is usually in the fine mode (particles between 100 nm and 2.5 µm), the largest number of particles is found in the very small sizes, less than 100 nm. As anticipated from the relationship of particle volume with mass, these so-called ultrafine particles often contribute only a few % to the mass, at the same time contributing to over 90% of the numbers (WHO, 2003).

Particulate air pollution is a mixture of solid, liquid or solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because: (i) these properties govern the transport and removal of particles from the air, (ii) they also govern their deposition within the respiratory system and (iii) they are associated with the chemical composition and sources of particles. These properties are conveniently summarised by the aerodynamic diameter, that is the size of a unit density sphere with the same aerodynamic characteristics. Particles are sampled and described on the basis of their aerodynamic diameter, usually called simply the particle size. The contribution of nitrogen (NO_x and NH_3) to fine particulates is related to the secondary formed aerosols in the atmosphere (formation of ammonium nitrates and sulphates) and do not play a role in the primary emitted particles, such as soot, heavy metals, dust, etc.

There is some doubt whether the secondary N part of fine particulates really contributes to the human health effects, or that specific components contribute to the health effects. If it is the mass of particulates, which is currently used in policies to reduce PM, than the contribution is significant. The relative contribution of reactive atmospheric N to overall particulate loads varies considerably between population centres (Malm et al., 2000). However, it is clearly an important driver of particulate air pollution worldwide, and can be dominant in some regions. For example, ammonium and nitrate containing particulates constitute as much as 65% of the total atmospheric load in southern California (Malm et al., 2000).

The current WHO Air quality guidelines provide exposure-response relationships describing the relation between ambient PM and various health endpoints. Guideline values (proposed) are given in Table 3.7 as it was felt that a threshold could not be identified below which no adverse effects on health occurred. In recent years, a large body of new scientific evidence has emerged that has strengthened the link between ambient PM exposure and health effects (especially cardiovascular effects), justifying reconsideration of the current WHO PM Air quality guidelines and the underlying exposure-response relationships (WHO, 2003). The European threshold is currently 40 $\mu g.m^{-3}$ PM_{10} as an annual average, while 35 days exceeding a threshold of 50 $\mu g.m^{-3}$ PM_{10} are allowed.

Table 3.7 *Particle limits (PM_{10})*

	Max. 24-hour	Annual mean value
WHO target value	dose-response	dose-response
EU limit value 2005	50 $\mu g.m^{-3}$	40 $\mu g.m^{-3}$
EU limit value 2010 (Prel.)	50 $\mu g.m^{-3}$	20 $\mu g.m^{-3}$
Guidance value IMM	30 $\mu g.m^{-3}$	15 $\mu g.m^{-3}$
Current levels in Europe		10 $\mu g.m^{-3}$ (remote areas)

Source: Elvingson and Ågren, 2004

Figure 3.17 shows that in the Netherlands the PM_{10} concentrations decreased to below the EU target value of 40 $\mu g.m^{-3}$ value (Buijsman, 2004). Secondary PM generally stayed the same over the years. Ammonium nitrates and sulphates, next to some organic compounds, form most of the secondary part.

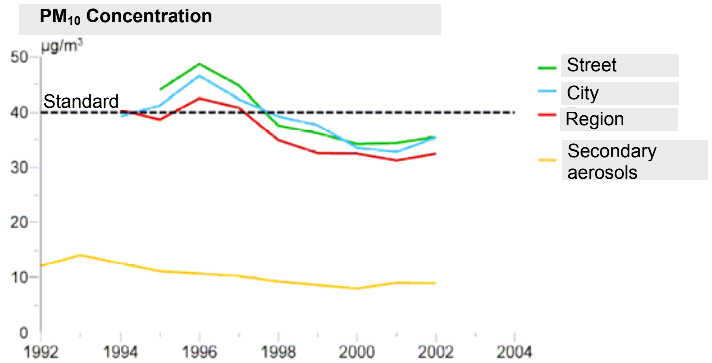

Figure 3.17 *Annual average total PM_{10} concentrations as measured in street canyons, cities and as regional background in the Netherlands ($\mu g.m^{-3}$)*

Figure 3.18 shows the average number of exceeding days of total PM_{10} concentrations in Europe. Exceedance days are defined as days with black smoke (BS) 24-hour average concentrations above 125 $\mu g.m^{-3}$; Total Suspended Particles (TSP) 24-hour average above 120 $\mu g.m^{-3}$; PM_{10} 24-hour average above 50 $\mu g.m^{-3}$. Number and set of cities and measuring methods vary from year to year, and this may cause much of the inter-annual variation. The increase after 1996 is mainly due to the introduction of PM_{10} data into the statistics. Only for the most recent years monitoring data on fine particulates (PM_{10}) are available more widely, these are shown separately at the right-hand side of the diagram.

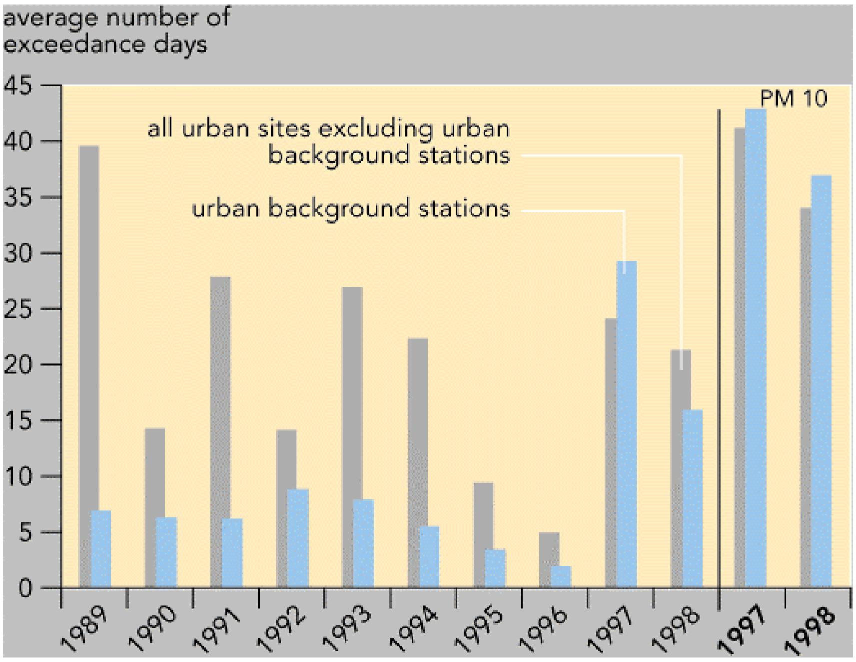

Figure 3.18 *Average number of exceeding days of total PM_{10} concentrations in Europe*

Pollen pollution

Third, human allergic response to pollen is a pervasive environmental health issue. Millions suffer from hay fever, allergenic rhinitis, and allergenic asthma each year, following exposure and sensitisation to pollen (NIH, 1993). Pollen counts are rising, probably for many reasons, including climatic change, disturbance-driven changes in species composition, and elevated atmospheric CO_2 (Wayne et al., 2002), but increasing N availability can also stimulate greater pollen production (Lau et al., 1995). The effects of N on pollen are likely to vary with species, but it is noteworthy that N additions to ragweed, a widespread producer of allergenic pollen, caused dramatic increases in pollen production (Townsend et al., 2003).

Indirect ecological feedbacks to health
Since N limitation of primary production is widespread in terrestrial and marine ecosystems (Vitousek and Howarth, 1991), human additions of N to the environment can cause many ecological changes (Vitousek et al., 1997), which almost certainly include the dynamics of some human diseases. For example, many infectious diseases are controlled by vector hosts, and mosquito-borne malaria alone accounts for more than a million deaths every year (WHO, 2001). Some evidence now suggests that the abundance and distribution of several important vectors, including the mosquito hosts of malaria and West Nile virus, may be affected by changes in N availability (Townsend et al., 2003). In general, as with many ecological responses to changing N, the dynamics of a given disease vector are likely to be complex, driven not only by the organism's direct response, but also by those of its food sources, and of the parasitic and predatory species that affect its abundance (Comiskey et al., 1999).

Eutrophication of coastal and marine eco-systems may also affect human health by the worldwide increase in harmful algal blooms, including shellfish poisoning, as well as toxins produced by various cyanobacteria, and by estuarine dinoflagellates (Burkholder, 1998). Increased N can also increase the availability of other key nutrients, changes that can, in turn, facilitate blooms of many species of harmful algae (NRC, 2000). Finally, the bacterium *Vibrio cholerae* is associated with a wide range of marine life, and cholera outbreaks have long been associated with coastal algal blooms (Colwell and Huq, 2001; Cottingham et al., 2003). Some evidence suggests that rapid growth of *V cholerae* can accompany that of marine algae in eutrophic conditions, and high nutrient conditions favouring algal growth have been implicated in recent cholera outbreaks (Epstein, 1993; Colwell and Huq, 2001). The study of links between ecological changes due to environmental N enrichment and the dynamics of human diseases is a relatively new field, but theoretical results suggest that reductions in diversity from other drivers can increase the transmission of vector-borne diseases (Ostfeld and Keesing, 2000). Many health implications of a changing global N cycle, especially those arising via complex ecological feedbacks, require substantial additional research.

3.5 Climate

A disruption of the N cycle can cause global warming due to elevated N_2O emissions, being one of the most important non-CO_2 greenhouse gas, together with methane. Inversely the impact of N emissions on fine particulate matter is such that it offsets the global warming potential. Below, we describe the contribution of N_2O and fine particulate matter to the overall emissions of greenhouse gases and a short expose is given of the potential impacts of climate change on plant species diversity in Europe

Nitrous oxide emissions and its contribution to greenhouse gas emissions
The contribution of different greenhouse gases (expressed as CO_2 equivalents) to the total emission in the Netherlands (approximately 220 Tg CO_2-eq) is given in Table 3.8. It shows that the contribution of nitrous oxide emissions (N_2O) to the total emissions is only 6%. Agriculture contributes approximately 10% to the total emission of greenhouse gases, with approximately equal shares of CO_2, CH_4 and N_2O (Olivier et al., 2003).

Table 3.8 *Emissions of greenhouse gases in the Netherlands in 2001 (Tg CO_2-equivalents)*

Sector	CO_2	CH_4	N_2O	HFC/PFC/SF6	Total
Agriculture	7.0	8.7	7.2	0	22.9
Other	172.9	11.7	8.9	3.4	196.8
Total	179.9	20.4	16.1	3.4	219.7

Source: Olivier et al., 2003

The contribution of different greenhouse gases (expressed as CO_2 equivalents) to the total emission in Europe (EU15) is given in Table 3.9. It shows that the contribution of N_2O to the total emissions is larger than in the Netherlands (approximately 9%). As with the Netherlands, agriculture contributes approximately 9% to the total emission of greenhouse gases. For CH_4 and N_2O the shares of agricultural and non agricultural sources are about equal (Olivier et al., 2003).

Table 3.9 *Emissions of carbon dioxide, methane, nitrous oxide, in EU 15 countries in 1996 (in Tg CO_2-equivalents)*

Sector	CO_2	CH_4	N_2O	Total	%
Agriculture	18.2	184.1	184.4	370.4	9.04
Energy	1093.4	1.3	191.4	1113.9	27.20
Industry	728.7	1.6	102.4	832.7	20.33
Transport	769.2	4.4	19.1	792.8	19.36
Other	745.4	216.8	23.5	985.7	24.07
Total	3338.6	408.2	348.8	4095.4	100

Sources: Emissions of atmospheric pollutants in Europe, 1980-1996. EEA report 9 (2000).
1 kg N_2O = 290 eq. CO_2; 1 kg CH_4 = 21 CO_2 eq. (Graedel and Crutzen, 1993)

Fine particles and their contribution to greenhouse gas emissions
Various components of fine particulate matter ($PM_{2.5}$) in the atmosphere have climate-forcing impacts, either contributing to or offsetting the effects of greenhouse gases (Hansen and Sato, 2001; Menon et al., 2002). In particular, black carbon particulate matter (BC) has recently been identified as an important contributor to radiative heating of the atmosphere (Jacobson, 2001, 2002). Organic carbon particulate matter (OC), which is often emitted along with BC, may act to offset some of the global warming impact of BC emissions (Hansen and Sato, 2001). N and S components also contribute to $PM_{2.5}$, offsetting the global warming potential of greenhouse gases (Schaap, 2003). The effect of aerosols on the radiation balance is quantified by IPCC with a range of uncertainty (see Figure 3.19).

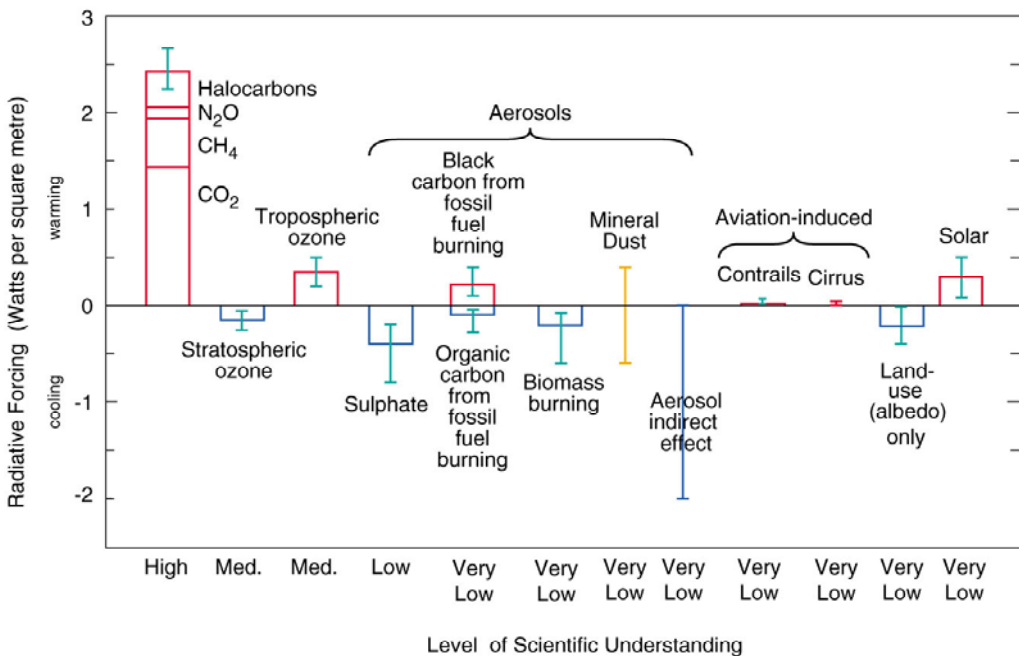

Figure 3.19 *The effect of aerosols on the radiative balance of the earth (IPCC, 2001)*

In order to investigate the $PM_{2.5}$ distribution over Europe we have used the fields of the inorganic components from Schaap et al. (2002), which are also shown in Figure 3.20. Sulphate contributes more than 3 $\mu g.m^{-3}$ to $PM_{2.5}$ over a region spanning from England, over north Western Europe to south Eastern Europe. The same applies to the Po valley and the northwest of Spain. Maximum contributions are calculated in the Ruhr area, southern Poland, Hungary and Rumania. To the north of 57 degrees latitude the annual averaged sulphate concentrations are lower than 2 $\mu g.m^{-3}$, whereas those in more remote continental areas are between 2 and 3 $\mu g.m^{-3}$.

High concentrations of nitrate are confined to continental areas, with maxima in north Western Europe, the UK and the Po valley. Averaged over the year concentrations of nitrate are as high as those of sulphate in Western Europe, whereas those of sulphate are higher in (south) Eastern Europe and Scandinavia. In contrast to sulphate, nitrate levels show a distinct seasonal variation. Maximum concentrations occur in winter, when ammonium nitrate is stable. During summer ammonium nitrate formation is limited over the largest part of Europe due to the high ambient temperatures. In the model sulphate and nitrate are neutralised by ammonium. Therefore, ammonium concentrations are significant and only somewhat lower than those of its associated ions alone.

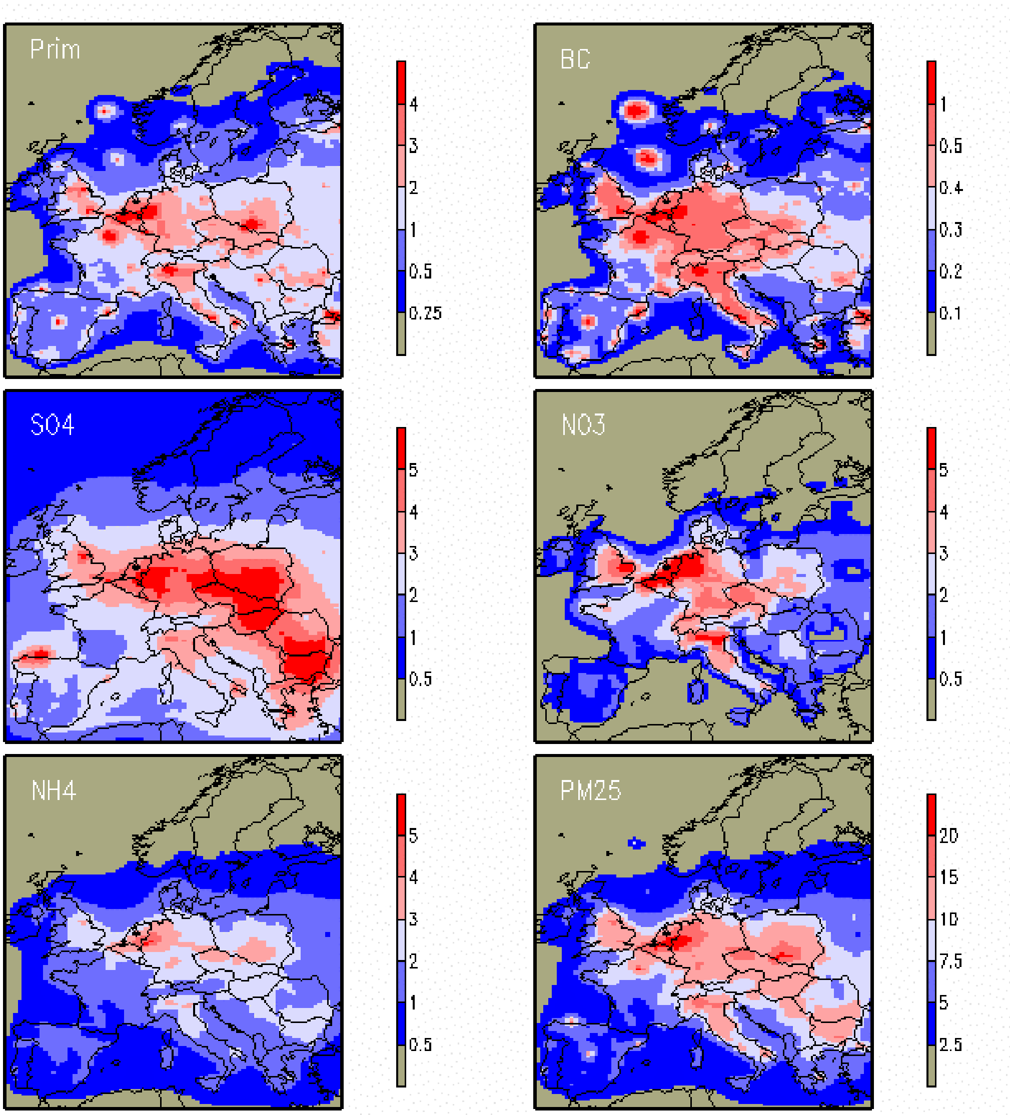

Figure 3.20 *Annual average distribution of Prim (primary aerosol), BC, SO_4, NO_3 and NH_4 and $PM_{2.5}$ over Europe ($\mu g.m^{-3}$)*

The sum of all modelled anthropogenic components of $PM_{2.5}$ is shown in Figure 3.20f. Highest concentrations of $PM_{2.5}$ are found in the most industrialised and populated areas of Europe. Concentrations exceed 20 $\mu g.m^{-3}$ over the south of the Netherlands, Belgium, the Ruhr area and southern Poland. Secondary maxima can be found in the Po valley, the Czech Republic and metropolitans of London, Manchester and Paris. Over Central and South Eastern Europe concentrations are calculated to be between 10 and 15 $\mu g.m^{-3}$. Towards the north the anthropogenic induced concentration of $PM_{2.5}$ trails of from about 4 in southern Scandinavia to less than 2.5 further north. Also the rural areas in Spain and southern France are relatively clean with respect to $PM_{2.5}$. Further, a number of cities can be recognised, e.g. Madrid, Barcelona and Athens.

Impact of climate change on plant diversity
At the moment hardly any information is available on the effect of climate change on plant diversity. Recently a global exploration based on model simulation was performed on the extinction risk of species from climate change (Thomas et al., 2004). For a mid-range climate-warming scenario they calculated for Europe a reduction in percentage of plant species ranging from 3 (with dispersal) to 16% (without dispersal). In comparison, for tropical regions (Amazonia) Thomas et al. (2004) calculate reductions up to 100%. At the moment, however, there are no observations available that confirm the loss of plant species due to climate change.

3.6 Visibility

The presence of particles in the atmosphere always results in a reduction of the visibility. In air pollution studies visibility can be defined as the maximum distance at which the outlines of a target can be recognized against the horizon as background (Horvath, 1981). Important factors that influence the visibility are the prevailing meteorology, population density, prevailing air pollution and type and density of vegetation. Pollution haze affects the visibility of the landscape by discolouring, reducing texture and making it harder to distinguish objects in the distance (Doyle and Dorling, 2002).

Two important N-containing compounds in the atmosphere contributing to visibility problems are ammonia (NH_3) and ammonium nitrate (NH_4NO_3) (e.g. Diederen et al., 1985; Kean et al., 2000). In addition, fine particulate salts of sulphates play an important role. Ten Brink et al. (1996) found that aerosol light-scattering in the Netherlands, in particular its humidity dependence, is determined by (ammonium) nitrate. They also observed that the aerosol light-scattering in arctic marine air was a factor of ten lower than the average value, while in polluted continental air it was up to a factor of ten higher. This was caused by the inefficient light-scattering of the large sea-spray aerosol in comparison with the efficient light scattering by the sub-micron continental aerosol, which contains a relatively large contribution of manmade aerosol. Calculations from Diederen et al. (1985) indicated the importance of transfrontier transport of nitrate (and sulphate) pollutants and their precursors for the air quality in the Netherlands.

Around 1980 the median visibility in the western part of the Netherlands was determined at about 9 km (Diederen et al., 1985). A high population density, high air pollution levels and a high relative humidity characterize this area. Analysis of visibility data for eight Meteorological Office network sites in UK indicated that around 1980 the visibility at those sites ranged between about 17 km at an urban (airport) site and 37 km at a rural site (Doyle and Dorling, 2002). They also showed that over the period from 1950 - 1997 the visibility at the majority of the sites examined improved up to median values of around 40 km in rural areas, with major improvements in the urban areas. These improvements are attributed to changes in personal behaviour, fuel use and vehicle fleet efficiency. No recent studies of visibility trends in the Netherlands are available for comparison.

In comparision with the United States, in Europe very little attention has been paid to visibility impairment and its social costs. This apparent lack of concern is surprising, considering the global spatial distribution of haze on the globe given in (Husar et al., 2000). On the basis of daily-averaged visibility data during the period 1994-1998, visibility reduction appears to be significantly higher in Europe than in the United States for all of the four periods of the year studied by the authors. This is confirmed by the fact that for only 7% of the European continent the critical threshold for visibility reduction (i.e. an extinction of 5%) has been exceeded (RIVM, 2001).

As pointed out previously, important sources of N-containing emissions to the atmosphere are animal waste, biological processes in soils, artificial fertilisers, transport and sewage treatment plants. Several policies have been developed to reduce these emissions (see Chapter 4), but their implementation usually takes time. It should be noted that technical measures can lead to a shift in emissions and therefore a potential shift in impacts. For instance Kean et al. (2000) report an increase in ammonia emissions from on-road vehicles, following the introduction of three-way catalytic converters designed to reduce NO_x and CO emissions.

3.7 Materials

N compounds can affect our cultural heritage, i.e. historical buildings and monuments. In urban areas, the contribution of vehicle emissions to this problem is of particular importance. The focus of the impact of air pollution on cultural heritage has been on sulfur compounds because of its acidifying effects. Ammonia can be corrosive at very high concentrations in the air. Furthermore, ammonium salts, such as NH_4NO_3 and $(NH_4)_2SO_4$ can be nitrified within building stones by bacteria forming nitric acid. This nitric acid can eat away the chalk of statues and buildings (see Figure 3.21).

Figure 3.21 *Statue eaten away by acid rain (Source: www.eces.org/gallery)*

This process has for instance been demonstrated by Keuken et al. (1990) who conducted research at an old church building in the city of Schagen in the Netherlands.

Ammonia corrodes some metals and composites and NO_x affects the deterioration of calcareous stone (Massey, 1999). The extent of corrosion can be enhanced by the presence of water (Massey, 1999). Copper, tin, zinc and composites of these metals corrode quickly in the presence of ammonia. NH_3 can also have an effect on non-metal materials. It can cause wood softening by interaction with the cellulose vessels. Furthermore it can cause expansion of natural rubber and can have a negative effect on concrete, when high concentrations of CO_2 are present. Nearly all kinds of plastics are sensitive to ammonia (Erisman, 2000).

3.8 Evaluation

Reactive nitrogen (N_r) does not flow (cascade) at the same rate through all sectors of the environment. Some systems (most notably forest and grassland soils) are able to slow down the continuation of the cascade by accumulating N_r and therefore acting as reservoirs. However, most systems have a finite capacity to accumulate N_r. As a system becomes saturated, more and more N_r moves from these storage reservoirs to systems downwind or downstream. Table 3.10 shows the various relevant systems, distinguishing those that have large accumulation potential and those from which N_r is most readily transferred. It also shows where N_r is likely to move to, and some potential effects of excess N within each system.

With more anthropogenic N_r present in the environment, it is likely to be increasingly mobilised from storage reservoirs, with resulting consequences for people and ecosystems.

Table 3.10 *Characteristics of different systems relevant for the N cascade*

System	Accumulation potential	Transfer potential	N_2 production potential	Links to systems down the cascade	Effects potential
Atmosphere	Low	Very high	None	All but groundwater	Human and ecosystem health, climate change
Agroecosystems	Low to moderate	Very high	Low to moderate	All	Human and ecosystem health, climate change
Forests	High	Moderate, high in places	Low	All	Biodiversity, net primary productivity, mortality, groundwater
Grasslands	High	Moderate, high in places	Moderate to high	All	Biodiversity, net primary productivity, groundwater
Groundwater	Moderate	Moderate	Moderate	Surface water, atmosphere	Human and ecosystem health, climate change
Wetlands, streams, lakes, rivers	Low	Very high	Moderate to high	Atmosphere, marine coastal systems	Biodiversity, ecological structure, fish
Marine coastal regions	Low to moderate	Moderate	High	Atmosphere	Biodiversity, ecological structure, fish, harmful algal blooms

Source: Galloway et al., 2003

Based on the information in the previous paragraphs combined with expert judgement, an overview of N-related effects and their role within the N cascade has been compiled (Table 3.11). In this table for each effect, the evidence for an adverse effects (high or low), the level of scientific understanding (high or low) and the scale at which the problem plays a role (from local to continental) is indicated. When the evidence for adverse effect is acknowledged to be very high, it implies that enhanced N emission definitely results in adverse effects. The level of scientific understanding indicates the extent of insight into the mechanisms (the cause-effect relation) behind a particular effect.

Table 3.11 *Overview of N-related effects and their role within the N cascade*

Effects	Evidence for effect[1)]	Level of scientific understanding [2)]	Scale[3)]
Species diversity of terrestrial ecosystems			
- plant species diversity			
Nature	++	+	L-C
Forests	?	+/-	L-C
- faunal species diversity	+	+/-	L-R
Forest vitality			
– Nutritional imbalance	++	+	L-R [4)]
– Soil acidification	?	+	L-R [4)]
– Increased sensitivity to frost, drought and diseases	+	+/-	L-R [4)]
Water quality and species diversity of aquatic ecosystems			
– Soft water ecosystems	++	+	R-N
– Coastal /marine ecosystems	++	+/-	C
Human health			
– Nitrate in drinking water	+	+/-	L-R
– Air pollution			
Ozone and NO_x pollution	++	+	L-R
Fine particulate air pollution	+	+	L-R
Pollen pollution	?	+/-	L-C
Climate			
– Nitrous oxide emissions	++	+/-	R-C
– Fine particulates	++	+/-	R-C
– Biodiversity	?	-	R-C
Visibility	+	+	L-R
Materials	?	+/-	L-R

[1)]+ = has probably an effect; ++ = has certainly an effect; - = has probably no effect; - - = has certainly no effect; ? = not known
[2)] Scientific understanding: +: high; +/-: intermediate; - low
[3)] L stands for Local, R for regional, N for national, C for continental and G for Global.
[4)] Because this is mainly a problem at relatively high deposition levels or atmospheric concentration which generally only occurs at a local or regional scale.

Most certain and widely accepted adverse impacts of elevated N use are:

- loss of plant diversity both in aquatic and terrestrial systems,
- decrease of forest vitality and eutrophication of fresh and marine aquatic ecosystems,
- adverse effect on human health due to elevated atmospheric ozone and NO_x concentrations,
- contribution of nitrous oxide to climate change.

The highest uncertainty amongst adverse effects exists for forest diversity, soil acidification, pollen pollution and materials. However, it is most likely that the extent of potential adverse effects is rather small. Finally, evidence for serious adverse effects on faunal species diversity and marine systems exists, but the level of scientific understanding is rather low.

4. NITROGEN POLICIES IN THE NETHERLANDS AND EUROPE

4.1 Introduction

Nitrogen has a good and a bad side. It is necessary for all forms of life and a crucial component in the increased production of food to feed the world population. At the same time it is an environmental threat because food cannot be produced without N losses to the environment and N_r is also formed when energy is produced from fossil fuels. This is the basic dilemma for N management policies. Furthermore, N is an important crosscutting theme over most of the key environmental problems for Europe such as climate change, biodiversity, ecosystem health, human health and groundwater pollution. The abatement of these N problems is addressed with a range of policy instruments and measures. There are obvious benefits if these problems could be considered in an integrated way and not as isolated phenomena. Such an approach would increase the possibility of keeping in pace with the necessary food and energy production while finding more (cost) effective solutions for both the unavoidable use and losses of N in agriculture and for the development of the abatement strategies in various sectors that leak N_r.

In the preceding chapters it has been shown that the N cascade is closely linked to different parts of the Dutch (and European) economy: agriculture, industry, energy, transport and households. Elevated N use has adverse effects on terrestrial and aquatic ecosystems and on human health. Policy measures aimed at reducing N-related pollution have been developed for the different economic sectors. At governmental level, different ministries deal with these sectors (e.g. the Ministry of Agriculture, Nature and Food Quality, the Ministry of Transport, the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and the Environment). Together these sectors form the *economic system* of a country. Various flows of N exist within and between these sectors. Besides, these sectors interact with the *natural environment*: the atmospheric system, the terrestrial system and the aquatic system (see Figure 4.1). Transport and exchange of different forms of N also exists within and between the atmospheric, the terrestrial and the aquatic system.

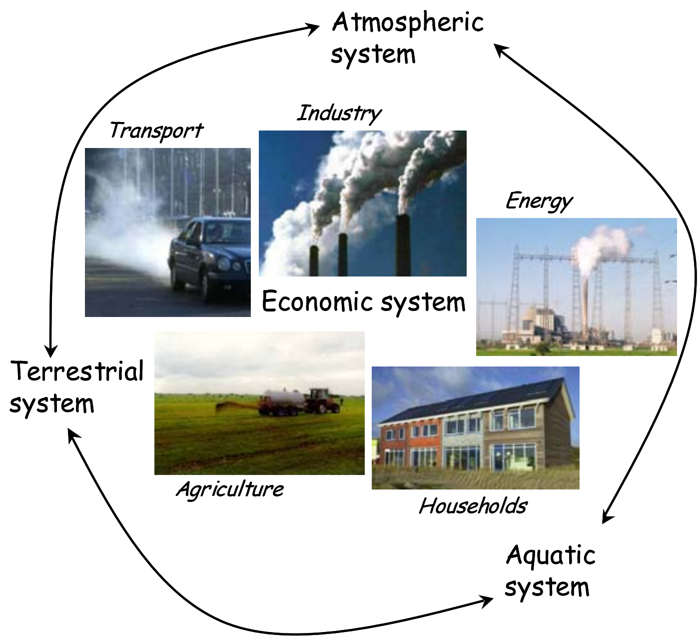

Figure 4.1 *The economic system and the natural system*

Various policy measures have been developed and put into place aiming at reducing the negative impacts on the natural environment. One way to classify the N abatement policies within the different economic sectors is based on how the proposed objective is reached, whether this is through:

(i) legal and fiscal rules: these measures cannot be avoided by those concerned and producers and/or consumers have a legal duty to obey them;
(ii) guidelines and incentives: these measures aim at stimulating positive behaviour by providing (technical) information or a financial incentive;
(iii) (social) education: trying to change consumer and producer behaviour through education, e.g. advertising campaigns, brochures etc.

In order to implement the various policies, they are usually translated into technical measures. Both N-related policies and technical measures are aimed at contributing to a sustainable development. Sustainable development requires a balance between society, economy and ecology, the so-called sustainability triangle. This should form the basis for the assessment of policies and technical measures to determine their effectiveness in keeping the benefits of N while reducing the negative impacts (Figure 4.2).

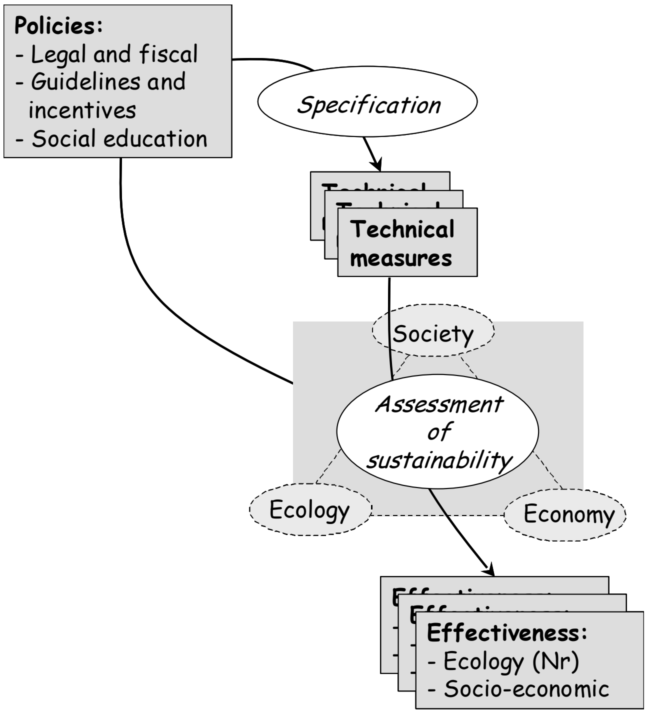

Figure 4.2 *Relation between policies and effects*

This chapter provides an overview of the current Dutch and EU policies related to N (Section 4.2). Next, an overview is given of the main technical measures per economic sector (Section 4.3). In Section 4.4 the policies and technical measures in various sectors of the economy are analysed and compared at national and European level. Finally the options for additional and/or innovative measures are discussed (Section 4.5) and the chapter ends with conclusions (Section 4.6).

4.2 Overview of current policies

An overview of the current N-related policies in the Netherlands and in Europe is given in Table 4.1.

Table 4.1 *Overview of N-related policies in different economic sectors in the Netherlands (NL) and in Europe (EU)*

Policies	**Economic sector**									
	Agriculture		**Industry**		**Energy**		**Transport**		**Households**	
	NL	*EU*	*NL*	*EU*	*NL*	*EU*	*NL*	*EU*	*NL*	*EU*
Legal and fiscal measures	-Reconstruction of intensive agriculture -Horticulture act -Groundwater act -Manure requirements -Law on ammonia and livestock -Arable cropping act -Act on fertiliser and manure use	-Nitrate Directive -Directive on organic production of agricultural products -Directive on national emission ceilings (NEC) -Water Framework Directive	-Air quality directive -Waste water treatment act -Groundwater act -Law on environmental tax (ground and drinking water, waste, fuel, energy)	-Directive on national emission ceilings -Ambient Air Quality Directive	-Air quality directive	-Directive on national emission ceilings -Ambient Air Quality Directive	- Air quality directive - (Road tax)	-Directive on air pollution by emissions from motor vehicles -Exhaust emission regulation for agricultural or forestry tractors -Directive on the promotion of the use of biofuels or other renewable fuels for transport	-Water services directive -Municipal waste water treatment act -Emission ceilings for waste incinerators -Law on environmental tax (ground and drinking water, waste, fuel, energy)	- Ambient Air Quality Directive - Directive on the quality of water intended for human consumption - Directive concerning urban waste water treatment - Water Framework Directive
Guidelines and incentives	-Incentives for sustainable agr. -Tax reduction for *green* investments -Subsidies for *green* practices (e.g. tree planting, set aside, ...) -Subsidies for test facilities sustainable agr.	-Common Agricultural Policy (CAP) -Codes of good agricultural practice -Gothenburg Protocol -IPPC -OSPAR	-Tax reduction for environmental investments -Energy programme (subsidies)	-Convention on long-range transboudary air pollution -BAT (Best Available Technology) principle -Gothenburg Protocol -IPPC		-Gothenburg Protocol -IPPC	- Programme on CO2 reduction in public transport (subsidies)	-Gothenburg Protocol -IPPC	-Energy programme (subsidies) (e.g. solar panels, insulation)	
Social education	-Subsidies for knowledge transfer sustainable agr. -Nitrate projects						- Advertising campaign on *new driving ("Het nieuwe rijden")*		-Consumer: reduce meat in diet -Energy use	

The various types of policies listed all have an impact on either the sources of nitrogen, or on the transport processes during the N cascade or on the availability of N at the receptors. The policies per sector are briefly described in the next sections.

4.2.1 Policies related to the agricultural sector

The Dutch agricultural policies related to the reduction of the negative impacts of N_r, can be subdivided into the following three categories:

(i) Policies aiming at reducing the N input into agriculture, e.g. maximum application rates for manures and artificial fertiliser, decreasing the number of animals in intensive livestock production systems and promoting organic farming;

(ii) Policies aiming at reducing the emission of N to water and the atmosphere, e.g. injection of animal slurry in the soil, covering manure storage, buffer strips along ditches and a ban on application of fertilisers and manures in winter;

(iii) Policies related to the spatial location of holdings in relation to natural areas and nature conservation (spatial planning, reconstruction, tree planting).

The Dutch government has started and stimulated several projects in the educational area. There are subsidies available for knowledge transfer on sustainable agriculture. Projects that are directly targeted at agricultural management including nitrate management are *Cows and opportunities* (in Dutch: *"Koeien en kansen"*) and *Farming with a future* (in Dutch: *"Telen met Toekomst"*). In these projects a number of pilot farms are monitored intensively and new measures are introduced, leading to a better understanding of various processes and development of management options for a sustainable agricultural sector.

The European environmental policies related to the reduction of the negative impacts of N_r in agriculture, focus on the reduction of NO_3-leaching to groundwater and surface water (EC Nitrate Directive), leaching of N to surface water (OSPAR and Water Framework Directive) and on a reduction of the input of artificial fertilisers (organic production).

The objective of the OSPAR Convention (1998) is to prevent and eliminate pollution entering the sea. The OSPAR Convention guides the international cooperation on the protection of the marine environment of the North-East Atlantic. One of the targets under this convention, which has not been reached so far, was to achieve between 1985 and 2000 a 50% reduction of the N inputs to surface waters.

In 2000 the European policies dealing with the protection and improvement of the quality of all water resources (e.g. rivers, groundwater and coastal water) have been integrated in the Water Framework Directive (WFD). According to the WFD, water management should be based on natural geographical and hydrological units, i.e. river basin management. The water quality should be protected to safeguard aquatic ecology, drinking water and bathing water. The WFD clearly has implications for agricultural management.

The Codes of Good Agricultural Practice focus on efficient use of fertilisers and restriction of losses of N_r through leaching and emissions. Efficient use is required by demanding that fertiliser use is in balance with crop demand. Losses to ground and surface water are restricted by requiring that fertilisers are only applied during the growing season and not near waterways or on steep slopes or frozen soils. Meanwhile, adequate storage of manure is required to prevent emissions to the air.

In 1999 the Gothenburg Protocol, i.e. the protocol to abate acidification, eutrophication and ground-level ozone, was adopted in Europe. Two of the pollutants for which emission ceilings are set in this protocol are NO_x and ammonia. The protocol requires farmers to take specific measures to control ammonia emissions. Once this protocol is fully implemented, Europe's NO_x emissions should be cut by at least 41% and its ammonia emissions by 17% compared to 1990

(Sliggers, 2004). During the preparation of this protocol it was estimated that an integrated and cost-effective approach to acidification, eutrophication and ground-level ozone in Europe would halve the costs (Amann et al., 1999). Parallel to this the EU adopted the National Emission Ceilings (NEC) Directive, based on the same assessment and starting points of the Gothenborg Protocol, but with somewhat deviating national emission targets. Also relevant for large agricultural facilities is the IPPC (Integrated Pollution Prevention and Control), which requires new or extending facilities for environmental analysis of activities. The IPPC Directive aims at minimising the pollution from various point sources.

4.2.2 Policies related to industry

In the Netherlands, various regulations deal with the emissions of N containing substances to air, surface water and groundwater. These regulations specify emission ceilings for N containing substances affecting air quality and guidelines for the monitoring frequency of various parameters in emissions to ground and surface waters. In addition, there are several incentives for stimulating businesses to invest in cleaner technologies, such as tax reduction and subsidies.

At a European level, the Gothenburg Protocol and the Convention on Long Range Transboundary Air Pollution (LRTAP) have contributed to the development of European Directives with respect to air quality, i.e. related to national emission ceilings (NEC) and ambient air quality. The IPPC is also relevant for large industrial facilities.

4.2.3 Policies related to the energy sector

The main national policy aiming at reducing N-containing emissions, which affects the energy sector is the *"Besluit Luchtkwaliteit"* (air quality directive). This directive, which relates to the European NEC Directive, defines the permissible NO_x concentrations and the required protocol to assess the emissions. The European Directive is a specification of the Gothenburg Protocol. Also relevant for energy facilities is the IPPC, which requires new or extending facilities for environmental analysis of activities. The Ambient Air Quality Directive is also relevant for energy sector.

4.2.4 Policies related to transport

The previously mentioned Dutch air quality directive is of major importance for the transport sector, requiring local and national monitoring of the air quality alongside the road network. One of the parameters for which a strict concentration limit has been specified is NO_x. In case maximum concentration level is exceeded, (technical) measures are required to reduce the concentration.

In the Netherlands there is discussion about the use of a differentiation in road tax to distinguish between cleaner and more polluting vehicles. An example of the way in which the government tries to change driving behaviour of consumers, is the advertising and information campaign *“Het nieuwe rijden”*, *the new way to drive*, which provides information on more economic and cleaner driving.

The government supports investments in new technologies and knowledge transfer leading to a reduction of the use of fossil fuels in the national CO_2-reduction programme. Subsidies are available for businesses, local or regional governments and organisations dealing with relevant areas.

There are several pieces of European legislation aiming at reducing the pollution from vehicles. This can be achieved through development of cleaner engines (e.g. emission standards for diesel vehicles) or through the promotion of renewable fuels (e.g. biofuels or hydrogen). The Ambient

Air Quality Directive is also relevant for transport, especially related to NO_x and particulate matter.

4.2.5 Policies related to households

The quality standards required for drinking water in the Netherlands are specified in the water services directive (*"waterleidingbesluit"*), in which maximum concentrations for nitrate and nitrite are defined. This directive influences the intake of N_r through drinking water. Another policy instrument that controls the use of natural resources and therefore affects the flows of N_r is the environmental tax (e.g. on ground and drinking water, fuel, waste and energy). In addition, the government provides subsidies for investment in energy saving measures (e.g. home insulation) or renewable energy by consumers (e.g. solar panels).

Two main pathways through which N is lost from households are the municipal wastewater and the household waste. These types of waste are treated in wastewater treatment plants and waste incinerators. In the Netherlands there are legal standards and guidelines for the monitoring of the quality of the emissions from these installations.

The Dutch policies affecting the flows of N_r related to households have a direct link with European policies. The EC has provided a legal framework, which has been implemented in legislation by the national government (i.e. related to air quality, drinking water quality and wastewater treatment).

The separation of household waste at the source, which is common practice in many European countries, enables recycling of the N in kitchen and garden waste.

4.2.6 Other relevant policies

In addition to the policies related to the economic sectors, there are a number of policies, aimed at protection of the natural system (see Table 4.2). Natural habitats and wild life are often sensitive to N_r (see Chapter 3) . The policies to protect these systems influence the potential for development of the other economic sectors and are essential in the process towards sustainable development. The presence and pathways of N_r are not necessarily specific items in these policies, however they need to be considered during implementation. The targets set under these directives for environmental protection are often much more stringent when expressed in terms of required emission reductions to meet these targets, than the emission targets under the sector and/or NEC Directive.

Table 4.2 *Examples of N-related policies to protect the natural system in the Netherlands and in Europe*

The Netherlands	Europe
• Nature conservation act • Flora and fauna act • Reduction plan other greenhouse gases (ROB)	• Directive on the conservation of natural habitats and of wild fauna and flora • Directive on the conservation of wild birds

The Bird and Habitat Directive requires that no human activity will impact on the preserved area. Eutrophication through N deposition is one of these impacts that should be prevented. This implies that the government will introduce zones of 500m radius around the preserved areas in which farmers are not allowed to extend their - emitting - activities.

The Reduction Programme of other (non CO_2) greenhouse gases (*"Reductieplan overige broeikasgassen"* or ROB) is part of the Dutch climate policy to reach the targets set in Kyoto. ROB aims at reducing non-CO_2 greenhouse gas emissions (including N_2O) in the Netherlands.

ROB stimulates business with subsidies, fiscal measures, research and knowledge transfer to reduce these emissions. For N_2O, ROB focuses on the reduction of emission during nitric acid production, catalytic converters in cars and in agriculture. For agriculture no specific targets are set, because calculations indicate that N_2O emissions from agriculture have decreased strongly because of the manure policy in the Netherlands.

4.3 Overview of technical measures and instruments

Van Grinsven et al. (2003) made an inventory of all the N-related measures. This overview is listed in Appendix A (in Dutch). A large number of measures are directly designed to reduce the N emissions. These measures can be subdivided into three categories depending on whether they target (i) the volume of manure, (ii) the emissions of NH_3, NO_x, N_2O and N to soil, air and water, or (iii) the receptor. In addition, there are a number of measures that have an indirect impact on N loss.

Measures targeting the volume of manure

- In the Netherlands, a system of manure production rights and livestock rights has been introduced in order to restrict total livestock numbers and the associated manure production. Further reduction of livestock numbers can be achieved through limitation of the manure production rights, resulting in a further reduction of emission to the air. The impact of these measures on nitrogen losses to ground and surface waters is less prominent.
- In 2002 a system of manure transfer agreements was introduced in the Netherlands to stabilize the national manure market: the national production of manure should also be applied nationally. From 2006 this system will be lifted, because the system was not effective.
- Manure processing enables application of the resulting product, e.g. pellets, outside the agricultural sector. Manure recycling results in a reduction of NH_3 emissions.
- Manure burning in a biomass plant also results in a reduction of NH_3 emissions.

Measures to reduce the emissions of NH_3, NO_x, N_2O and N to soil, air and water

Some measures specific for the agriculture are:

- Limits to the total amounts of N applied via fertilisers and manures in order to decrease N leaching to ground and surface water. This system has recently been developed and should be regulated. It is based on crop specific fertiliser recommendations and environmental targets for ground and surface water. This system will replace the current MINAS-system (N and P bookkeeping system) from 2006 as part of the implementation of the Nitrate Directive in the Netherlands.
- Reducing N content in animal feed.
- Housings and manures storages with low NH_3 emissions.
- Manure application techniques with low NH_3 emissions.
- Emission ceilings near natural areas are used to protect sensitive areas from deposition related to local emission sources.
- Optimise N application to crops via fertiliser and manure to reduce N leaching to ground and surface water and to reduce N_2O emission.
- Restrictions to the period in which ploughing of grassland is allowed to reduce N leaching to ground and surface water and to reduce N_2O emission.
- Buffer strips to avoid manure and fertiliser application near the edge of watercourses to reduce leaching and avoid surface runoff of N.
- Growing catch crops during winter.
- An educational programme for farmers based on pilot farms in which advanced measures are taken to decrease N emissions, e.g. the project *Cows and opportunities* and *Farming with a future*.

Measures targeting the emissions of NH_3, NO_x, N_2O and N to soil, air and water in other sectors are:

- Emission standards for heating and process installations have been specified to reduce NO_x-emissions.
- A system of emission trade has been developed to restrict the emissions of large companies.
- The EU has set emission standards for the transport sector resulting in a reduction of NO_x.
- A change in the tax system for new cars in the Netherlands has resulted in a shift from diesel to petrol / gas.
- N_2O loss from cars has been reduced by the application of catalytic converters.
- For a number of motor ways in the Netherlands an 80 km speed limit has been introduced.
- The development of new technologies, e.g. catalytic converters, can help to reduce N_2O-emissions from the chemical industry.
- Standards have been set for N concentration of effluent from (i) wastewater treatment plants, (ii) private homes that are not connected to a sewer network system and (iii) industry.

Measures targeting the receptor, i.e. the natural system

- Management practices in natural areas, like grazing or harvesting of plant material.
- Water management, e.g. cleaning ditches.

Measures with an indirect impact on N loss

- A number of measures aimed at the mitigation of climate change also affect NOx emissions. For instance, the reduction of the use of fossil fuels, increasing energy efficiency, energy taxes and the trade in CO2 emission rights.
- Energy production from biomass and the use of manure for biogas production also influence N fluxes besides those of CO2.
- In the Netherlands there are specific policy measures aimed at reducing the spread of pesticides and herbicides and of excess nutrients.
- A number of specific measures that are part of the EU agricultural policy (e.g. milk quota, area payment scheme) also have an indirect impact on N fluxes.
- Other measures in this category are: subsidies for organic farming, the measures against drought, set aside schemes, potential standards for soil organic matter content, (area) standards for animal welfare, and irrigation and drainage measures.
- Measures to decrease phosphorus (P) input to soils. The manure policy in the Netherlands aim at reducing both the N and P input to soils in order to decrease N and P emissions to ground and surface waters. P is important for the quality of surface water and strict standards are set for maximum P applications to soils. Because manures contain both N and P, a strict policy on P will also reduce the N input via manures and the associated N emissions to the environment.

4.4 Evaluation of policies and technical measures

In the previous sections a range of N-related policies and technical measures has been presented. The effectiveness of these instruments in reducing N_r is discussed below, starting with the policies. At the end of this section the impact of the instruments on atmosphere and biosphere is discussed.

4.4.1 Evaluation of policies

The overview of the effectiveness of European policies presented below is largely based on an evaluation report of the European Environment Agency (EEA, 2003). Firstly, the effective policies are presented and secondly the less effective policies.

Effective policies

(i) Legal and fiscal rules

- Wastewater treatment: According to the EEA wastewater treatment in all parts of Europe has improved significantly since the 1980s. The increase in the 1990s in the population connected to tertiary wastewater treatment, which removes nutrients and organic matter, has resulted in marked reductions in P and N discharges. N removal takes mainly place at the larger tertiary treatment plants, whereas P removal occurs at nearly all plants.
- Legislative support has helped producers of electricity from renewable sources to distribute the electricity produced.
- Fiscal support has stimulated the increased use of renewable energy.
- Policy-driven technological improvements and fleet renewal have contributed to improvements in the EU transport sector.
- Quality standards for emissions and fuel have greatly contributed to reduction of air pollution from road vehicles through the introduction of the three-way catalytic converter.
- NO_x emission in the EU has fallen due to a decrease in the use of N fertilisers. The associated N_2O emission from agriculture has also decreased.

(ii) Guidelines and incentives

- The proportion of renewable energy has increased, supported by policy interventions aimed at stimulating the growth of new renewable technologies (the aim is 10% in 2020).
- Financial (subsidies) and administrative support has stimulated new (technological) developments.
- In the EU NO_x, NO_3 and N_2O emissions from agriculture have fallen due to a decrease in the use of N fertilisers, falling cattle numbers and changes in manure management.
- The voluntary agreement between car manufacturers and the European Commission has stimulated the energy efficiency of new cars in the EU.

(iii) Education

- Political support has contributed to the expansion of renewable energy in some countries.
- Information, education and training have helped to raise the awareness of the benefits of renewable energy.
- The voluntary agreement between car manufacturers and the European Commission has stimulated the energy efficiency of new cars in the EU.

Less effective policies

A general problem with the implementation of some of the policies is the lack of enforcement or of an inspection regime. Other reasons for not being successful include the strong lobby of the farmers in politics up to the end of the last century (Spiertz et al., 2002). Furthermore, the economics of measures have not been profitable enough to implement them.

The fact that agricultural policies for many decades have been directed exclusively towards production increase, without taking into account the environmental impacts, can be considered a policy failure. A clear example of this is the European agricultural subsidiary system, which is entirely focussed on socio-economic factors, farmers' employability and supporting and increasing production, without taking the environmental consequences into account.

(i) Legal and fiscal rules

- Nitrate in groundwater: According to an evaluation in 2003 by the European Environment Agency, EEA (http://www.eea.eu.int), there was no evidence of a decrease (or increase) in levels of nitrate in Europe's groundwaters. It was found that nitrate drinking water limit values were exceeded in around one-third of the groundwater bodies for which information is currently available.
- Since the introduction of the system of mineral bookkeeping in the Netherlands in 1998, there has been a significant reduction of the N surplus in the agricultural sector due to a

reduction of the use of inorganic fertilisers. On the whole this has resulted in a reduction of the NO_3 concentration in ground and surface waters (RIVM, 2004b). However, on the sandy soils in the Netherlands the maximum concentration of 50 $mg.l^{-1}$ nitrate in groundwater, as specified in the EC Nitrate Directive, is still exceeded. It is expected that with additional measures, the Netherlands will be able to comply with the Nitrate Directive after 2006 (RIVM, 2004a).

- A direct connection between the application of N fertiliser and the nitrate content in deep groundwaters is hard to prove. There is often a significant time lag between changes in agricultural practices and changes in groundwater quality, depending on the hydro-geological conditions and the soil organic matter content.
- Environmentally related taxes in the EU are levied almost exclusively on households and the transport sector. The polluter pays principle is undermined by the exemptions and rebates for the industrial sector and the abatement measures are not directed at the areas where they are likely to have the greatest overall effect.
- The use of more fuel-efficient transport modes is not encouraged by the trends in transport fuel prices.
- In the EU there has been an overall increase of emissions from transport, despite various measures to reduce emissions, due to growing transport (EEA, 2003).

(ii) Guidelines and incentives

- CAP: the EU Common Agricultural Policy (CAP) has stimulated intensification of agricultural production and contributed to environmental problems. The Agenda 2000 reform of the CAP has not addressed the serious nitrate pollution problem in regions of intensive pig and poultry production (EC Court of Auditors, 2000).
- Without appropriate management, current fertiliser input in Europe may still be too high to be environmentally sustainable in the longer term.
- Water pollution in relation to high livestock population densities: in some EU countries, programmes to minimise this problem are underdeveloped and/or there is a lack of legislative enforcement coupled with poor or non-existent containment of manure.

(iii) Education

- The education programme for farmers that was linked to the Dutch manure policy has reached 20-30 percent of the farmers. About 50 to 80 % of theses farmers have used the knowledge in their management. The aim of the educational programme to reach all farmers was too ambitious (RIVM, 2004b).
- The anticipated effect of the promotion of organic food production in the Netherlands is hampered by the high prices that discouraged consumers. The Dutch consumers are accustomed to luxury food and energy use (transport, personal comfort, electricity, etc.).

4.4.2 Evaluation of technical measures

Van Grinsven et al. (2003) rated all the N related measures in their inventory on their effect on specific emissions and on their cost effectiveness (see APPENDIX A - in Dutch). These ratings are based on expert judgement. Table 4.3 provides a summary of a number of measures for each sector that have a large impact on the reduction of the emissions of one or more N-containing substances. These measures are applicable in the entire EU.

An analysis of the present extensive package of sectoral N measures shows that they have been effective in reducing individual flows and effects of N (van Grinsven et al., 2003). However, additional measures will be required to attain the targets for nitrate, surface water loading and NO_x emissions.

Less effective measures include:

- Manure transfer agreements (see 4.3) that result in a better distribution of manure, do not lead to a reduction of the total amount of manure produced and of the total potential losses.
- Measures to increase the reduction of N_2O from car catalytic converters turned out to be unnecessary, since the N_2O emission of the catalytic converters was already very low.
- The Clean Development Mechanism as part of climate policies enables the Netherlands to invest in measures in other countries - often against lower cost. However, at a national level this does not result in a reduction of the emissions of CO_2 and NO_x.

The economics of some measures have not been profitable enough to implement them, especially because of the low prices of products (local and global markets) and the cheap energy. If the cost of a measure cannot be paid off within a certain (short) time period it is impossible for individuals to invest in costly measures.

Table 4.3 *Technical specifications of effective N abatement policies in different economic sectors*

Economic sector	Technical measures	Impact on reduction of				Cost effectiveness
		NH_3	NO_x	N_2O	NO_3	
Agriculture	Reduce/optimise fertiliser use	++	++	++	++	high
	Decrease livestock in balance with carrying capacity of the soil	+/++	+/++	+/++	+/++	
	Reduce imported fodder	+/++	+/++	+/++	+/++	middle
	Low emission application manure	+	-	-	-	middle
	Manure processing (ferment.; gasific.)	+	0	0	0/+	middle/high
Industry	Low NO_x industry		++	?		middle
	Energy saving industry		+/+			high
	Shift from oil and coal to gas and renewables		+/++			
	Combined heat and power		+			high
	CO2 sequestration		+/++?			?
Energy	Shift to renewable energy (wind, solar)		++			middle?
	Energy from biomass	-/0	+	-/0	-/0	
	Biogas from manure	0/+	+/0	0	0	
Transport	Modal shift transport: road → water		+/++			high
	Reduced growth of aviation (freight and pas.)		+/++			
	Low NO_x and soot cars (Euro 5 and beyond)		+			
	More efficient cars and less car km's		+			
Households	Housing: energy efficient and sustainable (EPC)		+/++	+?		
	Energy saving and efficient equipment	+/-	+	+		
	Other 'Green' lifestyle aspects (e.g. less meat)	++	++	++	++	
	Improved municipal water treatment and waste process.	+?	0/-	+	+	

4.4.3 Impact on atmosphere and biosphere

The abatement of N through the different measures clearly shows a decrease in N emissions to the environment. Figure 4.3 shows the different emissions of N_r to the environment, as well as to the soil, sea, (ground) water and air. The overall decrease is about 20-30% (http://www.milieucompendium.nl, 2004).

The European NO_x emission was brought down by 21% in 2000 relative to 1990. Estimates of ammonia emissions are associated with very high uncertainties. Until recently only a few countries reported their emissions but the situation has improved and now there seems to be a consistent dataset available in which emission data are available from 1980 onwards. For NH_3 it shows an emission reduction of 14% between 1980 and 1998. With most countries using standard emission factors for NH_3, these differences are largely a result of estimated changes in animal numbers and fertiliser use. Hence the largest reported reductions occurred in Eastern Europe following the political changes of 1989-90, which led to major reductions in agricultural activity (e.g. Erisman et al., 2003). A few countries, such as Denmark, the Netherlands and Germany have taken measures to reduce NH_3 emissions. However, for NH_3, uncertainties in emissions are very large and even at the country scale current studies have been unable to obtain a satisfactory agreement between the official estimates of NH_3 emissions and measurements of the quantities of NH_3 and NH_4 present in air. Emission estimates for N_2O are also associated with a very high uncertainty. Emission statistics indicate, however, a decrease by about 10% in the EU between 1998 and 1990 (Erisman et al., 2003).

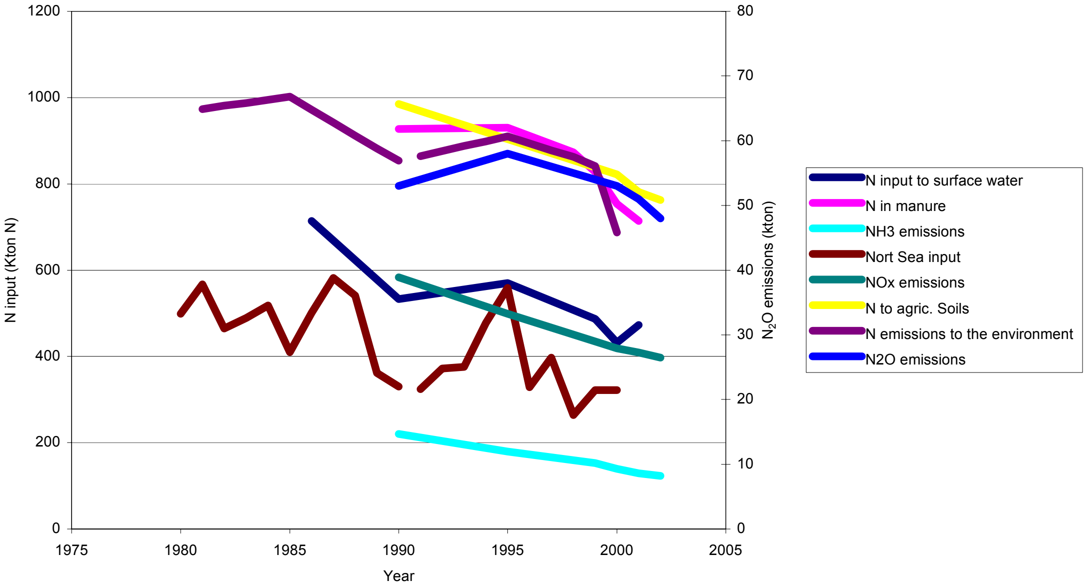

Figure 4.3 *N_r emissions to the sea, surface water, soil and air in the Netherlands (kton N)*

There are notable regional differences in the emission trends during the last two decades. For sulfur most of the emission reductions between 1980 and 1990 took place in north Western Europe. After 1990 significant emission reductions have been achieved all over Europe. For NO_x the picture is more complicated. Some countries report substantial emission reductions while a few report increases in their emissions. The largest emission reductions are reported from the former Eastern Europe where some countries report reductions of 40% and more. Most West European countries report emission reductions of 20-30% while in the Mediterranean Europe emissions were in 1998 about the same as in 1990. For NO_x the main measure to reduce emissions is exhaust gas regulations introduced in the EU countries in about 1990, resulting in the application of three-way catalysts in gasoline cars. Even regulations on heavy-duty vehicles have caused emission reductions of NO_x. Furthermore, selective catalytic reduction technologies (SCR) with ammonia or urea as a reductor have been implemented in many combustion plants.

The deposition data show more year-to-year variation than those for emissions due to the influence of meteorological factors, but the trend in deposition is less clear than the trends for emissions (see Figure 4.4). During the years there is no trend in modelled N deposition, whereas modelled emissions decreased by 21% (NO_x) and 14% (NH_3) in the same period. Possible reasons for this effect include non-linearity in S emission and deposition. Non-linearity is the difference between the reduction in emissions of SO_2 and that in total S deposition, which is lower because of the change in atmospheric chemistry and surface affinities for S. S emissions have decreased to a large extent in Europe and so has ammonium sulphate formation. This leaves more ammonia to form ammonium nitrates, leading to higher N deposition.

There are some concentration data that are in accordance with expectations, based on the emission trends, but are representative for a limited area only. Ambient concentration measurements show that concentrations decrease, but the extent is different in different locations in Europe (Erisman et al., 2003). The measurements are not representative for all situations in Europe. In contrast, nitrous oxide (N_2O) concentrations show a steady increase. These are representative for a much larger area than Europe and reflect global emission trends.

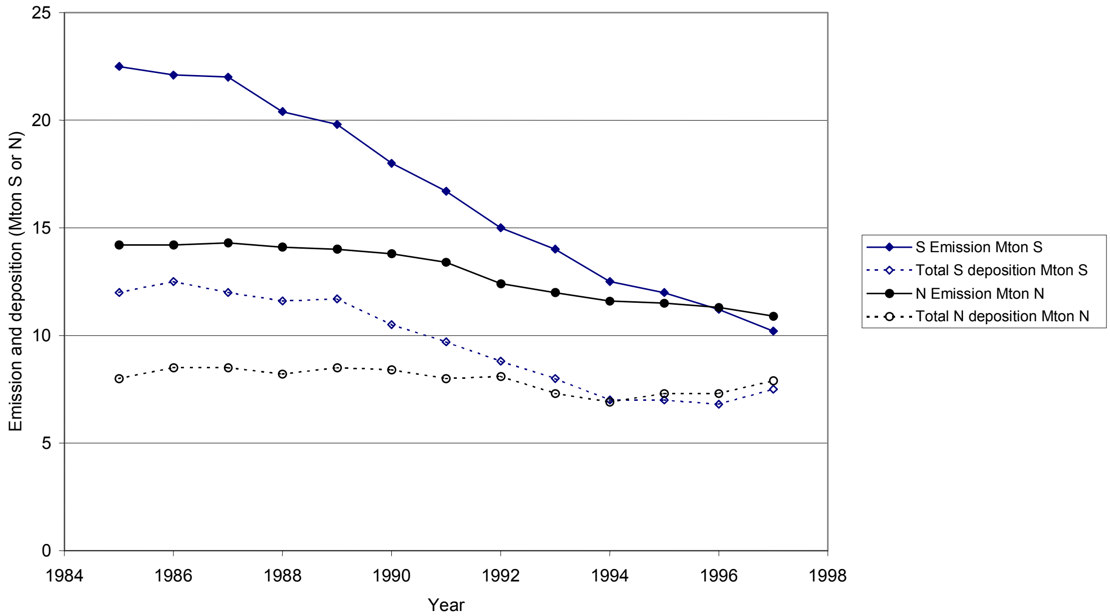

Figure 4.4 *Total (modelled) deposition and estimated emission in Europe between 1985 and 1997 (Mton S or N per year)*

Erisman and de Vries (2000) made an overview of N deposition measurements in Europe and showed that there has been a small but significant decrease. For example, micrometeorological observations at Speulder forest show a small downward trend in NH_x deposition, reflecting the measures taken in the Netherlands to reduce emissions. Measurements of total oxidised (NO_y) and total reduced (NH_x) nitrogen fluxes in throughfall over Europe show a downward trend, when comparing measurements between 1980-1993 and 1993-1997. Throughfall measurements for N, however, have to be interpreted with care because of the canopy exchange processes that take place.

4.5 Options for new additional and/or innovative measures

4.5.1 General approach

In the past, there have been N-related policies that did not take into account the environmental aspects of N use. For example, after World War II agricultural policies and subsidies in Europe have stimulated increased production of animal and crop products for several decades, without considering the adverse impacts on soil, air and water quality. Although this has certainly resulted in sufficient food for the population, the developed practices have proved unsustainable in the long term. This is a clear incentive for a more holistic approach to the use of N.

The lesson that can be learnt from the successful measures and policies and the conflicting ones is that N efficiency is a strong indicator (next to socio-economic indicators) of effectiveness of a measure. If the aim is to improve N efficiencies in the cascade the first step is to quantify the efficiencies. In Chapter 1 a schematic was presented of the cascade with fluxes between sectors and between parts of the economic system and the natural system (Figure 1.2). The N efficiency, N_{eff}, for individual production sectors in the cascade can be defined as:

$$N_{eff} = (N_{products})/(N_{inputs}) * 100\%$$

where $N_{products}$ and N_{inputs} respectively stand for the amount of N in the products and in the inputs. This efficiency can be calculated for each sector or element in the cascade that generates a product. N_{eff} can be used as the basis for the assessment and the identification of new policies or measures. Improvement of N_{eff} is most effective in the beginning of the cascade or at those points where several N flows come together.

Figure 4.5 shows the nitrogen fluxes between the different sectors and the natural environment in the Netherlands, based on Van Grinsven et al. (2003). The N efficiencies for the Dutch situation as calculated from this N cycle are presented in Table 4.4. A comparison between these efficiencies can only be made when also the importance of the related N fluxes and the associated N losses are taken into consideration. Furthermore, the costs associated with abatement measures require attention when developing new measures.

Table 4.4 *N efficiencies in the Netherlands*

Sector	N input (kton.y^{-1})	N output (kton.y^{-1})	N_{eff} (%)	N loss (kton.y^{-1})
Agriculture	859	288	34	571
Industry	1038	949	91	89
Fertiliser industry	2580	2526	98	54
Traffic and transport	88	0	0	88
Households	425	300	71	125
Waste treatment	86	34	40	52

The largest fluxes are clearly associated with the fertiliser industry. This sector also seems the most N efficient. The product of the sector is, however, an important input for the agricultural sector and therefore stands at the top of the cascade. The agricultural sector has the third largest N input and the largest N loss of the sectors considered. The agricultural sector is relatively inefficient in N use and produces a large absolute N loss (571 kton.y^{-1}). The N efficiency has become worse over the years as can be derived from comparison of the N balances between 1910 and 1999 in Chapter 2. The N in products from the agricultural sector ends up in the industry and eventually with the consumers, whereas the N losses end up directly in the natural system (air, soil and water). Limiting these losses and improving reuse of excess N may be a good way to mitigate the N cascade. The waste sector as indicated in the table above, seems to provide room for improvement. However, the fluxes are relatively small compared to the other sectors and waste handling takes place towards the end of the cascade. Therefore, improvement in this sector will contribute to reduction of the output of the N loss from this sector only.

Only 15% of the total amount of N fixed by the Dutch fertiliser industry is applied nationally. The other 85% is exported and applied elsewhere, contributing to the N cascade at continental/global scale. The figures give the impression that households are relatively efficient N users. However, their annual loss is second largest. In addition, it should be noted that the output of 300 kton N is fixed in products, like plastics and varnish, which eventually will end up as household waste.

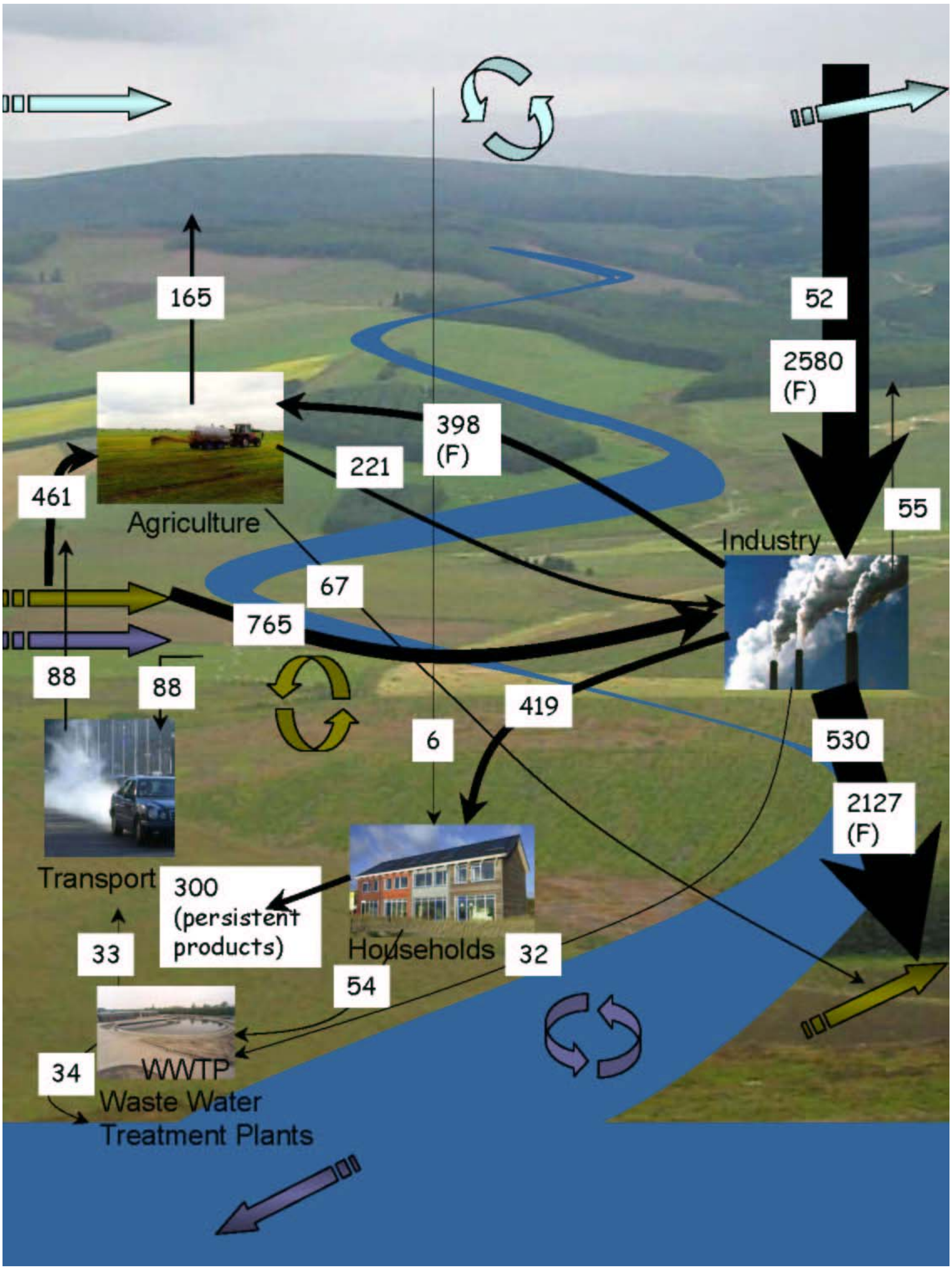

Figure 4.5 *N fluxes in the Dutch cascade*

N has been an environmental issue in the Netherlands for many years. Therefore, policies to combat different N issues are already developed to a large extent compared to other countries. Only recently N has also been recognized as an environmental threat in other European countries. The Dutch policies and measures have proved to have an effect on the N fluxes (see Figure 4.3). However, there is still a large discrepancy between the environmental targets and the current state of the environment. Currently the Netherlands are more and more adopting the EC regulations and directives, to transform the national policy.

4.5.2 Additional and innovative measures

In the National Environmental Plan 4 (NMP4, 2001) of the Dutch government it was recognized that the current most challenging environmental issues need system innovations and the terms *Transitions* and *Transition management* were introduced. The basis of transitions is that the government chooses long-term targets and that through cooperation of the different stakeholders supervised by the government, system innovations necessary to reach the long-term targets can be stimulated and introduced. Transition programmes have started for the four most challenging environmental problems: sustainable energy, sustainable mobility, sustainable agriculture and sustainable resources (including biodiversity). In September 2004 a workshop was organised to bring the experience of the four transition programmes together with the aim of developing innovative strategies for the N issues, providing a cross-link over all four transitions. The outcome of this workshop has been incorporated in this section.

Effective policies to reduce the cascade effect of nitrogen should be targetting the following aspects:

- limit N_r production or limit import of N through animal concentrates,
- increase efficiency of N_r use and close nutrient cycles at different scales,
- more evenly distribute N production over the country or over the whole EU,
- convert N_r to N_2 catalytically or by stimulating denitrification.

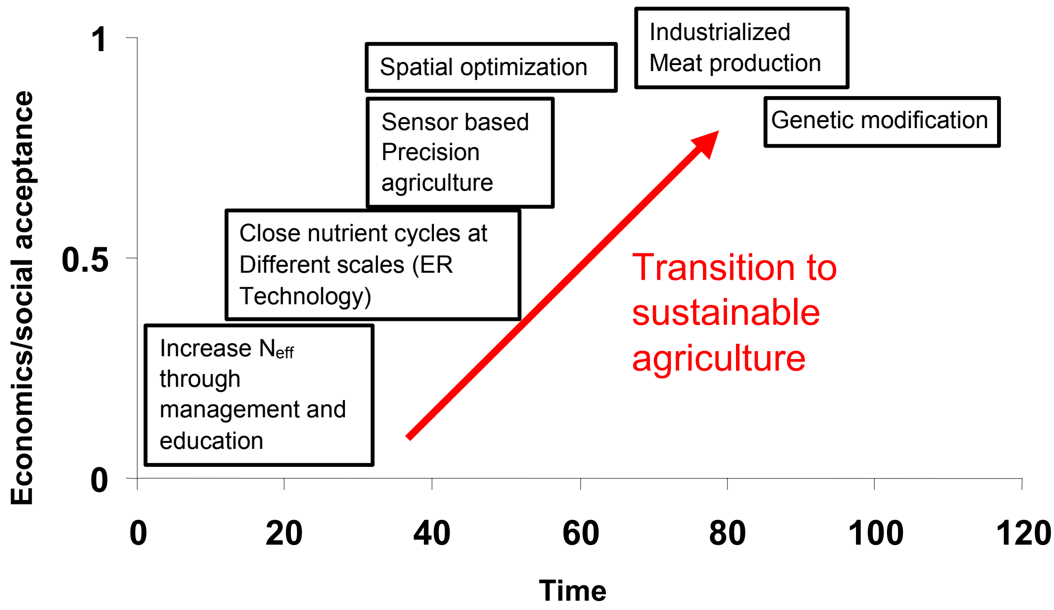

Figure 4.6 *Illustration of the transition to sustainable agriculture in the Netherlands*

Options to implement policies related to these aspects are discussed below. There is a clear preference to follow the priorities according to this list. This is illustrated in Figure 4.6. In any case, N_r production should be avoided, when unnecessary or ineffective. For example, transport of goods from one place to the other can be avoided if those goods can also be produced locally. Furthermore, over-consumption and luxurious use of food and energy can be avoided, leading to a direct decrease in N_r production. In many cases, the N_{eff} can be improved, as is shown in the previous section. The next step is to close nutrient cycles at different scales, avoiding transport of concentrates from one part of the world to the other and transporting fertilisers back. Then technologies will play a role, e.g. in the case of utilizing the energy and nutrients from waste, precision fertilisation, industrialisation of meat production and gene modification. At the same time, spatial optimisation might play a role to more evenly distribute N_r production and use. In the next section examples will be given of different measures and policy options to follow these paths.

Options to implement policies related to these aspects are discussed below. There is no need to choose for a particular policy or set of measures, and these policies and measures do not necessarily have to be implemented similarly and simultaneously.

Limit N production or import

Measures that limit N_r production are, for instance, decreasing livestock numbers, limiting fertiliser production and application, reducing car kilometres, decreasing industrial production, limiting fossil fuel burning etc. Although these measures are very effective in reducing N_r, they are not always favourable because they generally restrict the production of food, goods and/or energy needed to sustain a certain way of life. One potential way to limit N production or import - without leading to huge social or economic cost - is by influencing consumer behaviour. Howarth et al. (2002) show one simple example: if the average American were to switch to a diet more typical of some European regions, future US fertiliser use could decline substantially. The prospect of switching to the *Mediterranean diet* is particularly intriguing, not only because it would greatly lower N pollution, as a result of lowered meat consumption, but also because this diet is healthier than today's average American diet (Curtis and O'Keefe, 2002). Thus, the potential clearly exists for maximizing the health benefits of some human alteration to the N cycle, while also greatly reducing both the environmental and the health costs. Consumers can be made aware of the current production practices of their food, for instance by labelling of products. Such a label could indicate the footprint of the product in terms of N requirement.

The introduction of a tax on fertilisers may result in a reduction of fertiliser application and at the same time lead to an improved N efficiency. It will not necessarily lead to a reduced production.

Increase the N efficiency

Measures that increase the N efficiency throughout the cascade provide a large potential (see Section 4.5.1). Options for increasing the N efficiency should be considered in each sector of the economy. Another approach is to try to close the nutrient cycle at the regional or global scale. Social education of producers and consumers can play an important role in achieving these objectives.

A fiscal measure aiming to stimulate action to increase the N efficiency is to put a tax on the produced N_r or on the N surplus at farm level (Kleinhanss et al., 1997) and create a trading system of N_r rights. Such a system is being implemented for the large combustion sources of NO_x in the Netherlands. The trading system for these sources will be operational in 2005. The system aims at a reduction in 2010 of NO_x from these sources with 45% relative to 2000.

An example from the USA is the N trading system in Long Island to alleviate hypoxia (see: http://dep.state.ct.us/wtr/lis/nitrocntr/nitroindex.htm). An analysis of the total maximum daily load (TMDL analysis) for N, required by federal law, was submitted to the US EPA, calling for a 58.5% reduction in the point and non-point source N loads. The sources of N are well understood and are dominated by sewage treatment plant contributions although non-point sources, such as urban runoff and atmospheric deposition, are large enough to be of managerial interest. Nevertheless, most of the N control burden will fall upon point sources, particularly municipal sewage treatment plants (STP). The nitrogen credit exchange allows considerable flexibility in where reductions can take place, rather than forcing an equal level of N reduction from each source. The highest impact and least costly projects that move forward quickly will be able to remove N below their individual allocations. The credit exchange established an economic allocation taking both cost and environmental impact into consideration. The excess N removed is sold, in the form of a *nitrogen credit* to the exchange where other sources may purchase them at a cost lower than would be incurred by implementing additional projects at those sources.

The NO_x trading system could be combined with a trading system for CO_2. Furthermore, a trading system could be developed for ammonia emissions, or even for total N_r production (see N_r ceilings).

In the agricultural sector initiatives to close the N cycle can have a huge impact. Examples of initiatives aimed at involvement and education of agricultural producers to stimulate optimisation of N management are projects such as *Cows and opportunities*, *Farming with a future* (see also Section 4.2.1) and VEL VANLA (see below). The first two examples are projects started by the Dutch government. *Cows and opportunities* is directed at pilot dairy farming systems in which nutrient management is optimised in order to comply with the targets set in the Dutch manure policy, i.e. decreasing N inputs via fertiliser and manure and achieving the nitrate standards in groundwater. *Farming with a future* is a similar project, but with arable and intensive vegetable farming systems.

VEL VANLA is an initiative started by two local environmental cooperations of farmers and local landowners. Their objective is to get to a situation of sustainable agriculture, which also protects the environments, local ecological values and the local landscape. Several research projects have been started to support this initiative. In general, N application rates have become excessive and far beyond the point that the yield of crops or grass is increased (Erisman and Monteny, 1998). It has been shown by VEL VANLA in the north of the country that focusing on N efficiency improvement in the agricultural system both leads to less N leakage to the environment without affecting milk production rates and grass yields (Verhoeven et al., 2003). This is an integral approach at farm level and can be extended to regional levels, leading to a decrease in nitrate leaching to groundwater, decrease in NH_3 and N_2O emissions. This approach can be applied in every land-bound production, because it optimises the external N input, the N cycling at the farm level and the N outputs.

In the case of intensive livestock production it is much more difficult to reach a closed N cycle at farm scale, because of the lack of land area to use the produced N_r for crop growth. In this case an increase in scale together with optimised use of manure for e.g. energy production and nutrients might have some potential. On the other hand, extensivation and focusing on new products might provide a counter movement. Increase in scale can be achieved by increasing the production from individual farms, but also by changing the ownerships of farms to a cooperative, which can more easily do the long-term investments necessary to limit N_r emission to the environment.

An education program in the Netherlands, which is not specifically targeted at farmers, is the reduction programme other (non-CO_2) greenhouse gases (in Dutch: *"Reductie Overige Broeikasgassen", ROB*): education for different economic sectors to reduce non-CO_2 greenhouse gas emissions (including N_2O) in the Netherlands.

At European level, including environmental performance in the CAP (Common Agricultural Policy) subsidiary system, or fertiliser levies could stimulate measures to increase N efficiency at farm level (Kleinhanss et al., 1997). When aiming at closing the N cycle at regional and global scale, the impact of transportation of natural resources and products should be taken into consideration. To avoid transport, it would be better if food was produced close to the consumers. The import of concentrates from overseas to feed animals, the import of legumes produced in far away countries, the disturbed balance between organic manure and added fertilisers etc. are all examples of a system that is out of balance. One of the main issues here is the lack of internalisation of environmental costs in energy production, transport and products. If a ‘real price’ system could be introduced, most of these transport issues would not be economically feasible. Part of the solution with closed cycles resides with the consumers. If they were willing to buy local products or to pay a fair (higher) price for the other products, the cycles would automatically be more closed. This, however, requires a system approach at a range of scales at the same time. To enable an informed decision by the consumers their awareness of the current production methods and with the related negative impacts should be increased. This can be achieved through for instance a labelling system of products based on a footprint analysis.

A more far-reaching approach would be a national introduction of a modern version of a production system from the past, when much more products were consumed and produced locally. In the present situation this could result in (a cooperation of) neighbourhood farms that produce mainly for the local market. The products can be available from supermarkets or special shops on the farm. This system will lead to a reduction in transport and will bring the production process closer to the consumers: they can see their food grow. An additional benefit from this system is the contribution to the sustainability of rural areas. However, this system has also negative consequences: the product choice may be limited, the export of agricultural products will decline and the food prices may go up. An overall assessment of the socio-economic and environmental impact of such a system and the associated practical implications of its introduction should be studied, for instance in an experimental region. There are however various examples of parts of this system operational, and these could also be evaluated in detail to further develop this concept.

Improve distribution of N production

A new integrated/holistic approach could be the implementation of N ceilings, which are based on the different effects of N in the cascade and couple the different sectors (Erisman et al., 2001; van Lent and Erisman, 2003). These N ceilings could be specified in legislation. Figure 4.7 shows a schematic of the principle of emission ceilings. N ceilings, in the form of a combined ammonia emission and a nitrate-leaching ceiling are estimated based on the environmental targets, which are mainly determined by the local and regional surroundings of the area. If all municipalities in the country would have a N ceiling, the country emission ceilings will be met. A regional N ceiling would enable the implementation of a N trade system within the region. In the form of a directive, such as the EC Nitrate Directive this would provide a legal rule to combat N_r.

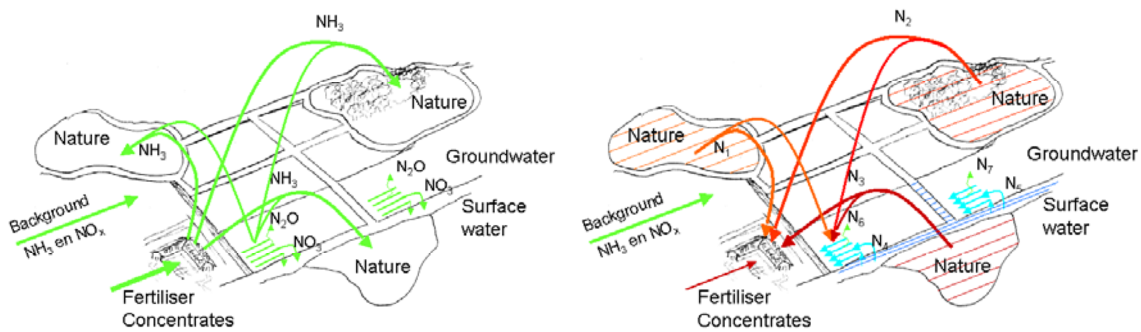

Figure 4.7 *N ceilings for agriculture*

A first step could be the spatial optimisation of ammonia emissions, in Europe and within the Netherlands. Emissions of ammonia from agriculture are concentrated in different areas of Europe. This leads to local impacts and to long-range transport. If the emissions could be more equally spread over the continent, the environment could better cope with the more equally spread ammonia deposition. Spatial optimisation could be achieved by optimisation of emissions, given the distribution of critical loads. This could lead to regional ammonia ceilings combined with a trade system.

Convert N_r to N_2

Technological measures that reduce N_r emissions include the development of catalytic converters for diesels, the recycling of manure nutrients with energy production and the introduction of agro production parks at harbours, etc. Other options include:

- Close cycles at farm level by manure fermentation to produce energy and at the same time increase the fertilisation value of manure, leading to renewable sources from organic material (biogas, biofuel).
- Nitrification inhibitors (Romstad et al., 1997).

Assessment tools

An interactive tool for educational purposes, which is based on an integrated approach to solving the N problem, is the computer programme NitroGenius. For the second international Nitrogen Conference held in the US in 2001, a group of scientist developed a nitrogen decision support system for the Netherlands (NitroGenius). NitroGenius has the form of a game and gives the players, representing different groups of actors (Agriculture, Industry, Consumer, Policy), insight into the complexity of N pollution problems and in the interaction between different sectors and impacts when looking for solutions. The system includes a model of N flows at relevant spatial and temporal scales and an economic model describing impacts of control measures on gross domestic product, unemployment, energy use and environmental costs. Playing the game shows that the N problem in the Netherlands can be solved through careful planning and selection of abatement measures (Erisman et al., 2002). This instrument may serve an educational purpose for various different stakeholders, but, if further elaborated, can also play a role in policy development.

The Regional Air pollution INformation and Simulation (RAINS) model, developed by the International Institute for Applied Systems Analysis (IIASA) in Austria, is an instrument for analysing the impact of various environmental control measures on air pollution and costs. The objective and domain of RAINS exceeds that of NitroGenius. The RAINS model is currently being extended to include also greenhouse gas mitigation. The resulting multi-pollutant / multi-effect approach enables an integrated assessment of air pollution control and greenhouse gas mitigation measures (Klaassen et al., 2004a). Many air pollutants and greenhouse gases have common sources and their emissions interact in the atmosphere. Example calculations by Klaassen et al. (2004b) demonstrate potential economic - in terms of cost-effectiveness - and environmental - in terms of human health - benefits from a combined approach towards greenhouse gas mitigation and air pollution control. Enabling these integrated assessments of various measures can serve as a guideline for policy development.

4.6 Conclusions

For many decades, the Netherlands has profited from the cheap availability of N_r. This has been important for economic development in various sectors, but has also resulted in the negative impacts of intensive agriculture, industrialization, urbanization and mobility in the present situation. A strong tension exists between economical and societal interests and environmental effects, which poses quite a challenge. In this report options have been put forward to substantially reduce the loads of N_r to the environment.

The N issues have grown into international problems, including transboundary transport of N_r, large scale transport of nutrients over the globe and N_2O contributing to climate change. Therefore, and intergovernmental process should be initiated to combat N_r. During the 3rd International Nitrogen Conference, held in Nanjing in 2004, the Nanjing Declaration was signed and accepted by UNEP (see Appendix B). The objective of the Declaration is to give a strong signal to governments and other bodies about both the beneficial role of N_r and the evidence of the (potential) impacts resulting from the disturbance of the N cycle at the global, regional and local scales due to the increased need for food and use of energy, and to call for action. This might be the start of an intergovernmental process.

Involvement of local stakeholders in implementation of policies and specification of measures is considered very important. Targets should be based on all effects (no trade-offs), on sound science and a clear long-term vision, which takes into account the Dutch position in Europe. The overall development should be guided towards closing the nutrient cycles and minimizing resource use. Therefore, the scientific community should come up with simple, easy to determine indicators that can be used to implement, monitor, evaluate and maintain policies, for instance N_{eff}-indicators.

Some of the options should be agreed upon within the framework of the European Union, because it affects other countries or the competitiveness of Dutch entrepreneurs. Such measures include taxes or financial grants, and the target setting for N losses. Furthermore, the closing of cycles should be tackled at various scales at the same time. There is a strong tendency to seek improvements in technological options. There are potential technologies that might lead to substantial emission reduction (catalytic converters, hydrogen economy, nitrification inhibitors, fermentation of manure, etc.). These are important, but the reduction in environmental load they cause should not lead to increased import of raw materials, influencing cycles at supranational scales. Furthermore, other components (such as carbon) and issues (like access to freshwater) should be taken into account to prevent trade-offs. If financial incentives are given it is important to secure the period that these incentives will last, in order to guarantee a return on investment.

To stimulate innovation we suggest the creation of an experimental region within the Netherlands where viable options that do not fit within current regulations can be tested. Some experimentation already takes place in the VEL VANLA project in the north of the Netherlands. This is also a recommendable approach for the concept of the neighbourhood farm, mentioned in the previous section.

The following actions seem to have the largest prospects:
(i) Create experimental area to demonstrate the potential for:
  - Closing the regional cycle;
  - Hydrogen economy;
  - Labelling of products (footprint);
  - Digesting of manure for energy and nutrient production;
  - Education and ‘example’ farms.
(ii) NO_x emission standards for cars (EU);
(iii) NO_x emission trading with CO_2 for industry (create a price).

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LIST OF ABBREVIATIONS

Al	Alluminium
AOT40	Accumulated Ozone concentration over a Threshold of 40 ppb
BC	Black Carbon
Ca	Calcium
CAP	Common Agricultural Policy
CO2	Carbon dioxide
EC	European Commission
EEA	European Environment Agency
EU	European Union
EU15	European Union with 15 member states
EU25	European Union with 25 member states (after 1-5-2004)
ICP	International Cooperative Programme
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
K	Potassium (Kalium)
LAT	Lower Assessment Threshold
LRTAP	Long Range Transboudary Air Pollution
LV	Limit Value
Mg	Magnesium
N	Nitrogen
N_2	Nitrogen gas
N_2O	Nitrous oxide
Na	Natrium
NEC	National Emission Ceilings
NH_3	Ammonium
NO_2	Nitrogen dioxide
NO_3	Nitrate
NO_x	Nitrogen oxides
N_r	Reactive nitrogen (all nitrogen compounds except N_2)
OC	Organic Carbon
OECD	Organisation for Economic Cooperation and Development
OSPAR	Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic

P	Phosphorus
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter less than or equal to a nomial 10 microns
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than or equal to a nomial 2.5 microns
S	Sulfur
SO_2	Sulfur dioxide
TSP	Total Suspended Particles
UAT	Upper Assessment Threshold
UN/ECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
VOC	Volatile Organic Carbon
WFD	Water Framework Directive
WHO	World Health Organization

APPENDIX A OVERVIEW OF TECHNICAL MEASURES AND EFFECTS IN THE NETHERLANDS

The table presented in this Appendix is in Dutch and is taken from a study of the nitrogen fluxes and nitrogen policies in the Netherlands (van Grinsven et al., 2003). The table shows the relation between the technical measures and various nitrogen related issues and can be used for an integral assessment of new policies.

Table A. *Huidige, voorgenomen en mogelijke beleidsinstrumenten met effect op stikstof*

	Onderwerp / Refnr. bijlage	Maatregel	Grijpt aan op Nr (of niet)	Effect op omvang veestapel	Status beleid	NH3	NOx (en effect op ozon)	N2O	overige CO2 equivalenten	N depositie natuur	Belasting NO3 grondwater	Belasting N oppervlaktewater	Kosteneffectiviteit (euro/kg N)
Volumebeleid	*Mest*												
	1.1	mestproductierechten / dierrechten	Nr	<V	1	+		(+)	(+)	+	+	+	
		korting, afroming of opkoop van mestrechten	Nr	<V	1	+		(+)	(+)	+	+	+	
		verdere korting, afroming of opkoop mestrechten	Nr	<V	3	+		(+)	(+)	+	0	0	*laag / middel*
		dierrechten afschaffen	Nr-	>V	2	-		(-)	(-)	-	-/0	-/0	
	1.2	mestafzetovereenkomsten	Nr	0V	1	0		0		0	0	0	
		aanscherpen normen mestafzetovereenkomsten	Nr	<V	3	+		(+)	(+)	+	0	0	*laag / middel*
	1.3	meer mestverwerking, afzet in NL buiten landbouw			3	+	(-)	0	(-)	+	0	0	*hoog*
		mestverbranding en energiewinning	Nr		3	+	-	-/0	-	+	0	0	*hoog*
		meer mestverwerking t.b.v. mestexport			3	+	(-)	0	(-)	+	0	0	*hoog*
Emissiebeleid	*Ammoniak*												
	2.1	eisen ureum getal melk (voedingsaanpassingen)	Nr		2	+		0?	0?	+	-/0	-/0	*middel*
		voedingsaanpassingen intensieve veehouderij	Nr		3	+		+?		+	-/0	-/0	*middel*
	2.2	eis Groen Label stallen			1	+		0		+	0	0	
		AMvB Huisvesting (intensieve veehouderij)			1	++		-/0		+	-/0	-/0	*middel / hoog*
		emissiearme stallen melkvee			3	++		-/0		+	-/0	-/0	*laag*
		gebiedsgerichte aanscherping AMvB Huisvesting			3	+		-/0		+	-/0	-/0	*laag / middel*
		emisievrije stallen intensieve veehouderij			3	++	-	0?	-	++	-/0	-/0	*laag*
		afdekplicht mestopslag			1	+		0	0?	+	0	0	
		NH3-reductie compostproductie champignons			1	+	-		-	+			
	2.3	emissieplafond in zone rond natuur (WAV)			1					+			
		emissievrije zone rond natuur, verplichte opkoop			3					++			*laag?*
	2.4	emissiearme mestaanwending			1	++	-	-/0	-	+	0	+	
		aanscherping emissiearme mestaanwending			2	++	-	-/0	-	+	-/0	-/0	*middel / hoog*
		FIR toevoeging / bovengronds mest aanwenden			3	-	+		+	0/-	+	-	
		emissiehandel NH3 bij regionale NH3-plafonds			3	+				+			*laag / middel*
	NOx												
	3.1	emissie-eisen stookinstallaties (BEES)	Nr		1	0	++	-/0	-	+			
		SEP-convenant/BEES energie	Nr		1	0	++	-/0	-	+			
		eisen Nederlandse Emissierichtlijn (NER)	Nr		1	0	+	-/0	-	+			
		aanscherping BEES/NER	Nr		3	0	+	-/0	-	+			*hoog*
		emissie-eisen CV-ketels	Nr		1		+			+			
		Besluit emissie-eisen HNO3-fabrieken	Nr		1	0	+	-/0	-	+			
		Besluit Luchtemissie Afvalverbranding	Nr		1	0	+	-/0	-	+			
	3.2	emissiehandel NOx bedrijven	(Nr)		2	0	++	-/0	-	+			*hoog*

Table A., continued

	Onderwerp / Refnr. bijlage	Maatregel	Grijpt aan op Nr (of niet)	Effect op omvang veestapel	Status beleid	NH3	NOx (en effect op ozon)	N2O	overige CO2 equivalenten	N depositie natuur	Belasting NO3 grondwater	Belasting N oppervlaktewater	Kosteneffectiviteit (euro/kg N)
Emissiebeleid	*NOx*												
	3.3	emissienormering wegverkeer	Nr		1		++	0		+			
		verschuiving brandstofmix wegverkeer (<diesel)	Nr		1		+		?	+			
		verdere aanscherping emissienormen wegverkeer	Nr		3		++			+			*middel / hoog*
		zero-emission vehicles	Nr		3		++		+	+			*laag*
		kilometerheffing	Nr	<km	3		+		+	+			
		brandstofmix zonder diesel (2010)	Nr		3		++		-	+			*laag*
		binnenvaart gemiddeld EURO4 uiterlijk 2020 (NMP4)	Nr		3		+		-?	+			
		aankoop dieselvoertuigen ontmoedigen	Nr		3		+		-	+			
		binnenvaart/railverkeer NOx handel	(Nr)		3		+		-?	+			
		binnenvaart/railverkeer NOx heffingen	(Nr)		3		+		-?	+			
		SCR bij vrachtwagens	Nr		3	-/0	+	-/0	-	+			
	N2O												
	4	N2O autokatalysatoren via EU regels (onderdeel ROB)			1			0					*laag*
		afvoeren van gewasresten najaar (ROB)	Nr		3		0	+	0		+	+	*laag*
		klaver inzaai (bij klaver niet in MINAS)	Nr-		3			-			-	-	
		tegengaan van scheuren van grasland	Nr		3			+			+	+	*hoog*
		N2O reductie chemische industrie (extra p.UK1)	Nr		3		0	++			0	0	*hoog*
	N bodem / water												
	5.1	uitrijverbod meststoffen e.a. (BGM)			1	-		+		-	+	++	
	5.2	Invoering MINAS + voorlichting mineralenmanagement	Nr		1	+		+		+	++	+	
		MINAS-verliesnormen 2003	Nr		2	+		+		+	++	+	*hoog*
		MINAS-verliesnormen aanscherpen	Nr	<V	3	-/+		(+)	(+)	-/+	++	+	*laag / middel*
		aanvoerposten MINAS uitbreiden (o.a. klaver)	Nr	<V	3	+		(+)	(+)	+	+	+	*laag / middel*
		MINAS op gebiedsniveau (sturen Nr-plafond)	Nr	<V	3	+		(+)	(+)	+	+	+	
		verplichting teelt 'vang'gewas	Nr		3	0		0/+		0	+	+	*hoog*
		NH3 bron receptor relatie opnemen in MINAS			3	0				+			
		MINAS-heffing omhoog	Nr		3	0/+		0/+		0/+	0/+	0/+	
		meer droge zandgronden aanwijzen	Nr	<V	3	-/+		(+)	(+)	-/+	+	+	*laag / middel*
		kunstmestheffing	Nr		3	0		0		0	0/+	0/+	
	5.3	N-cyclus sluiten op melkveebedrijven	Nr		3	+		+	+	+	++	+	
	5.4	doorvoeren Nitraatrichtlijn, afschaffen MINAS	Nr	<V	3	++		(+)	(+)	+	-/0	-/0	*laag / middel*
	5.5	bredere mestvrije zones			3						-/0	0/+	*laag*
	5.6	lozingenbesluit stedelijk afvalwater (rwzi's)	Nr		1	-	-	-	-	-		++	
		lozingenbesluit huishoudelijk afvalwater	Nr		1			-				+	
		lozingseisen waterbeheerders naar industrie	Nr		1	-?	-	-	-	-		++	
		overstorten niet meer op oppervlaktewater			2							+	*laag*

Table A., continued

	Onderwerp / Refnr. bijlage	Maatregel	Grijpt aan op Nr (of niet)	Effect op omvang veestapel	Status beleid	NH3	NOx (en effect op ozon)	N2O	overige CO2 equivalenten	N depositie natuur	Belasting NO3 grondwater	Belasting N oppervlaktewater	Kosteneffectiviteit (euro/kg N)
Effectgericht beleid													
	6	OBN plaggen, maaien, bekalken	Nr		1						+	+	
		OBN overig			1						0	0	
		regulier natuurbeheer	Nr		1						+	+	
		waterreiniging voor drinkwaterconsumptie	Nr		1								
		verplaatsing bedrijven (o.a. Reconstructiewet)			2	0				+			
		windsingels rond stallen als biofilter			3	+?		0		+?	0		
		realisatie grote eenheden natuur			2					+			
Overig beleid	*Klimaat*												
	7.1	UK1 (incl. MJA's, REB en Convenant Benchmarking)	Nr		1		+		++	+			
		UK1 reservepakket (excl N2O)	Nr		3		+		+	+			
		UK2, Joint Implementation	Nr		2		0		0	+			
		UK2, Clean Development Mechanism	Nr		2		0		0	0			
		UK2, Internationale emissiehandel	Nr		2		0		0	-/0			
		energie uit biomassa (NL teelt op braakgrond)			3	-/0	+	-/0	+	0	-/0	-/0	
		biogaswinning uit mest			3	0/+	+/0	0	+	+	0	0	
	Verspreiding												
	7.2	besluit glastuinbouw (recirculatie; bestrm)			1							+	
		teeltvrije zones waterlopen (WVO; bestr.m.)			1							+?	
	Ander beleid												
	7.3	landbouwbeleid (GLB) oa melkquotering	Nr	<V	1	+		(+)	(+)	+	+	+	
		stimulering biologische landbouw			1	0/+		0/+		0/+	+	+	
		GeBeVe/SGB (o.a. anti-verdroging)	Nr?		1			-			+	+	
		verschuiving van prijs- naar inkomenssteun GLB			2	0		0		0	0	0	
		cross-compliance inkomenssteun GLB			2	0/+		0/+		0/+	0/+	0/+	
		afschaffing melkquotering	Nr-	>V	3	-		(-)	(-)	-	-/0	-/0	
		extra braaklegging (groene braak)	Nr		3	+		+		+	+	+	
		EU-normen voor organische stof bodem			3	0		0		0	+?	0	
		oppervlakte-eisen dierenwelzijn			1	-		?		-			
		verdere anti-verdrogingsmaatregelen			3			-		0	+	+	
		verbetering irrigatie en drainage			3	0		0/+		0	0/+	-/+	

Toelichting

Status beleid: 1 = Huidig 2 = Voorgenomen 3 = Mogelijk
Bereikt effect bij doelgroepen *(huidig beleid) c.q. mogelijke bijdrage aan verdere reductie (voorgenomen en mogelijk beleid)*

++	grote bijdrage aan afname emissie cq belasting
+	kleine bijdrage aan afname emissie cq belasting
0	geen netto-effect op emissie cq belasting
-	toename emissie cq belasting
	geen effect op emissie cq belasting of nog in te vullen
-/0, 0/+, -?, 0?, +?	effect onzeker en/of nader uit te zoeken
(+) of (-)	effect wordt teniet gedaan door gelijktijdige verandering veestapel of mestgebruik (bij mestexport) in het buitenland (relevant voor broeikasgassen)
Kosteneffectiviteit:	hoog/middel/laag relatieve maat om maatregelen onderling te vergelijken: resp. <2, 2-10 en >10 Euro/kg N Waar geen kosteneffectiviteit is gegeven, is deze niet bekend of niet goed te bepalen.

APPENDIX B NANJING DECLARATION

Nanjing Declaration on Nitrogen Management

Presented to the United Nations Environment Programme.

Nanjing, People's Republic of China, 16 October 2004.

Co-Chair
of the Conference

Prof.
Zhoaliang Zhu
Soil Science Institute
Chinese Academy of Sciences
People's Republic of China

Co-Chair
of the Conference

Prof.
Katsu Minami
National Institute of
Agro-environmental Sciences
Japan

Chairman
of INI

Prof.
James Galloway
University of
Virginia
USA

Nanjing Declaration on Nitrogen Management

The participants of the Third International Nitrogen Conference, held in Nanjing, People's Republic of China, 12 – 16 October 2004

AFFIRM the principles of the Millennium Development Goals and the World Summit on Sustainable Development to speedily increase access to basic human needs such as energy, water, food security and the protection of human health and biodiversity.

AFFIRM the scientific findings of the International Nitrogen Conferences and the International Nitrogen Initiative (INI).

ACKNOWLEDGE that reactive nitrogen plays a vital role as a nutrient in the production of food, fiber, and other societal requirements for the growing population.

RECOGNIZE that, although anthropogenic production of reactive nitrogen exceeds natural creation in many regions of the world, other areas suffer from the opposite problem - a deficiency of reactive nitrogen in the soil, contributing to food insecurity and malnutrition. These areas include most of Africa and parts of South America and Asia.

RECOGNIZE that, although many people suffer from malnutrition, a growing proportion of the world's population consumes excess protein and calories, which may lead to human health problems. The associated production of these dietary proteins (especially animal products) leads to further disturbance of the nitrogen cycle.

ACKNOWLEDGE that reactive nitrogen is a by-product of fossil fuel combustion that contributes to the welfare of humanity by supplying electricity, transportation and energy.

NOTE WITH SERIOUS CONCERN that in many parts of the world, significant amounts of reactive nitrogen are lost to the environment in agricultural and industrial production and fossil fuel combustion. This has lead to disturbances in the nitrogen cycle, and has increased the probability of nitrogen-induced problems such as pollution of freshwaters, terrestrial and coastal ecosystems, decreasing biodiversity and changing climate and pose a threat to human health.

ARE FURTHERMORE CONCERNED that, with the rapidly increasing world population, the disturbance of the nitrogen cycle will become worse unless adequate measures are taken.

AFFIRM that since the different forms of reactive nitrogen can be transformed into one another and are very mobile in the environment, an integrated approach to optimize nitrogen use whilst preventing nitrogen pollution, is necessary.

ARE KEENLY AWARE of the urgent need for international cooperation to decrease the disturbance of the nitrogen cycle.

ENCOURAGE countries to coordinate their research, exchange solutions, and work together with the International Nitrogen Initiative and its Regional Centers, including participating in the International Nitrogen Conferences as recurrent opportunities to discuss scientific progress and issues related to policy.

CALL UPON the United Nations Environment Programme, as the environmental conscience of the United Nations system, to promote understanding of the nitrogen cycle, assess consequences of its disturbance, provide policy advice and early warning information, and catalyze and promote international cooperation. This should be done in conjunction and close cooperation with: the Consultative Group on International Agricultural Research, the Food and Agriculture Organization, the World Health Organization and other appropriate United Nations organizations, stakeholders, the International Nitrogen Initiative and its Regional Centers, and other relevant organizations.

WELCOME the new International Assessment on Agricultural Science and Technology for Development and recommend that it should fully consider agricultural nitrogen issues.

Hereby declare their commitment to facilitate the optimization of nitrogen management in food and energy production, and environmental protection.

Call upon their national governments to optimize nitrogen management on a local, regional and global scale by:

1. **Supporting further assessment of the nitrogen cycle, its benefits for humankind, and its consequences on human health and the environment.**

2. **Focusing efforts on increasing the efficiency and effectiveness of agricultural production and energy use, while decreasing the adverse effects of reactive nitrogen.**

3. **Promoting exchange of information and technology, raising public awareness, encouraging research and development of solutions to reactive nitrogen problems, and monitoring disturbances of the nitrogen cycle.**

4. **Taking action to enhance availability to reactive nitrogen as food, fiber and other basic needs in regions of nitrogen deficiency and avoid nitrogen pollution. This can be done by continual development and promotion of:**

   a) A code of good agricultural, forestry, and aquacultural practices, recognizing the needs for specific practices to be tailored to specific conditions and improving utilization of nitrogen in food production;

   b) Strategies for sustainable energy use to prevent the formation of nitrogen oxides in fossil fuel combustion, and

   c) Application of emission reduction technologies (e.g. wastewater treatment, selective catalytic reduction).